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Paris, France, 14-15 September 2021

6. Developing new indicators for sustainable finance…

7. … by leveraging innovation

Progress, challenges and recent innovations in sustainable finance statistics

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Executive summary

On 14–15 September 2021, the Bank of France, the Deutsche Bundesbank and the Irving Fisher Committee (IFC) on Central Bank Statistics co-organised an **international conference on *Statistics for Sustainable Finance*** in Paris. Sustainable finance has attracted an increasing amount of attention in recent years and, in turn, the availability of relevant data has become a primary concern for policymakers, especially central banks and financial supervisors. Sustainable finance refers to the process of taking environmental, social and governance (ESG) considerations into account when making financing decisions, with the aim of fostering long-term investment in sustainable economic activities.

The event focused on the progress achieved so far in developing sustainable finance statistics. It also reviewed the remaining challenges as well as the opportunities opened up by technology innovation. As an international forum for central bankers, other officials, private sector participants and scholars, the conference provided a venue to discuss the present state of, and the outlook for, statistical sustainable finance frameworks across different jurisdictions.

A specific focus was put on the financial risks that have been rising in parallel with the growing **threat of climate change**, highlighting the urgent need to make available relevant climate-related data on a timely basis. Central banks have been at the forefront of the efforts to identify the core climate-related information needs and develop alternative solutions to address them. The most important data gaps identified include the lack of granular firm/asset-level data to meaningfully measure the carbon footprint of economic and financial activities. In addition, there is a need to establish forward-looking data (eg emission pathways). In both cases, the data

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currently available lack reliability and comparability, which would be essential if physical and transition risks are to be properly measured and monitored.

The conference confirmed that, given their dual role as both compilers and users of official statistics, **central banks are particularly well placed to contribute to these issues**. Indeed, the event was complemented by an IFC survey on sustainable finance data for central banks published in December 2021 (IFC (2021c)), which put forward three main recommendations for central banks' work on sustainable finance statistics, namely: (i) to intensify the identification of data needs to pursue relevant policies; (ii) to cooperate with traditional and new stakeholders, including providers of alternative data sources, to close data gaps; and (iii) to lead by example to enhance the use of sustainable finance data for policy purposes, ideally by covering the large spectrum of central bank policy tasks

The following points were highlighted during the conference in order to close the existing sustainable finance data gaps:

First, central banks and financial supervisors have an important role to play in developing sustainable finance statistics. Their main focus has been on establishing analytical frameworks, designing sustainability indicators and actual monitoring. This has allowed existing data shortages to be identified, eg on the relationship between sustainability and market performance (with due consideration for the pricing of climate-related risks); on the measurement of sustainable investment activities (ie "green finance"); and on indicators to estimate carbon footprint. Relatedly, there is a lack of harmonised standards and methodologies, which can give rise to undesirable incentives (eg "greenwashing" behaviour) and lead to misleading interpretations of developments in financial markets. A specific goal is to establish a comprehensive statistical framework for capturing the external costs of greenhouse gas (GHG) emissions (ie "carbon pricing"), which is a precondition for ensuring that climate-related risks are incorporated by market participants and that capital is efficiently allocated to sustainable activities.

Second, central banks/supervisors have become key users of relevant sustainable finance data, with a strong appetite for climate risk-related information. One reason is that global warming and the green transition are affecting a wide range of their policies. In particular, there is a clear link between physical/transition risks and financial stability objectives, for both micro- and macroprudential policy purposes. Climate change, and sustainability issues more generally, are also relevant for central banks' reserve management tasks and for the conduct of monetary policy. Reflecting these various use cases, central banks have set up increasingly detailed data sets; for example, to collect granular information at individual loan and security levels to assess firms' carbon footprints, financial institutions' exposures to climate risk etc. In addition, central banks and other public sector entities are relying increasingly on commercial data providers, but combining the various data sets involved raises challenges in terms of coverage, reliability and the difficulty to match the datasets as such.

Third, addressing sustainable finance data gaps requires careful prioritisation. In the medium to long run, there is a clear need for more comprehensive data sets, with greater consistency and quality. The promotion of common international standards is the prerequisite for the efficient development of adequate statistical definitions and classifications (or "taxonomies"). Common standards would also ensure that the collected data are articulated with policy objectives and subject to proper disclosure requirements – which is the key to guiding investors and pricing the related risks effectively.[2]

Fourth, more and better cooperation between stakeholders is required, especially with the private sector and academia, and between jurisdictions. Such cooperation is essential for taking stock of useful statistical initiatives (for instance, as regards ESG data catalogues and information repository hubs),[3] promoting best practice (eg for leveraging new approaches, compiling data in the required formats, or presenting information in useful dashboards),[4] and identifying novel climate-relevant indicators.

Lastly, exploiting less conventional data sources and tools might be an important way of bridging existing information gaps. Innovative text-mining techniques can, for instance, help to extract relevant information from firms' climate-related disclosures, with granular firm-level data scraped from the web and used to estimate missing GHG emission data. Similarly, artificial intelligence (AI) approaches can be used to better monitor and understand the development of sustainable finance. Needless to say, substantial investments, especially in terms of IT hardware, software and staff skills are required to support such initiatives.

1. Introduction

The hybrid IFC Conference on "Statistics for Sustainable Finance" on 14–15 September 2021 was attended by almost 800 participants, representing about 90 institutions from the public and private sectors. The aim was to discuss how to best **address current measurement issues in the ESG area and develop economic and financial statistics on sustainable finance, also based on the use of innovative approaches**. Users and producers of such statistics – with a prominent intermediary role played by central banks as both compilers and consumers of statistics – saw the event as an opportunity to discuss the data and analytical needs as well as the challenges faced. The focus was on the various initiatives already undertaken by IFC member central banks (Schmieder and Triebskorn). A question more for the medium term was how to develop a comprehensive framework for developing sustainable finance statistics to support policy needs.

The conference provided a useful opportunity to review the importance of ESG issues for the conduct of economic and financial public policies (Section 2). It also allowed for an in-depth assessment of the resulting sustainable finance information

2 Important efforts in this context are the proposed new G20 DGI initiative, aimed at strengthening and harmonising economic and financial statistics in the area of climate change (FSB and IMF (2021)), and the FSB roadmap on climate-related financial risks (FSB (2021)), aimed at promoting firm-level disclosure, compiling relevant (ie consistent) data, and establishing and running vulnerability analyses.

3 The forthcoming data repository established by the Network for Greening the Financial System (NGFS) of central banks and financial supervisors is an example of a key initiative to identify relevant data sources (NGFS (2021)). The IFC has also conducted a stock taking exercise of the ESG metrics and the underlying indicators considered of particular relevance by central banks when pursuing their policy objectives (IFC (2021c)).

4 See IFC (2019) and, as an illustration, the IMF Climate Change Indicators Dashboard developed in support of addressing data needs for macroeconomic and financial policy analysis.

needs (Section 3) and of the way to address associated data gaps (Section 4), with a specific focus on the tracking of green finance (Section 5). Lastly, the event shed light on alternative types of indicator to be developed in the area of sustainable finance (Section 6) and on innovative approaches that could be followed here (Section 7).

2. Importance of ESG issues for economic and financial public policies

Strong policy attention

Reflecting growing public interest in sustainability issues, the integration of ESG considerations into economic and financial policies is a focal point of interest. For instance, a recent survey by Volz et al among 26 Asia-Pacific central banks and supervisory authorities shows that they had recently been paying considerably more attention to sustainability challenges, as compared with 2019, with most of them gradually implementing measures to monitor and act under relevant circumstances. The finding that climate change and the green transition are affecting a wide range of central bank and supervisory policies is in line with other studies (eg IFC (2021c)).

Financial stability is one of the main areas in which central bankers and supervisors need to better take sustainability dimensions into account. To the extent that sustainability-related issues are associated with growing risks, it lies within central bank and supervisory mandates to monitor the resilience of market participants and financial institutions. For example, firms with higher carbon emissions tend to have higher credit risk, and disclosure of forward-looking targets to cut their emissions would improve their carbon balance and thereby lower their credit risk, as argued by Vozian et al. Hence, it is important for central banks and supervisors to account for these dimensions in their prudential policy framework, from both a micro- and macro- perspective.

The relevance of ESG metrics for credit risk assessment is also important for **the conduct of other central bank operations**, especially as regards their reserve and asset management activities as well as the conduct of monetary policy. This reflects the growing need of central banks to take ESG factors in consideration when assessing the balance sheet implications related to collateral operations and/or asset purchase strategies.

In turn, **central bank actions can have a significant impact on the pricing of sustainable financial instruments**. One case study presented by Macaire and Naef on green bonds in China suggests that their prices appear supported by their eligibility as collateral for central bank operations. This would suggest that monetary policy can help lower capital costs for ESG financing.

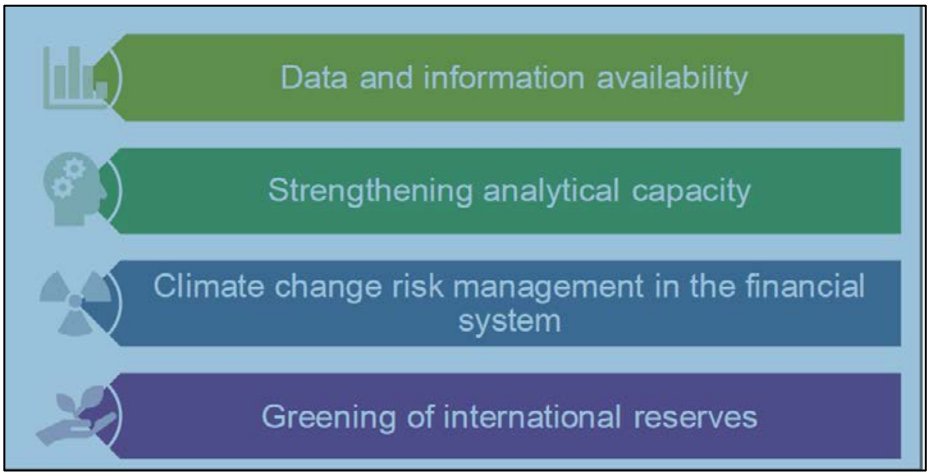
Data collection progress

Reflecting the above, it should not be surprising that public authorities in general, and central banks and financial supervisors in particular, are striving **to build comprehensive, reliable, standardised and granular ESG data**. Specific attention is being paid to climate-related risks, in the form of transitional and physical risks that could substantially affect the solvency of financial institutions and hence financial stability. The identification, measurement and monitoring of such risks is a key priority for national authorities and international financial institutions alike. If these stakeholders were to rely on misleading information, for example, they would miscalculate not only the impact of specific financial instruments designed to deal with climate change but also the risk profile of financial institutions.

A structured approach has proved helpful to ensure the integration of ESG-related factors in policy considerations. The strategic climate change roadmap of the Central Bank of Costa Rica, presented by Alvarado-Quesada, provides one such example (Graph 1). A key message is that bringing cross-departmental experts together is beneficial as it fosters synergies for the pursuit of sustainable finance policies. Moreover, the improvement of data availability and the strengthening of in-house analytical capacities should go hand in hand. Another example is the ECB's monetary policy strategy review, in which climate change features prominently. Specifically, Lane (2022) highlights the importance of establishing relevant data (clarifying definitions and taxonomies while proactively dealing with data quality) as a basis for the measurement of macroeconomic and financial stability risks (Graph 2). Financial stability risks are captured based on the carbon footprint of activities and the risk exposure of financial institutions, including exposures in the balance sheets of central banks (such as the ECB).

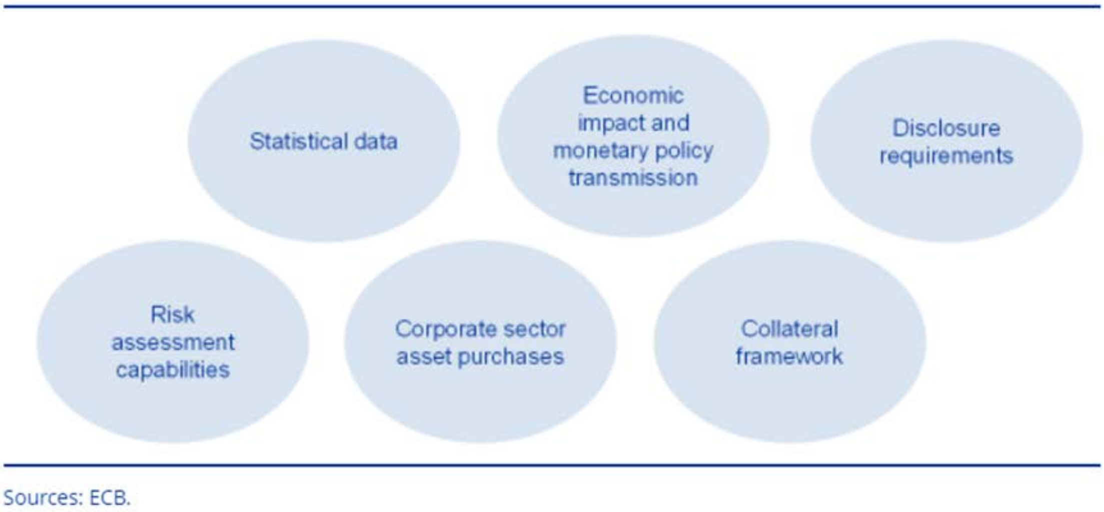
Moreover, there is value in the **development of rich data bases and robust IT infrastructure** to adequately conduct policies addressing ESG issues. Central banks have already launched several initiatives to support the compilation of granular information on financial institutions and develop sustainable metrics to support relevant analyses (Israël and Tissot (2021)). In the ESCB context, for example, investment data identified at the loan-by-loan (Ana credit) and security-by-security (Securities Holdings Statistics) levels using pertinent legal identifiers (from the Register of Institutions and Affiliates Database (RIAD)) were matched with firm-level data on carbon emissions by Colangelo and Israël. Similarly, the Bank of Italy's central credit registry provides granular data on loans, which have been used by Faiella and Lavecchia to measure the carbon footprint of credit institutions and assess the exposure of the Italian financial system toward transition risks.

Climate change roadmap of the Central Bank of Costa Rica (BCCR) Graph 1



Source: I Alvarado-Quesada, "BCCR's experience in environmental accounting and advancements of the Climate Change Strategic Analysis Group", *IFC Bulletin*, no 56, May 2022.

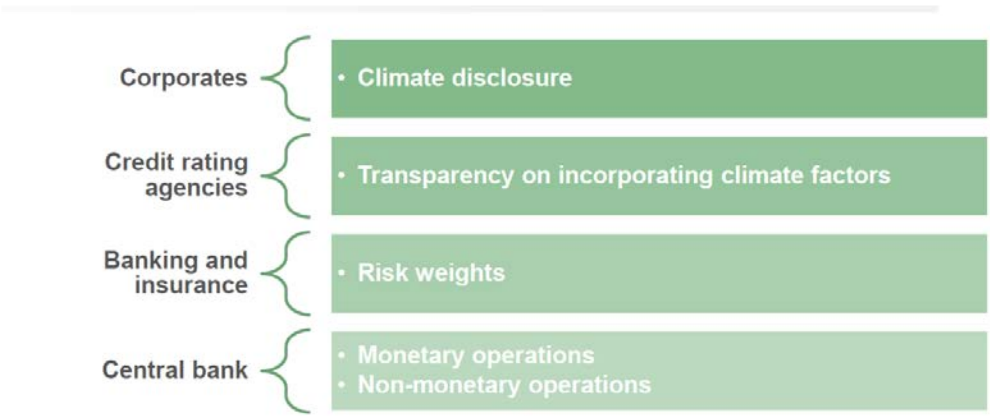
ECB climate change action plan Graph 2



Source: Lane (2022).

Yet, a key challenge faced by this endeavour has been the lack of granular and comparable firm-level data, especially on carbon emissions. In practice, policy analyses have tended to rely on proxies derived from macro statistics such as air emission accounts. Authorities have also worked to ensure stronger firm-level disclosure requirements and the harmonisation of green data standards. Experience shows that another success factor has been the interaction between the various stakeholders involved in the provision of the related data, as illustrated in the case of initiatives to tackle transition risks (Graph 3). Central bank statisticians have been able to usefully support these coordination efforts, making use of their role as key intermediaries to promote a constant dialogue between producers and users of ESG-related data.

Transition risk: Policy objectives of different stakeholders Graph 3



Source: S Carbone, M Giuzio, S Kapadia, J Krämer, K Nyholm and K Vozian, "The low-carbon transition, climate disclosure and firm credit risk", *IFC Bulletin*, no 56, May 2022.

3. Identifying sustainable finance statistical needs

Taking stock

As discussed above, analysing and acting on sustainable finance requires various pieces of information to be considered, ranging from ESG issues being identified and addressed (eg climate change risk), effective dialogue between the diverse stakeholders involved (eg private investors, policymakers), and taking account of various motivations – for instance to facilitate a meaningful carbon pricing of economic activities, or support more robust policy choices etc (Graph 4).

The implication for public statisticians is first to take stock of the information already at hand in terms of existing methodologies and concepts (eg taxonomies), the raw data available and the way these data are transformed into relevant information (eg disclosure mechanisms, compilation processes, dissemination etc). Central bankers can make a key contribution in this area, drawing on their experience in compiling and using high-quality indicators at the micro and macro level. Indeed, around 80 ESG metrics (and more than 1,000 underlying indicators) have been identified as being of particular relevance by 60 IFC central bank members when pursuing their policy objectives (IFC (2021c)). Examples include granular emission data as a key input for developing meaningful climate-related analyses and, at a more macro level, the measurement of financial flows through green investment channels as well as data on natural disasters.

Key information building blocks for the sustainable finance agenda Graph 4

Keywords

Source: IFC Conference.

A stocktaking of existing data is particularly key in the (relatively new) field of sustainable finance, for which existing sources of information may have not yet been fully exploited, reflecting also the important role played by private sector data stakeholders and the high number of stakeholders involved in the ESG area more generally (Graph 5). Cases in point are statistics on electricity usage or data compiled from a wide range of disciplines (eg climate science specialists), which are usually not in the "standard" information universe of central bank statisticians.

Another point is to **ensure that the existing data provides useful information**. To this end, a structured approach can help to identify the relevant elements for sustainable finance; collect comprehensive information on the data considered (ie "metadata"), which could usefully be stored in dedicated data repositories/information hubs; assess the quality of these data[5] and ensure sufficient conceptual consistency, not least to support harmonised international comparisons (being particularly important because of the global nature of sustainable development issues).

Options for making better use of existing data | Graph 5

Source: Authors' analysis.

Next, an important step is to carefully assess actual data needs, with due consideration for the heterogeneity of the various stakeholders involved in sustainable finance. For instance, a key objective for financial investors is to access detailed information on the climate footprint of companies to weigh the consequences of their investment decisions. Turning to public authorities, policymakers need micro and macro data sets of sufficient quality, for instance when setting carbon taxes or measuring and benchmarking carbon emissions.

Lastly, the comparison of the actual statistics available with users' information needs allows **data gaps to be identified as well as the ways to close them.** Here again, institutions such as central banks can play a key role in identifying these

[5] The concept of "data quality" being considered in a broad sense, covering the various characteristics sought for official statistics (IFC (2021b)).

sustainable finance data gaps, not only by referring to their own experience as data producers but also, as data users, by providing direction on the new statistics to be developed. For instance, they have been at the forefront of the efforts to identify data needs to support forward-looking assessments of physical and transition risks or to track carbon pricing, especially by calling for the relevant data quality aspects and disclosure mechanisms to be developed.

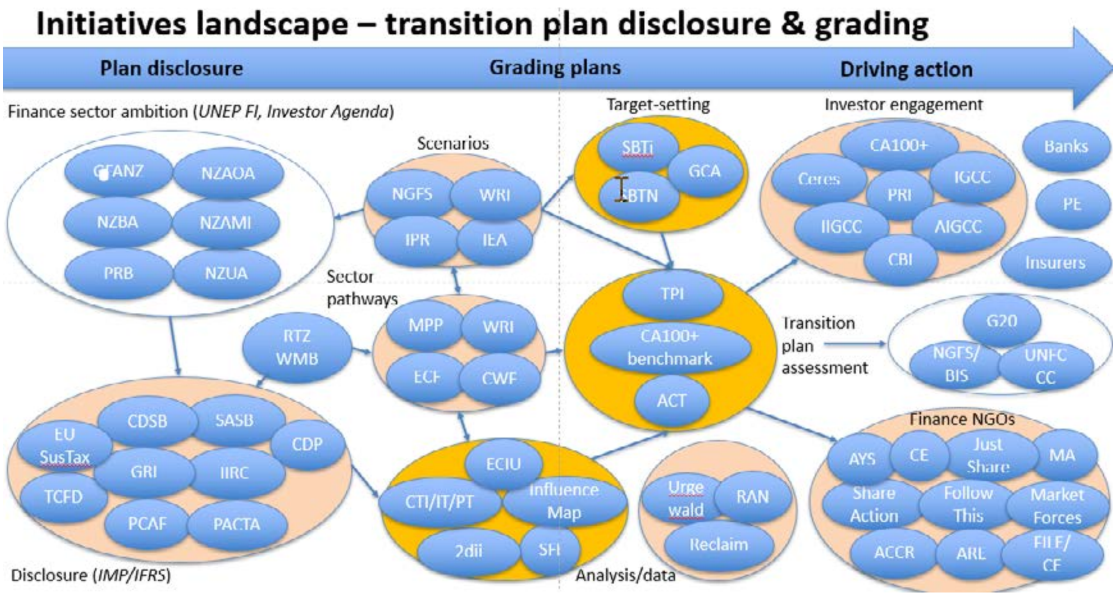
Main statistical shortcomings

The approach described above has already helped to identify three main shortcomings of the current landscape for sustainable finance statistics:

First, the availability and reliability of granular firm-level data is incomplete (Grisey). Existing reporting standards are still fragmented, as illustrated by Hugman as regards the various initiatives related to transition plan disclosures and gradings (Graph 6). There is also a lack of adequate metadata information, which would be a key building block for starting the compilation of a comprehensive and consistent "cloud" of ESG data.

Second, **more statistical methodological guidance is needed in the form of standardised definitions and taxonomies**, as emphasised by the recently surveyed central banks from both advanced and emerging market economies (IFC (2021c)). Such guidance would help to overcome the challenges arising from both the complexity of the many data dimensions considered (eg from the past records of national disasters to the long-term horizon of climate change simulations) and the rapidly evolving debate surrounding ESG issues. It would also facilitate the various perspectives involved in tackling those challenges, eg to address the data needs supporting complementary top-down and bottom-up regulatory approaches, as noted by Gueddoudj.

Initiatives on transition plan disclosures and gradings | Graph 6



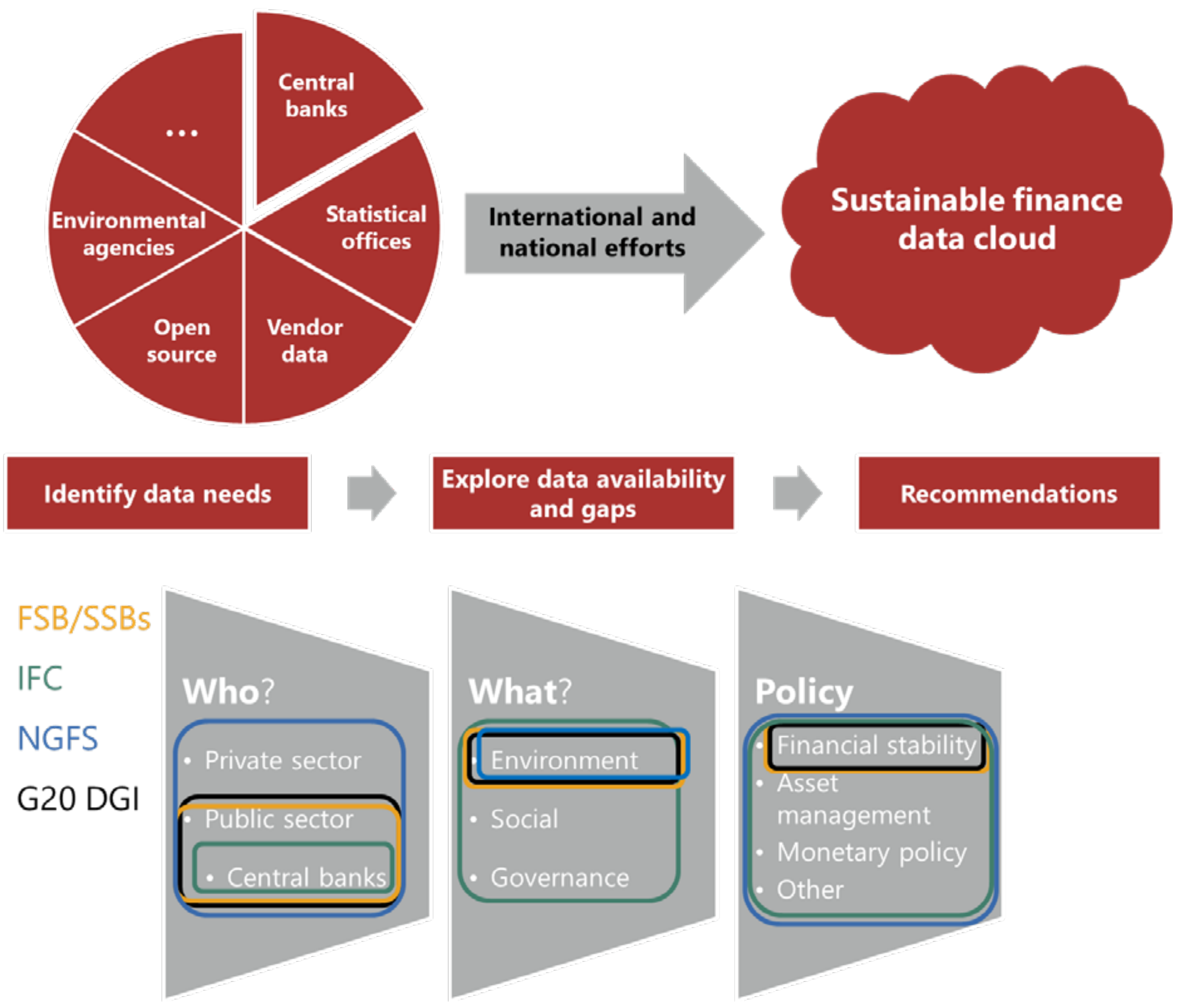
Source: M Hugman, "Private financial institution perspectives on climate and nature data", *IFC Bulletin*, no 56, May 2022.

Third, better international cooperation is needed to address the intrinsic analytical complexity of global sustainability analyses. For instance, greater transparency on national practices related to ESG statistical compilation and on the concepts involved would improve international comparability. It would also reinforce disclosure efforts in the global financial industry, and raise the overall quality of the data compiled and the associated analytical exercises. Moreover, it would help users take advantage of the growing ESG data sources that could be drawn from outside the traditional perimeter of official statistics (Section 6).

4. Closing sustainable finance data gaps…

Numerous global initiatives have been launched in recent years to identify the most important ESG data needs and address the related data gaps (Graph 7), with a primary focus on climate change and its financial stability implications.

Overview of global initiatives on sustainable finance data Graph 7



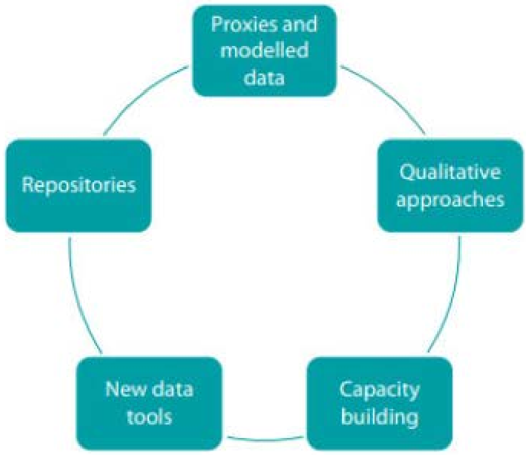
Source: IFC (2021c).

These initiatives have been **supported by a growing number of stakeholders**, including international organisations (eg BIS, IMF, OECD, UN), financial standard setters and the FSB, as well as the NGFS network of central banks and financial supervisors. Some key examples are the NGFS initiative to promote agreed benchmark scenarios (NGFS (2021)), the recent International Financial Reporting Standards (IFRS) initiative to promote global sustainability disclosure standards, and the ECB guidance on conducting economy-wide climate stress tests (ECB (2021)). The various working groups set up in the context of all these initiatives have involved private and public parties and helped spread knowledge and best practices – for instance, as regards climate scenario modelling, the use of commercial data sources, and the compilation of forward-looking indicators at the firm and country level.

To address sustainable finance data gaps effectively, these various initiatives have highlighted a number of important points to focus on:

- **International consistency**. Harmonising the various concepts, methodologies and processes involved in sustainable finance requires cooperation among a wide range of stakeholders. It is also essential to ensure a sufficient degree of consistency between the various national initiatives undertaken to collect sustainable finance data and to facilitate the dialogue between subject-matter experts and academics as well as policymakers.
- **Medium- to long-term perspective.** Near-term solutions may be useful in addressing urgent data needs but should be complemented by more sustained statistical efforts to develop comparable and comprehensive data sets. To be effective, the pursuit of such a holistic goal should follow a stepwise approach to deal with the complex, multi-layer ESG data universe – by identifying existing sources, as a first step, followed by establishing methodologies for compiling adequate data bases, and by developing relevant meta data to ensure the reliability of the information compiled. This is the approach foreseen for the implementation of the recommendations of the new G20 Data Gaps Initiative (DGI; IMF and FSB (2021)) that will comprise a detailed, multi-year workplan to address policy relevant data gaps with a specific focus on climate change.
- **Usefulness of the information collected.** In addressing sustainable finance data gaps, a delicate balance has to be found between having more data available (ie through disclosure requirements) and transforming these into useful information, in turn supporting policy knowledge (Drozdova (2017)).
- **Multi-pronged approach.** Using the maximum of available information while exploring new data collection opportunities in parallel calls for a constant updating of the stocktaking approach advocated in Section 3 (Graph 8). For instance, existing data could be stored in specific information repositories and complemented by a regular update of various elements (such as the existence of complementary sources, the availability of new tools, potential data overlaps and/or gaps), as suggested by Triebskorn et al. This approach would facilitate the development of useful statistical concepts, capacity-building (both in terms of infrastructure and staff skills) and the dissemination of innovative methodologies. Moreover, it would help address different and evolving user needs in terms of data sources and data quality requirements (eg accessibility, availability, reliability, comparability).

Dealing with data gaps requires a multi-pronged approach, using existing sources and frameworks while promoting new tools — Graph 8



Source: L Grisey, "The NGFS (Network for Greening the Financial System) Progress Report on Bridging Data Gaps and beyond", *IFC Bulletin*, no 56, May 2022.

5. … with a focus on tracking green finance

Global policy attention has focused on green finance, ie the mobilisation of financial flows to fund sustainable development priorities. There has been a massive increase in volumes of such instruments, issued by private firms and the public sector, as well as a spike in the number of issuers.

Regarding climate change, for instance, an important policy objective is on the one hand to ensure the necessary financing (eg to meet the goals agreed on in the Paris agreement and the transition goals towards a net zero carbon economy); on the other hand, more insights are needed on how climate change might affect financial markets and financial stability in the short, medium and long term. The analysis of the issuance (ie suppliers) and holdings (ie recipients) of green bonds is an important element to assess these various points. For instance, the Portuguese experience presented by Conceição et al has shown the usefulness of monitoring investors´ financing needs and the conditions on which these could be met. This is key for detecting the underlying risks and informing decision-makers and the public.

Sustainable finance represents a new area of economic activity. But significant data gaps stand in the way of analysis in this area. One challenge is that available data often do not meet high statistical standards. This calls for data quality to be improved as a prerequisite for developing robust analysis and assessing any potential policy implications. In particular, ensuring greater disclosure and availability of green financial instruments would facilitate a closer alignment of market prices and the greenness of firms' activities. Attention should be put on developing adequate definitions and standards for green finance market products, for example by setting up a consistent and harmonised system for ESG labels, as argued by Capota et al and further discussed in the box below.

Box 1

Measuring ESG factors in debt statistics

Green, Social and Sustainability (GSS) bonds were created to fund projects that have positive environmental, social and/or governance (ESG) benefits. The market for GSS bonds reached a significant milestone in 2021, with the annual issuance of $1 trillion of new debt. A growing literature (see the references listed below) suggests that certified GSS bonds are associated with better financing terms.

While the outlook for further growth in this market is promising, ESG investors face some challenges:

- The first relates to the lack of harmonised, formal criteria for what constitutes a green or sustainable bond. The International Capital Market Association (ICMA), which represents financial firms and promotes the smooth functioning of global debt securities markets, formulated Green and Social Bond Principles as well as the Sustainability Bond Guidelines, which have become important global standards for GSS activity-based debt instruments. Indeed, most issuers of GSS bonds follow the ICMA guidelines, and provide documentation for how the bond proceeds will be used and the ESG impact a bond is expected to have. However, the current guidelines lack precise definitions. Issuers thus have considerable leeway to interpret GSS credentials to their own advantage. As a result, self-labelled bonds may be "greenwashed" with unsubstantiated claims about a project's impact. Regulators are increasingly stepping in to homogenise ESG taxonomies and standards across countries and sectors. Some jurisdictions have introduced rules explicitly requiring external reviews as a benchmark. Independent validation firms, however, remain unregulated and the proliferation of standards, concepts and taxonomies they employ makes it difficult to compare projects financed by GSS bonds. Public debate on taxonomies for GSS bonds is likely to continue for some time.
- The second challenge investors face is a lack of timely and accurate data on GSS-related activity. The availability and quality of such data varies across countries and sectors, and covers mainly large multinational firms. This calls for further harmonisation work at the international level. The Financial Stability Board has already set up the Taskforce for Climate-related Financial Disclosures (TCFD) to improve and increase reporting of climate-related financial information. Similarly, the IFRS Foundation, which promotes international financial reporting standards, has been charged with facilitating consistency of disclosure standards for sustainability-related projects. In late 2022, it will issue the climate disclosure standard based on its International Sustainability Standards Board (ISSB), eventually replacing the guidance provided by the TCFD.

① This box was prepared by Jakub Demski (BIS).

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Despite these shortcomings, existing data on green finance instruments can be used to analyse the impact of climate change and the associated physical and transition risks for financial markets. For instance, the available statistics on syndicated loans, as analysed by Ehlers et al, suggest that climate-related risks are being more effectively priced since the Paris agreement, although the relative impact is modest in view of the step increase in carbon prices that is needed to meet the Paris goals. Another limitation is that only greenhouse gas emissions directly caused by firms (so-called "Scope 1") are priced, not those indirectly caused by production inputs, transportation etc. (ie Scope 2 and 3).

Moreover, recent studies suggest that the financing of firms with strong ESG ratings may bring financial stability benefits. The main mechanism at stake appears to be through the impact on these firms' risk premia. According to Liberati and Marinelli, there is a statistically significant negative risk premium on ESG bonds compared with conventional ones with the same characteristics. Furthermore, this negative risk premium appears to have increased following the Covid-19 shock, at least for some sectors. Similarly, Capota et al find that ESG funds did perform better than their non-ESG counterparts during the Covid-19 turmoil. Other studies suggest that sustainable finance might bolster corporates' resilience during crises, although further evidence might be needed to confirm this finding. One recent example has been the analysis of firms from different countries to understand the relation between their environmental and social score and their financial performance during the Covid-19 pandemic. The results typically show that some firms with better sustainability footprints were able to outperform others, but that this ability is difficult to confirm empirically for all firms in general.

6. Developing new indicators for sustainable finance…

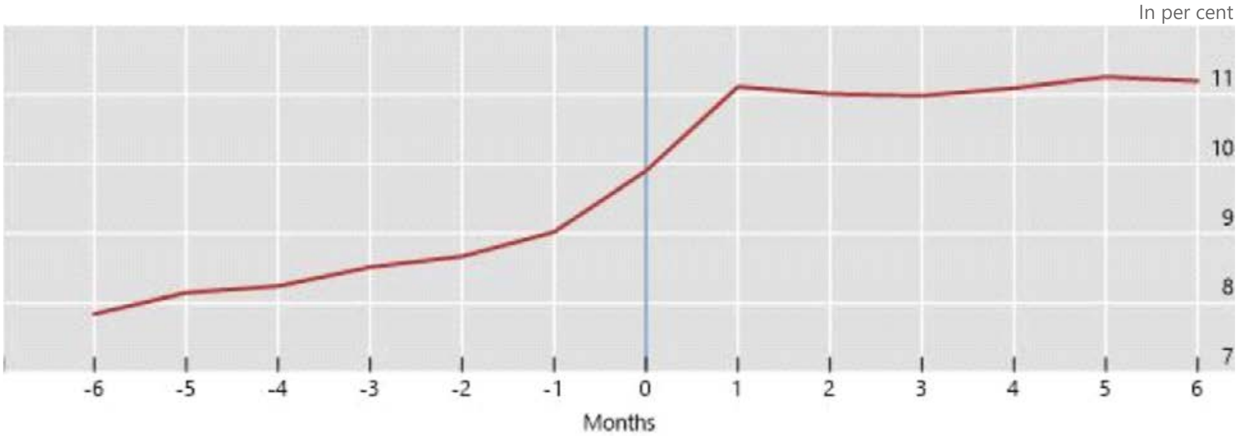
As noted above, establishing meaningful definitions for relevant sustainability metrics is critical to support public policy. Yet ESG topics represent a new area for central bank statisticians, who should be proactive in identifying new types of indicator for sustainable finance. This often requires the bridge between economics and natural sciences to be crossed, eg with economists benefiting from the experience of climate experts and vice versa. Besides the core ESG issues analysed in this paper, a broader perspective should encompass concepts such as global sustainability accounting – cf for instance the new ledger proposed by Bordt and Saner (2022) in response to a call by the UN Secretary General for new metrics to complement GDP.

The starting point is to develop clear legal or regulatory requirements (eg in the context of global IFRS sustainability disclosure standards) **as well as voluntary guidelines to measure the sustainability of financial instruments and financial activities.** Yet the criteria governing ESG disclosures are found to vary considerably across data providers and even for the same firm (Berg et al (2019)). The fact that alternative climate risk metrics exhibit significant variation is confirmed by Colesanti Senni et al, who analysed a wide range of forward-looking transition risk metrics covering 1,500 firms from 14 different sources. Given the deep uncertainty related to the analysis of climate risks, such differences in the data analysed may not be avoidable, and this should not be an issue per se if the causes were properly understood. However, the analysis suggests that firms' transition risk estimates are highly dependent on underlying assumptions as well as scenario and model characteristics. Such elements should therefore be explicitly understood to ensure that, first, ESG metrics rely on a sound and homogeneous methodology and on coherent assumptions; and second, that the data reported in this context are sufficiently reliable and homogeneous to support policy needs.

Another point is to **ensure statistical harmonisation**, arguably one of the most important challenges when it comes to establishing relevant sustainable finance indicators. However, agreeing on harmonised metrics involves many stakeholders at a time when concepts as well as regulations are still evolving. One way is to collect "best practice indicators" collected outside formal frameworks but, at least indirectly, influenced by ongoing international and other harmonisation initiatives. The example provided by Ortiz shows how a set of such ("informal") indicators can be derived to measure the contribution by the financial system to achieving the (clearly formalised) Sustainable Development Goals (UN (2015)).

Many national initiatives are already under way to improve existing metrics with a specific focus on clarifying ESG labels applied to financial instruments. These aim to serve investors as a "guarantee" for the asset composition of their portfolios, allowing them to align their sustainability preferences with their asset management strategies. For instance, the carbon footprint of two French labelled funds was compared by Nefzi with that of other funds to assess their environmental performance. The results, illustrated in Graph 9, emphasised the importance of granular entity-level data to precisely estimate the carbon footprint of financial institutions and the contribution of ESG labelling to climate change mitigation.

Average share of green bonds in portfolios before and after the labelling — Graph 9



Source: D Nefzi, "Measuring the development of French labelled funds and their contribution to sustainable financing of the economy", *IFC Bulletin*, no 56, May 2022.

A final issue is **that any statistical formalisation of the ESG indicators to be collected should have a global nature**, requiring the support of all financial authorities and market participants to use the same "proper" metrics across borders. The new G20 DGI, as expected to develop after 2022, will provide a framework for developing the needed concepts, methodologies and processes. These efforts are being complemented by those of the BIS, the FSB and the financial standard setters, as well as the IMF, the NGFS, the OECD and the UN, covering a wide range of topics. In view of these ongoing initiatives, sustainable finance metrics are likely to continue evolving rapidly ((IFC (2021c); NGFS (2021)). As argued in Section 4, it will therefore be important to set up adequate information repositories to keep track of these developments.

7. … by leveraging innovation

New tools

Innovation can be applied to collect, analyse and synthesise sustainable finance statistics more efficiently. It can facilitate the construction of new indicators and enhance computational/visualisation capacities. This can, in turn, support analyses that are still in their infancy (eg climate risk pricing), ensure regulatory compliance (eg disclosures requirements), and improve the capture of complex information – eg through natural language processing (NLP) tools.

However, the ability to use innovative approaches (eg data science, AI) **requires a quantum leap in the available infrastructure, both from a statistical and an IT perspective**.

On the **statistical side**, important efforts are also needed to cope with large amounts of granular data, for instance in terms of statistical nomenclatures and concepts (eg taxonomies, instrument labelling), granular identifiers (eg the Legal Entity Identifier (LEI)), data-sharing possibilities (IFC (2016b)) and transmission standards (eg Statistical Data and Metadata eXchange (SDMX); IFC (2016a)). The importance of enhancing the global statistical infrastructure to improve existing core statistics and address new data needs has been highlighted by the consequences of the recent Covid-19 pandemic (Rosolia et al (2021)).

On the **IT side**, there is an increasing demand for high-performance computing (HPC) and big data capabilities, for instance to develop data-centric analytical models and benefit from advanced types of computing technology (eg graphics processing units (GPUs); see IFC (2020)). More powerful hardware supplemented by new software can also help to make use of vast amounts of structured and unstructured data. As argued by Papenbrock and Schwendner, such IT infrastructure can facilitate a number of tasks to compile and make use of sustainable finance data (eg timely risk identification, monitoring and early warning exercises, quality control, interpretation and optimisation).

International organisations (eg the OECD and NGFS) and central banks have already worked on developing comprehensive ESG databases that exploit IT and statistical innovation. Such databases can help to effectively calibrate ESG models, which can serve as important benchmarks supporting sustainability policies. Yet, there are many challenges involved. For instance, it is important to allow interested stakeholders to get (at least partial) access to this information. Another issue relates to shortages in terms of IT budget and staff skills, especially in public institutions. Furthermore, there is a constant need to trade off short- and long-term solutions, in terms of both the staff resources to be mobilised and the underlying infrastructure to be set up.

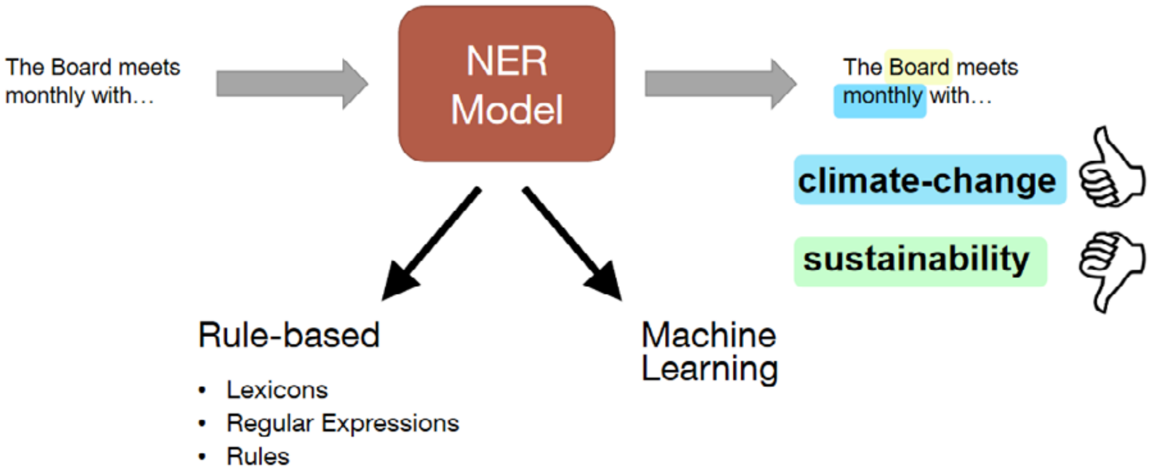
A practical roadmap

The experience of central banks suggests a number of ways to address the challenges above and make the most of innovation.

First, there is a clear business case for **developing comprehensive ESG data platforms that would benefit all stakeholders**. Such centralised information repositories will typically disclose information on carbon costs, including industry averages and firm-level estimates (putting pressure on companies to disclose more information themselves). Central banks, statistical institutes and international organisations would be best placed to foster such a development. These efforts could be complemented by a micro-level auditing of environmental disclosures to favour the dissemination of consistent indicators, as argued for instance by von Kalckreuth to assess the direct and indirect carbon impact of industries, companies and products.

Second, the use of data science and AI should be accelerated in the private financial services industry as well as in supervisory circles (Wibisono et al (2019)). Establishing complex investment/risk management activities in green finance, as well as the need to develop data-driven policies, require the use of massive amounts of rich data and can greatly facilitate their interpretation (eg large-scale visualisation tools, clustering techniques, network analyses). At the same time, these innovative approaches can help their users to compile new types of data or enhance their quality (IFC (2021a)).

Named entity recognition (NER) model — Graph 10



Source: A Moreno and T Caminero, "Application of text mining to the analysis of climate-related disclosures", *IFC Bulletin*, no 56, May 2022.

Attention has focused on using specific techniques to analyse climate-related disclosures and in turn support investors' decisions as well as the design of public policies. Moreno and Caminero have, for instance, developed a scraping solution to analyse Spanish banks' ESG disclosures (in the form of their Pillar 3 reports; see BCBS (2018)) and information on their directors' remuneration, which pointed to significant improvements in terms of governance. The approach was complemented by the use of machine learning (ML) techniques to input textual information on a massive scale and provide insights on selected topics of particular interest (eg climate change, sustainability) (Graph 10). Similarly, Bua et al have applied a textual-based framework to construct indicators for the two key climate risk types (ie physical and transition risks) and analyse the sensitivity of French equity prices to them. This was done by comparing information from Reuters News with textual databases related to scientific work on climate change (Graph 11).

Third, an effective near-term solution for bridging data gaps is to construct "transitory" indicators by proxying missing data. For instance, the Netherlands

Bank has modelled country-sector level indicators as a proxy for assessing (missing) company-level emissions. Such an approach could go beyond measuring carbon emissions and cover a broader range of ESG topics (eg water pollution).

While innovative types of indicator can help to close data gaps, **this is often a second-best solution that should be complemented by increased disclosure efforts.** Indeed, Dijk et al have shown that a physical risk model based solely on publicly available data (eg historical macro data for storms and floods) could lead to misleading results because of the omission of relevant, more specific information – in this case, loss data at the regional and company level were found to crucially improve the model's calibration.

Physical and transition risk vocabularies | Graph 11

(a) Physical risk vocabulary (b) Transition risk vocabulary

Source: Bua et al (2021).

Fourth, innovation in the finance sector itself can also impact ESG factors. For instance, Yilmaz Özsoy and Galanti have analysed the development of digital finance (eg mobile money, cryptocurrencies such as Bitcoin) in sub-Saharan African countries and its contribution to sustainable development. This was found to have been associated with a reduction in CO_2 emissions through greater efficiency in the provision of banking services (ie lower transportation costs, reduced need for brick-and-mortar offices). This suggests that measuring progress in digital finance could indirectly provide useful insights on the evolution of selected ESG factors.

8. Conclusion

The IFC event showed that ongoing international work can be an essential catalyst for developing sustainable finance statistics. Several global initiatives have been launched towards harmonising ESG concepts (including taxonomies), methodologies and processes. They have gone hand in hand with national initiatives and efforts undertaken by the various stakeholders formally or informally involved in the sustainable finance agenda.

The **new G20 DGI** represents a key opportunity to further support these various efforts. First, because it emphasises the priority of developing adequate statistics on climate change, and second, because of its focus on facilitating access to private and administrative sources of data as well as on data-sharing. This will undoubtedly open up additional avenues for improving sustainable finance statistics.

Central banks can contribute significantly to ensuring the success of this DGI, in line with the IFC's recommendations for dealing with sustainable finance challenges and gaps (IFC (2021c)), namely, (i) identifying data needs from a policy perspective; (ii) ensuring cooperation between traditional and non-traditional stakeholders so as to overcome data gaps, especially at the micro level; and (iii) leading by example by improving central banks' use of sustainable finance data.

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International Conference on "Statistics for Sustainable Finance", co-organised with the Banque de France and the Deutsche Bundesbank

14-15 September 2021, Paris, France, hybrid format

Opening remarks[1]

François Villeroy de Galhau, Governor, Banque de France

[1] This presentation was prepared for the conference. The views expressed are those of the author and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

François Villeroy de Galhau: Speech -International Conference on Statistics for Sustainable

Speech by Mr François Villeroy de Galhau, Governor of the Bank of France, at the International Conference on Statistics for Sustainable Finance, jointly organised by the Bank of France, Deutsche Bundesbank and the Irving Fisher Committee on Central Bank Statistics, Paris, 14 September 2021.

* * *

Ladies and Gentlemen,

It is a pleasure to welcome you today with Sabine Mauderer to the Banque de France Conference Centre, for the first International Conference on Statistics for Sustainable Finance, jointly organised with the Deutsche Bundesbank and the Irving Fisher Committee, under the aegis of the Bank of International Settlement. This subject is more topical than ever, after the dramatic weather events of this summer, from floods in northern Europe and China to heat domes and burning forests in southern Europe and North America. As statisticians and economists, you are well aware that these human and ecological dramas translate into economic losses.

This conference also takes place a few weeks after the publication of the first part of the IPCC's Sixth Assessment Report,[1] calling for an acceleration of climate action. The development of sound climate-related data is a key ingredient if we are to meet this challenge. As the 19th century physicist Lord Kelvin put it: "When you can measure what you are speaking about, and express it in numbers, you know something about it." Data are a pre-requisite for public authorities to design policies that account fairly for the environmental costs or benefits of economic activities. In a nutshell, accelerating the green transition requires accelerating green data.

However, there is a great challenge for statisticians and data providers: the opposition between the urgency to provide climate-relevant data, and the inevitable step-by-step process required to achieve this in a reliable, comparable and comprehensive way. To overcome this opposition, let me suggest a two-pillar approach: (i) *In the short term, strengthen actions to solve technical difficulties:* central banks are naturally at the forefront because of their double capacity, as practitioners of sustainable finance and compilers of official data in this domain. (ii) *In the longer run, achieve consistency at the international level:* sustainable finance is needed worldwide to address climate change on a global basis. Working towards a convergence of standards at this global level is essential.

**

I. In the short term, strengthen actions to solve technical difficulties

Through many aspects of their activities, central banks are fully involved in establishing methodologies, **promoting high standards in data production and disclosure practices**, and acting as examples for other market participants.

As a supervisor, the *Autorité de Contrôle Prudentiel et de Résolution* (ACPR) conducted a bottom-up stress test specifically designed to assess the exposure of financial institutions to climate-related risks.[2] This pioneering experimentation will pave the way for other exercises currently in preparation, at the Bank of England as from June 2021 or at the ECB in 2022. **As a monetary authority**, the Governing Council of the ECB adopted an action plan to include climate change considerations in its monetary policy strategy, within the framework of its mandate. Among other actions, we plan to account for climate change criteria in our collateral assessment and in our corporate sector purchase programme. We will therefore introduce new disclosure requirements for private sector assets as a new eligibility criterion or as a basis for a differentiated treatment for collateral and asset purchases. Finally, **as an investor**, the Banque de France was in 2019 the first Eurosystem central bank to publish a yearly dedicated report on its responsible investment policy. We put our words into action: we are completely exiting coal by 2024.

Central banks are also key contributors for **identifying current data needs**. As regards this particular question, two dimensions should be taken into account. The first is the "snapshot" of the existing risks, covered by disclosure rules, including "granularity" and "coverage". Indeed, we need more granular and comparable data, notably geographical data at the firm and asset levels. The second dimension is the "time" dimension, which I call the "video" of the risks. One lesson that we have learnt, in particular with our work on climate risk stress testing, is the need for more forward-looking assessments of both physical and transition risks. Moreover, our experience suggests that large data gaps exist for forward-looking data, such as emissions pathways and companies' transition targets, including interim targets. These lessons that we "learn by doing" must be shared and capitalised on if we are to make rapid progress on the production of relevant sustainable finance statistics. Regarding this aspect, the NGFS "Progress report on bridging data gaps"[3] published before the summer is an important step forward. Let me stress the key role of this NGFS network: created here in Paris in December 2017, with its global secretariat provided by the Banque de France, it now brings together more than 90 central banks and supervisors worldwide.

II. In the longer run, achieve consistency at the international level

Common standards for taxonomies and sustainability reporting, at the international level, are the pre-requisite for building comparable statistics on sustainable finance. Against this background, the recommendations of the NGFS aimed at fostering a rapid convergence towards global disclosure standards are of course extremely relevant.

As of today, there are several ongoing standard-setting initiatives to develop frameworks or standards for voluntary climate-related reporting by companies. Among them, the recommendations from the FSB Task Force on climate-related financial disclosure (TCFD) have been widely adopted by large international companies over the past four years, and are therefore an obvious baseline for the global standardisation of climate-related disclosure. However, voluntary reporting does not ensure the completeness and the comparability of data and enforcement by public authorities is essential to foster reliability and safeguard the trust of the public. Jurisdictions around the world are therefore increasingly taking actions to implement mandatory disclosure requirements.

In this regard, within the European Union, the adoption of the European taxonomy of sustainable activities and the release of the Commission proposal for a Corporate Sustainability Directive are important steps forward. Thanks to the very efficient work undertaken by the European Financial Reporting Advisory Group (EFRAG), a first set of European sustainability reporting standards is expected by 2022, addressing legitimate ambitions. It will indeed be comprehensive, covering a broad spectrum of risks (climate, but also social and environmental) with a double materiality approach, in order to disclose the complete impacts of one activity on the climate, environment and society. In parallel to the work done by the EU, US regulators have signaled a clear acceleration of their agenda whereas other jurisdictions support the decision from the IFRS Foundation to work on global sustainability reporting standards.

These initiatives are the proof that world economies are more committed to tackling climate change. Yet, without close international coordination, this may lead to fragmented disclosure requirements, inconsistent with the objective of fostering the international comparability and accessibility of climate-related data. Hence, at this stage, I believe that the convergence of standards requires a better and shared understanding of the end game, **more "co-construction" between private initiatives** and **public authorities at the international level.**

Climate is a global public good, and climate-related data are also public goods. Thus, the construction of global standards should not be a competitive environment, but a collaborative one, with public authorities cooperating form the start at a global level. Eventually, difficult choices will have to be made in order to achieve a global standard framework, acknowledging the need for pragmatism, but without reducing our ambition to cover all relevant aspects of climate-related economic activities.

As statisticians, you have the expertise to design bridges between heterogeneous data sources in order to establish official statistical series. Furthermore, aggregated statistical categories encompass the entire economy (for example, not only listed companies but also small and medium-sized enterprises) contrary to the more focused scope of the sustainability reporting standards.

Therefore, statisticians can contribute to **the global roadmap**, by ensuring that ultimately the production of sustainable finance data fits coherently into the international statistical standards. Let me be more specific. Thanks to the sponsoring of the IMF and the Financial Stability Board (FSB), since the Global Financial Crisis, the G-20, via the Data Gaps Initiative (DGI), has had an instrumental role in strengthening and harmonising financial statistics. At the last G20 meeting of the Ministers of Finance and central banksGgovernors in Venice, a third chapter of the DGI was proposed. This new chapter of the initiative will notably focus on climate-related financial data gaps. I look forward to the forthcoming detailed work plan[4] that will be presented next month at the G20 summit in Rome.

Because of its flexible structure and its ability to take onboard many stakeholders, this DGI-3 could serve as the appropriate forum to support the coordination of the growing number of initiatives aimed at developing the statistical infrastructure to measure climate-related financial risks.

**

Since the early 2000s, private and public initiatives have flourished to try to bridge the gap between the investors' demand for and the supply of ESG information. These initiatives have not yet achieved their full maturity nor expanded their coverage widely enough to ensure that climate-related risks are appropriately priced and to support the decision-making for a fully efficient allocation of capital. The discussions you are about to have today are thus crucial. The key lessons that will be drawn from your exchanges will certainly deserve a place on the agenda of a forthcoming Governor's meeting at the BIS. I now pass the floor to Sabine Mauderer*Herzlich willkommen!*

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1 www.ipcc.ch/assessment-report/ar6/ IPCC = Intergovernmental Panel on Climate Change / Groupe d'Experts Intergouvernemental sur le Climat (GIEC)

2 acpr.banque-france.fr/les-principaux-resultats-de-lexercice-pilote-climatique-2020

3 www.ngfs.net/sites/default/files/medias/documents/progress_report_on_bridging_data_gaps.pdf

4 www.g20.org/wp-content/uploads/2021/07/Communique-Third-G20-FMCBG-meeting-9-10-July-2021.pdf

International Conference on "Statistics for Sustainable Finance", co-organised with the Banque de France and the Deutsche Bundesbank

14-15 September 2021, Paris, France, hybrid format

Keynote speech

The simple economics of climate change[1]

Professor Christian Gollier, General Director, Toulouse School of Economics

[1] This presentation was prepared for the conference. The views expressed are those of the author and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

International Conference on Statistics for Sustainable Finance

Keynote lecture

Christian Gollier, TSE

The simple economics of climate change

- Externality problem:
  - Private interests are not aligned with the common good;
  - Corporate profits do not mesure the social creation of value.
- Substituting within 30 years all fossil fuels by decarbonized energies is expected to be very costly.
  - Some will have to bear the costs.
  - Utopia of a happy transition.
- Least-cost strategy for the transition:
  - Implement all abattement efforts whose cost per tCO2 saved is less than an upper limit, called « the carbon value ».
  - The more ambitious the target, the larger the carbon value.

Cost per tCO_2 saved

Coal replaced by natural gas	~30€
Reducing speed limit from 90 to 80 km/h on roads	<50€
Domestic fuel replaced by heath pump	~50€
Natural gas replaced by biofuel	~250€
Coal replaced by solar PV panels (feed-in tariff 2020)	~300€
Energy efficiency certificate (insulation)	~350€
Reducing speed limit from 130 to 110 km/h on highways	~500€
Coal replaced by solar PV panels (feed-in tariff 2010)	~1500€

	Boiteux (2001)	Quinet 1 (2009)	Quinet 2 (2019)
2010	32	32	
2020	43	56	69
2030	58	100	250
2050	104	250	775
Growth rate	2.9%	4.9%	8.0%

Table: Social cost of carbon (in euros per metric ton of CO2) recommended in France by three different commissions. Source: France Stratégie.

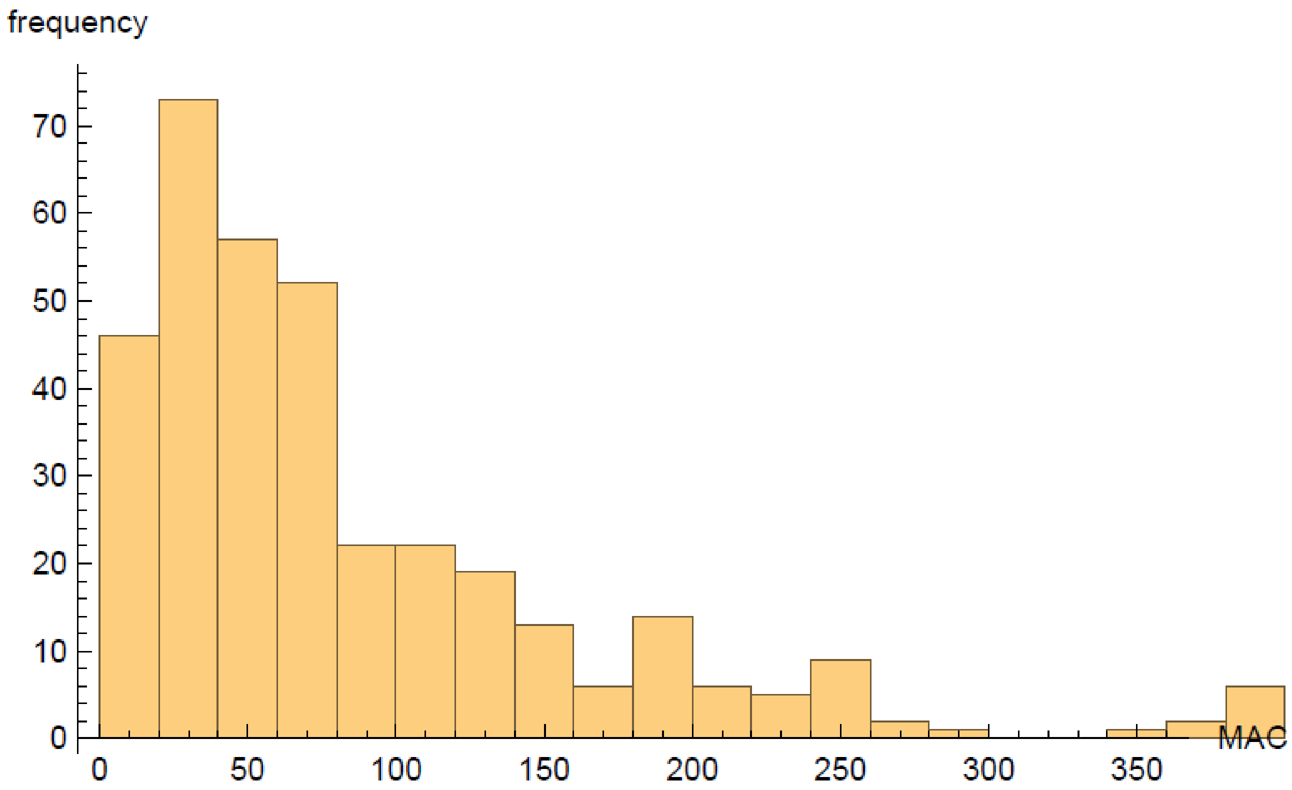

Figure: Histogram of the world marginal abatement costs for 2030 extracted from the IPCC database (https://tntcat.iiasa.ac.at/AR5DB). We have selected the 374 estimates of carbon prices (in US\$2005/tCO_2) in 2030 from the IAM models of the database compatible with a target concentration of 450ppm.

From a carbon *value* to a carbon *price*

- How should we reorganize our economy to make sur that all socially desirable actions are performed?
  - Impose a uniform carbon price equaling the carbon value compatible with the target.
  - Fit For 55: Two markets for emission permits.
  - Redistribute the carbon dividend to the citizens. Social acceptability?
- In the absence of such a public policy, people/corporations should use an « *internal carbon price* » to act responsibly.
  - Consumers, corporations, investors.

Challenges of corporate climate responsibility

- Compatibility of altruism and competitivity?
  - Do stakeholders value better behaviors?
  - Under perfect competition, more responsible firms are less competitive.
    - I am responsible, but I am death!
    - CBAM.
- Internal carbon pricing as a risk management tool.
  - It is rational to value investments by taking account of the price of carbon that will prevail in the future.
  - Stranded assets: Be prepared! Model of the BdF (Cette and co-authors)
  - Problem: uncertain carbon price. Inefficient risk sharing.

Climate finance

- Theory: The social value of a firm is equal to its market value minus the PV of its flow of CO_2 emissions, monetized t using carbon value.
  - A firm « compatible with 2°C » is a firm with a positive social value.
- Climate funds should also use an internal price of carbon, made publicly transparent.
  - Optimize portfolio using standard risk/return tradeoff, but on social rather than market valuations.
  - Superior to alternative strategies (exclusion, best in class,…), typically less transparent, obviously not least-cost efficient.
  - Send the right incentive to firm through heterogenous costs of capital.
- CSR indices (CAC40 ESG,…) should be based on the ranking of social capitalizations.

Data issues

- We are not there yet, partly because of data issues.
- For climate finance, we need data on corporate climate emissions
  - Current emissions, and prospective emissions given the current capital structure.
- Issue on the scope: Risk of multiple counting.
  - If all players along the value chain are made responsible for their own emissions, the right incentives will be in place. Scope 1 ok.
  - Otherwise, larger scopes should be considered.
  - It is critically important to harmonize the solutions to this issue.

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Keynote speech

Assessing and acting on climate risks requires better data and taxonomy[1]

Luiz Awazu Pereira da Silva, Deputy General Manager,
Bank for International Settlements

1 This presentation was prepared for the conference. The views expressed are those of the author and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

Assessing and acting on climate risks requires better data and taxonomy

Keynote speech by Luiz Awazu Pereira da Silva

Hello everyone. I am honoured to have the opportunity to address this conference.

The BIS, as provider of secretariat for the Irving Fisher Committee on Central Bank Statistics (IFC), is proud to support the committee in this most timely event, co-organised with the Bank of France and the Deutsche Bundesbank.

I want to share with you today some personal messages on climate risk, the role of the international community and what all this means for your work as producers and users of data.

My quick summary is: **assessing climate risks and acting on them requires better data and taxonomy**; climate risks are large and material and there is urgency to act; for actions to be effective, filling data gaps – and better exploiting available data – will be crucial for calibrating the transition path, measuring progress and detecting unintended side effects. The existence of data gaps should not be an excuse for inaction. Rather, it means climate policies need, on top of better data to quantify risks, significant coordination across jurisdictions and across sectors, using multiple instruments and mobilizing adequate financing for the transition to net zero.

To start, physical risks due to climate change are real, significant and mounting; each of us can see devastating weather events around the world. Beyond circumstantial evidence, scientists in the latest IPCC report are telling us exactly that. True, weather is not climate. But various data sets are confirming worrisome trends: the increasing volume of weather-related economic losses in general, and uninsured losses in particular. Here is a first instance where measurement and data are necessary.

We need to assess better these climate-related losses that could become --some already are-- huge systemic losses that can derail entire economies, especially when these losses trigger other phenomena (eg., massive migration, etc.) that may occur much faster than we anticipated.

In addition, we need to assess where climate-related risks are creating financial markets failures. For example, there are entire regions of the World (red zones) where insurance is not available anymore. Data on these circumstances are key because the best science today tells us that we are on the path of a four (4) degree Celsius average temperature increase.

There is urgency to act. Urgency in addressing these risks arises because of their size, and their asymmetric and irreversible nature. Scientists are telling us that global warming is not a process that will self-correct. The irreversible nature of some of the effects of climate change is also something that price discovery mechanisms alone have difficulties taking into account. So, a wait-and-see attitude today is a very risky proposition. It is also irresponsible and unfair to future generations. The prudent line is deploy mitigation policies now.

At the BIS, one of our contributions has been to alert about this new type of systemic risk, we called it a **Green Swan**. A Green Swan is not the Black Swan conceptualized by Nassim Taleb for the Global Financial Crisis that can be seen as a very rare, unlikely or unexpected event (a so-called tail risk). A Green Swan on the contrary is <u>certain</u> to happen, what is unknown is when and how it will manifest itself. Green Swans have devastating consequences for our societies if we deplete the rest of our carbon budget. They will trigger much more than just financial losses or threats to global financial stability. Indeed, they can be life threatening.

The Covid-19 pandemic is perhaps an illustration of what we thought about climate change. The conditions leading up to it were slow moving, but when the adverse global effects materialise, they happen quickly.

In short, even though we don't have full information to quantify the cost of a climate Green Swan, we know enough by now that (a) it'd be more prudent to take action to reduce the chance of a climate Green Swan, and that (b) we need to shed light on the climate-related risks we are already exposed to.

But then, for acting effectively you need **better data** and **adequate taxonomies**. And then you need to **disclose this information** so that risks are properly mapped and priced.

Better data on climate risks is essential for evaluating the robustness of the financial sector, for performing adequate stress-tests and for designing the proper supervision procedures. Better data also provides relevant information for market participants to price climate risks in their portfolios and redirect accordingly their investments.

What constitutes better data in this context? In its May 2021 progress report on bridging data gaps, the Central Banks and Supervisors Network for Greening the Financial System (NGFS) has flagged several key areas of note:

First, firms' carbon emissions data are currently limited and lack granularity. There are also gaps in geographical data on asset locations. All these are needed for evaluating both transition and physical risks.

Second, there are significant data gaps in firms' plans for reducing emissions, their plans for offsetting carbon footprints and their transition targets. This forward-looking data is essential for assessing future climate risks since we know that their nature cannot be properly assessed with backward-looking data.

Indeed, knowing where we are and where we want to go with some degree of granularity is imperative. It means strengthening data gathering on these aspects. It also means better using already existing data.

These are key steps to enable the use by all economic actors of common Climate Scenarios for central banks and supervisors, such as the ones released by the NGFS in June 2021, which require a lot of data.

They are also essential for the work on portfolio design strategies aiming at alignment with different jurisdictions' official net zero emissions commitments.

Then, an **agreed upon taxonomy** is needed to effectively help finance the transition. We need a classification system that translates climate and environmental objectives into specific criteria to assess the sustainability of economic activities. Why is it critical? To guide investors, to avoid "green washing" and to facilitate trust and adequate pricing of risks.

A growing number of asset managers as well as central banks and supervisors find it increasingly important to have clarity as to what constitutes "green" investments and loans and what does not.

This clarity is a necessary condition for a smooth and meaningful transition to a "greener" financial system and economy, whether in terms of climate or other environmental aspects. For this reason, the stepping stone to good taxonomies ought to be clear identification of the policy goals (for example, the climate-related goals of the Paris Agreement). This principle would greatly help benchmarking investments project across taxonomies because they can be more easily related to the specified goals.

Taxonomies that are developed in a consistent manner across jurisdictions could also help market practitioners to reach a harmonised understanding about green objectives behind assets that are available in different jurisdictions. The collaboration of the EU and Chinese regulatory authorities to develop a Common Ground Taxonomy is a path-breaking effort in this regard. And the International Platform on Sustainable Finance (IPSF) launched in 2019 could facilitate harmonisation and consistency of taxonomies across more jurisdictions.

Designed properly, taxonomies can help to raise market transparency by reassuring investors that their funding is contributing to the specified goals and ensuring that assets that cannot achieve these objectives are clearly identifiable to investors.

Taxonomies should provide a strong signal about the non-financial benefits of a given asset, and thus mitigate "greenwashing", ie a false or misleading signal of environmental benefits.

Finally, in order for climate risk data to be effective, the information needs also to be properly **disclosed**. This is the recommendation of the FSB Task Force on Climate-related Financial Disclosure (TCFD), for all firms and economic sectors.

Proper disclosure of climate risk related information is especially pertinent for the actors in the financial sector because they need to be able to adequately manage and price climate risks on an ongoing basis in their day-to-day operations – not just when there is a regulatory stress testing exercise. This requires proper procedures that can also help to improve lending, investment and insurance strategies, taking advantage of common climate scenarios.

Therefore, a number of parts such as data, taxonomies and future commitments are needed to be put in place, known and disclosed simultaneously to quantify physical and transition risks and to be capable of envisaging a transition toward net zero.

Against this backdrop, more official guidance based on these three elements – data, taxonomy and disclosure – will bring the benefits of an orderly transition. Uncertainty on the transition path could lead to severe financial instability, a kind of climate Minsky moment. Transition risks could be somehow increasing if precisely data is missing, directions are unclear and adaptation plans are neither clearly stated nor coordinated. A rise in transition risks could unfortunately trigger at some point a disorderly overshooting that is very frequent in financial markets.

For example, in the absence of specific regulatory guidance, many asset managers and pension funds may start anticipating and begin divesting from certain types of assets. Indeed, reputational pressure seems to be mounting. That can trigger potentially large financial swings. The role of public guidance would be to support the efforts to fill data gaps, homogenise the green taxonomy, indicate direction and facilitate the creation of a path of gradual adjustment that is sustainable, reasonable and agreed upon.

An important part of this public guidance should take the form of a trajectory for the carbon tax. Another is to facilitate the emergence of reporting standards on emissions by corporates as mentioned earlier. All this data will help to properly map climate risks. We know it is critical because the Global Financial Crisis has shown that even small pockets of high credit risk can paralyse the global financial system.

Therefore, better data on climate risks, disclosure and a homogeneous green taxonomy, will enhance policies to address climate change. All this is very important because these policies require coordination between all actors in society and all countries; there is no single "silver bullet". Climate change is a global negative externality. Therefore, we are increasingly aware that to tackle the complexity of global warming, no single country, no single agent can do it alone. Rather, the move to net zero requires cooperation between various agencies in Government including the Treasury, the private sector and civil society. The central banking community is playing its part through the NGFS. The private sector has been very active too, for example with a new alliance called the "Glasgow Financial Alliance for Net Zero".

A coordinated approach by many actors will operate using several instruments. As mentioned earlier, the instruments include carbon tax, better measurement and disclosure of risks, improving taxonomy of green financial instruments, developing new technologies, new investment instruments, financial techniques to design portfolios toward net zero, fostering research, etc. Institutions like the BIS are contributing in areas where we have expertise: integrating climate risks into financial stability frameworks, developing standards, and also working on concrete banking products that helps finance green projects, among others. One example is the BIS Innovation Hub's first green finance project, Genesis, which explores the tokenisation of government green bonds in small denominations to give greater access to retail investors, combined with real-time tracking of environmental outputs.

Cooperation needs also to be international. That is for two reasons. First leakage is a major threat to de-carbonizing the economy. If a country has an ambitious carbon price trajectory but does not apply to its imports, it defeats the purpose. Second, the transition to net zero requires financial and technological resources that many developing countries do not have.

Indeed, climate policies have distributional impacts and present difficult political economy challenges. The challenges of the political economy of successful structural reforms are immense and climate policy can be seen as the mother of all structural reforms. To be successful it has to change relative prices to impact the composition of consumption, investment and public spending all together in the global economy and within a very tight timeframe of a couple of decades before we reach dangerous tipping points.

Finally, financing the transition to net zero could become a Schumpeterian creative-destruction process. Using private-public cooperation to mitigate climate risks can produce better odds of making the post-Covid recovery more sustainable and more inclusive. It may also contribute to enhance the innovative process of moving toward a net zero carbon economy through massive investments in new technologies and in alternative energies. It will be also critical to be able to develop practical methodologies to align financial portfolios with the 1.5 degree ambition and show a feasible transition path to achieve that.

In addition, the transition to net zero needs new investment resources. Public and private investment funds, making resources available to developed and developing nations can complement efforts by multilateral, regional, national development banks. Both have an important role to play in the transition, as well as the whole private financial sector. During the industrial revolution in the 18-19th century, the private financial sector financed the evolution from agrarian to industrial societies. Given the huge financing needs of the transition to net zero, it has an important role to play in the transition to a low carbon economy working with the right combination of policies and with the public sector.

To conclude: Climate change is an urgent and critical issue. It needs coordination, determination, cooperation and consensus building. Consensus is needed because fighting climate change is the mother of structural reforms and we know from experience that reforms always have significant redistributive consequences.

This conference is an important reminder of the need to bring the best minds together to continue working on data, taxonomies, using common climate scenarios and disclosure procedures in order to better quantify climate risks and ensure an orderly transition preserving financial stability. The coming COP26 in Glasgow is an opportunity to re-affirm commitments, mobilize resources, work on these challenges, propose and implement practical solutions.

Thank you.

International Conference on "Statistics for Sustainable Finance", co-organised with the Banque de France and the Deutsche Bundesbank

14-15 September 2021, Paris, France, hybrid format

Data needs, an overview on the Irving Fisher Committee stock taking[1]

Christian Schmieder, BIS, and Elena Triebskorn, Deutsche Bundesbank

[1] This presentation was prepared for the conference. The views expressed are those of the authors and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

Int. Conference on Statistics for Sustainable Finance

Session 1: Sustainable finance: Addressing data needs

Data needs, an overview on the Irving Fisher Committee stock taking

Christian Schmieder (BIS) and Elena Triebskorn (Deutsche Bundesbank)

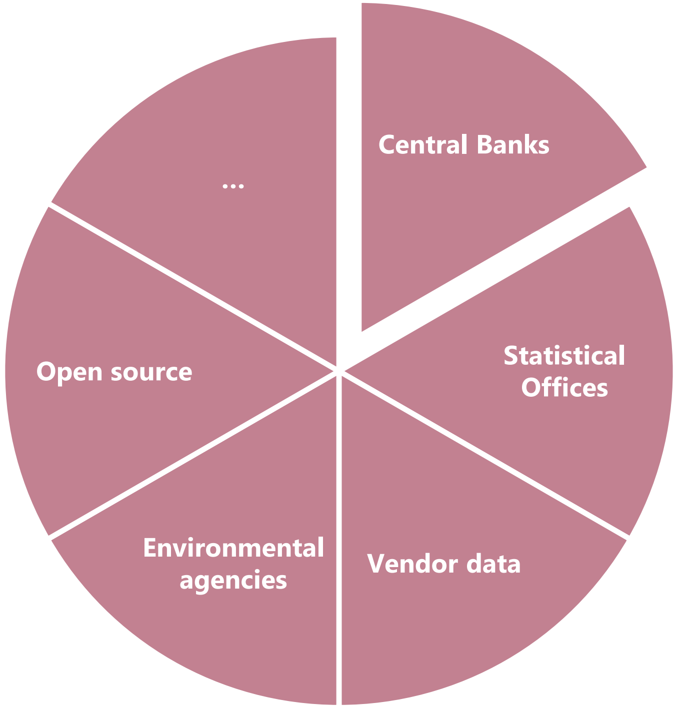
14 September 2021

The views expressed in them are those of their authors and not necessarily the views of the BIS or Deutsche Bundesbank.

IFC survey on sustainable finance: Purpose and key facts

- **Objective**
  - Focus on Central Banks (CB): Stocktake of sustainable finance data needs & data availability
  - Complement existing / ongoing work by other initiatives (eg G20, FSB/SSBs, NGFS etc) – perimeter differs: sustainable finance definition, policy objectives, actors covered, data issues
- **Perimeter**
  - Sustainable finance definition: Broad - ESG: Environmental, Social and Governance
  - All CB policy objectives (Fin stability / supervision, Asset management, Monetary Policy, etc)
  - Survey among IFC CBs - 58 answers (28 advanced economies, 30 EMEs)
  - Focus on operational elements (data collection, data gaps)
- **Timeline**
  - Today's presentation of results and recommendations
  - Publication of IFC Report by end 2021

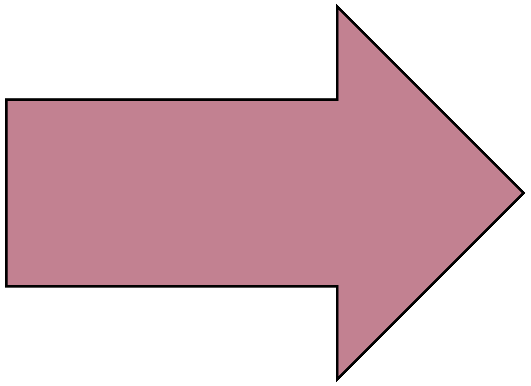
Contribution of IFC work: act as a facilitator and amplifier to establish data



International efforts:

FSB/SSBs, **IFC**, NGFS, G20/ UN

National efforts

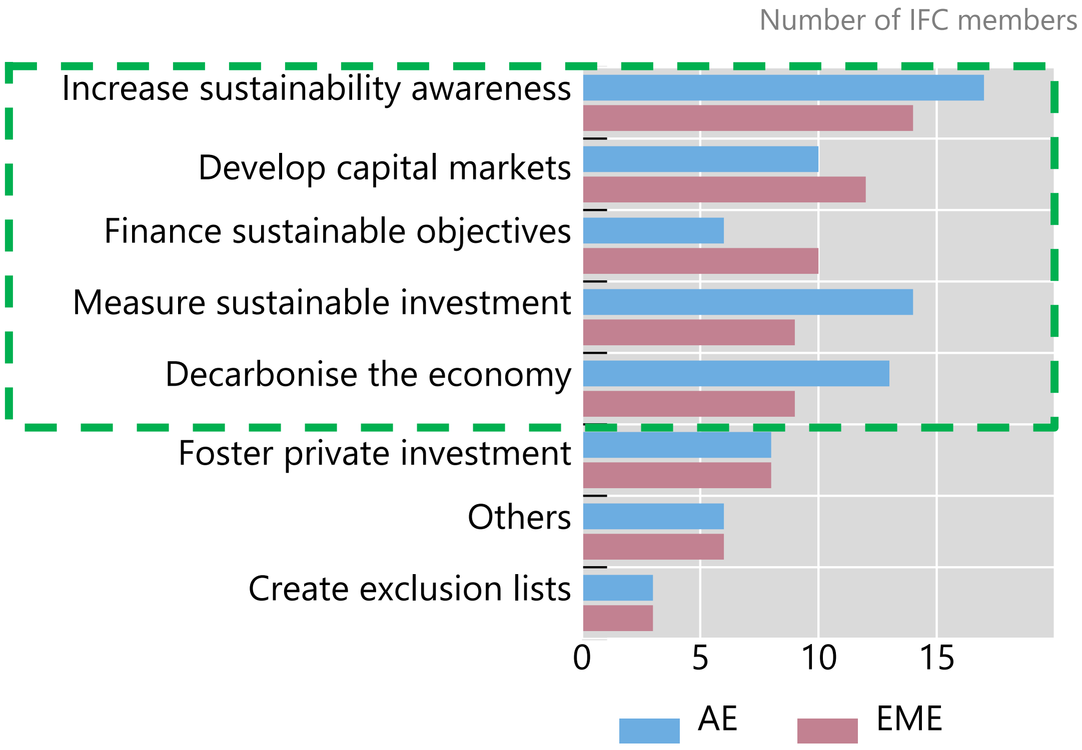


Key findings

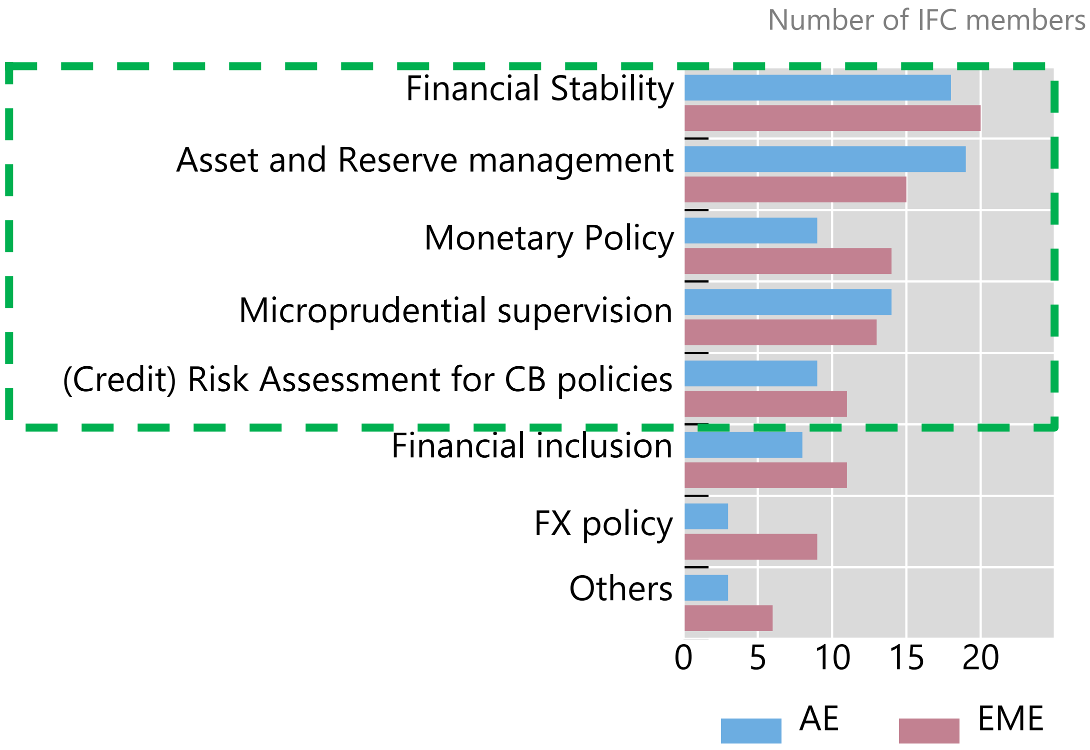
- **Sustainable finance is of growing interest for Central Banks**, although stances vary widely
- **Central Banks** are perceived as **key stakeholders for sustainable finance policies**
- **Central Banks’ data needs are closely linked to their core mandates** - prudential and financial stability analysis, asset/reserve management and monetary policy
- **Environmental indicators are most relevant at current juncture**, while the use of social and governance indicators is more limited so far
- **Data challenges:**
  - **Missing taxonomies /regulation lead to data gaps / data issues**
  - Macro data available, but substantial **gaps with respect to granular firm level data**
- **Solutions to close data gaps:**
  - Cooperation among all stakeholders (public sector entities and private sector)
  - New data collection initiatives, use of technology

Finding 1: Sustainable finance is of growing interest for Central Banks

Broad Central Bank policy objectives



Specific Central Bank policy objectives

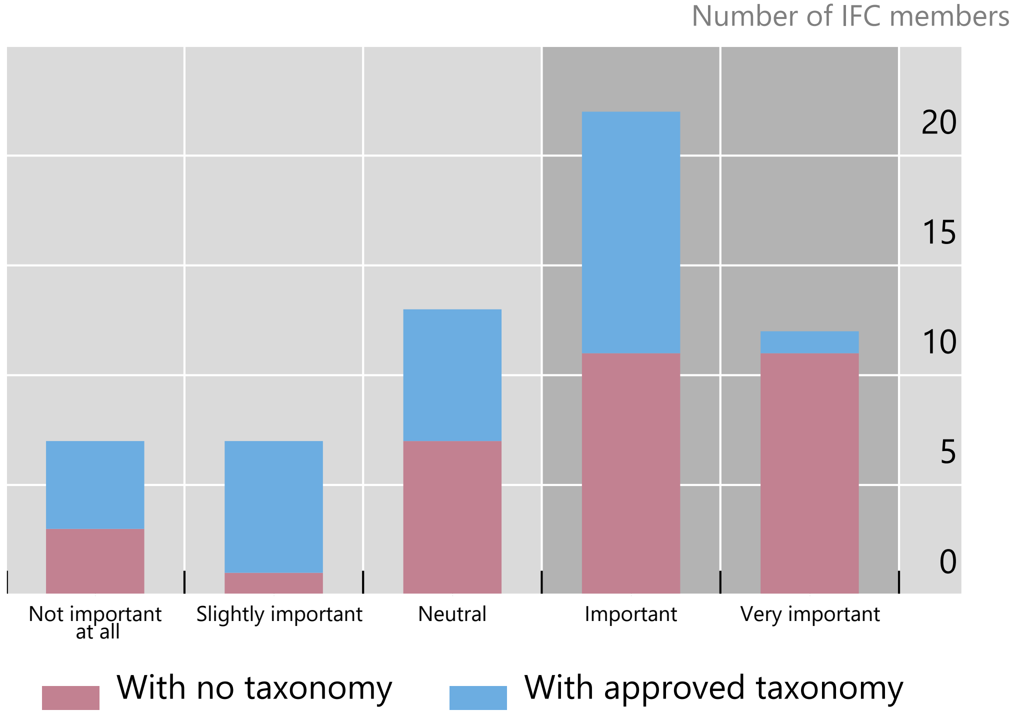


Source: IFC survey

Finding 2: Central Banks are important stakeholders for sustainable finance policies

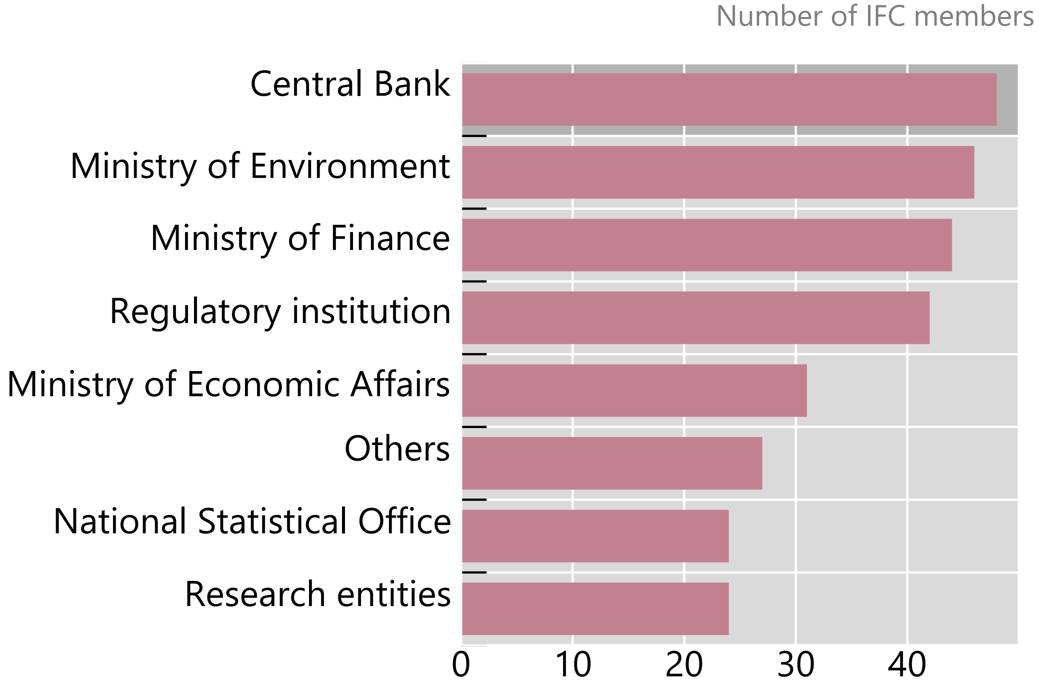
Central Bank's Role

Importance of Central Banks in national governance processes



Source: IFC survey

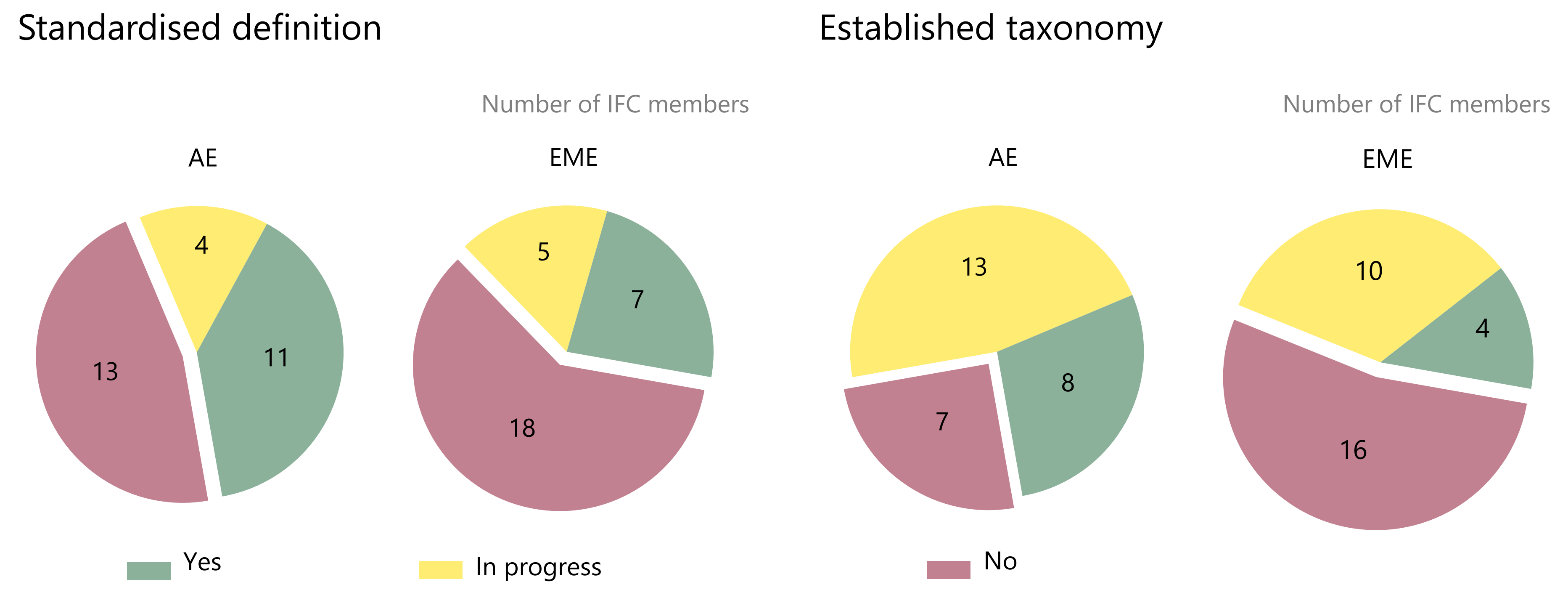
Involvement of institutions in sustainable policies



CBs are perceived as important stakeholders to facilitate establishing taxonomies jointly with ministries and regulatory institutions

Finding 3: There are substantial differences between Central Banks

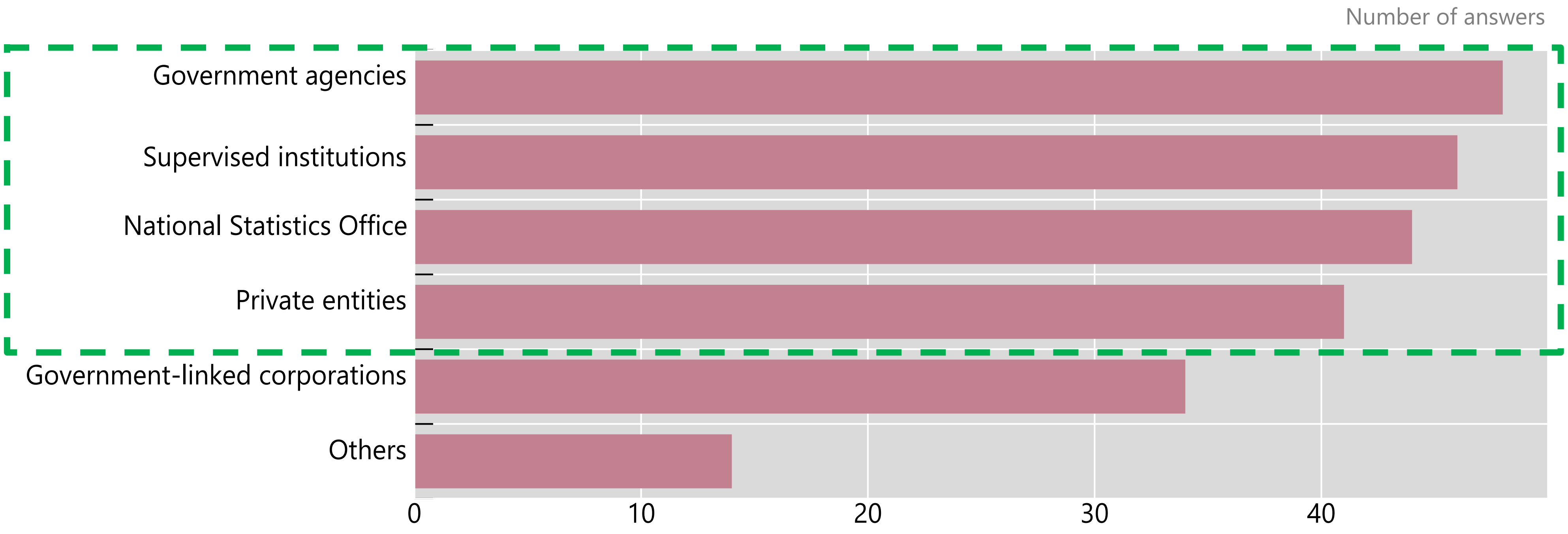
- Differences are visible in definitions and taxonomies but also with respect to conceptual challenges, reporting requirements, data quality issues (also related to technology gaps) and confidentiality questions.
- Differences reflect a number of factors, including different starting points and mandates.



Source: IFC survey

Findings 4: Central Banks rely on a range of different data sources

Key data providers for central banks



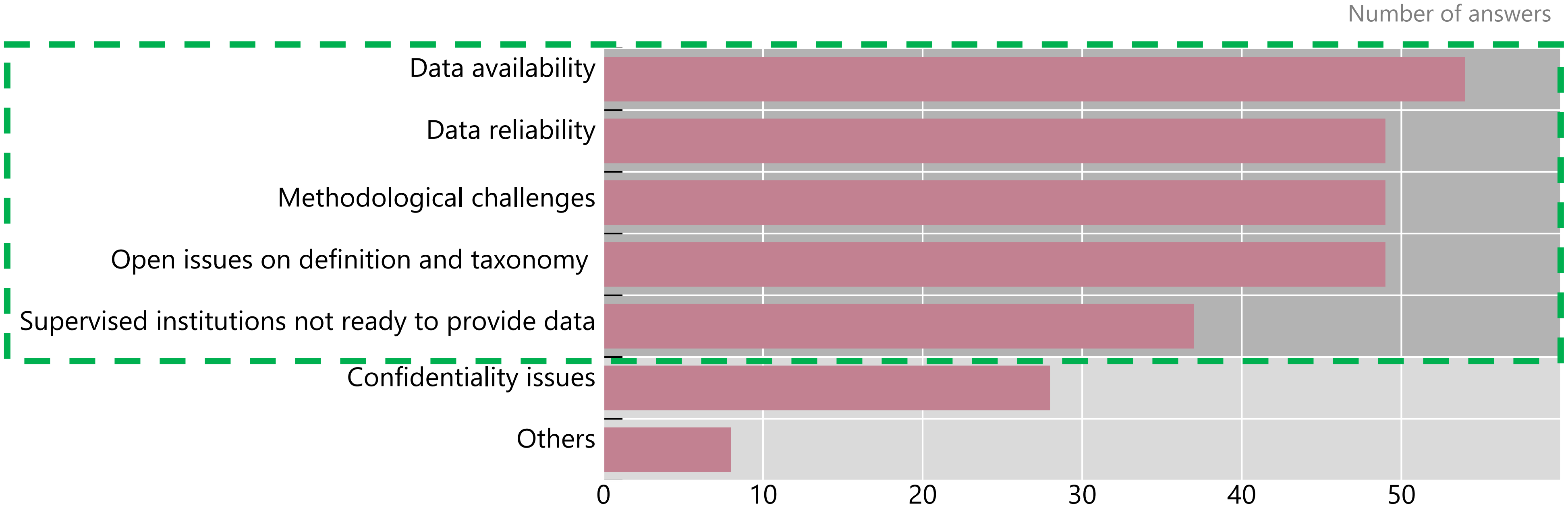
Source: IFC survey

Cooperation needed between central banks, national statistics offices and government agencies, vendors as well as international organisations to close data gaps.

Finding 5: There are a number of data challenges identified by CBs

- Besides data gaps and data quality issues, there are challenges related to methodology (eg definitions and taxonomies)
- Clarifying existing and forthcoming standards with supervised institutions and establishing sound reporting processes for supervised institutions is another key priority

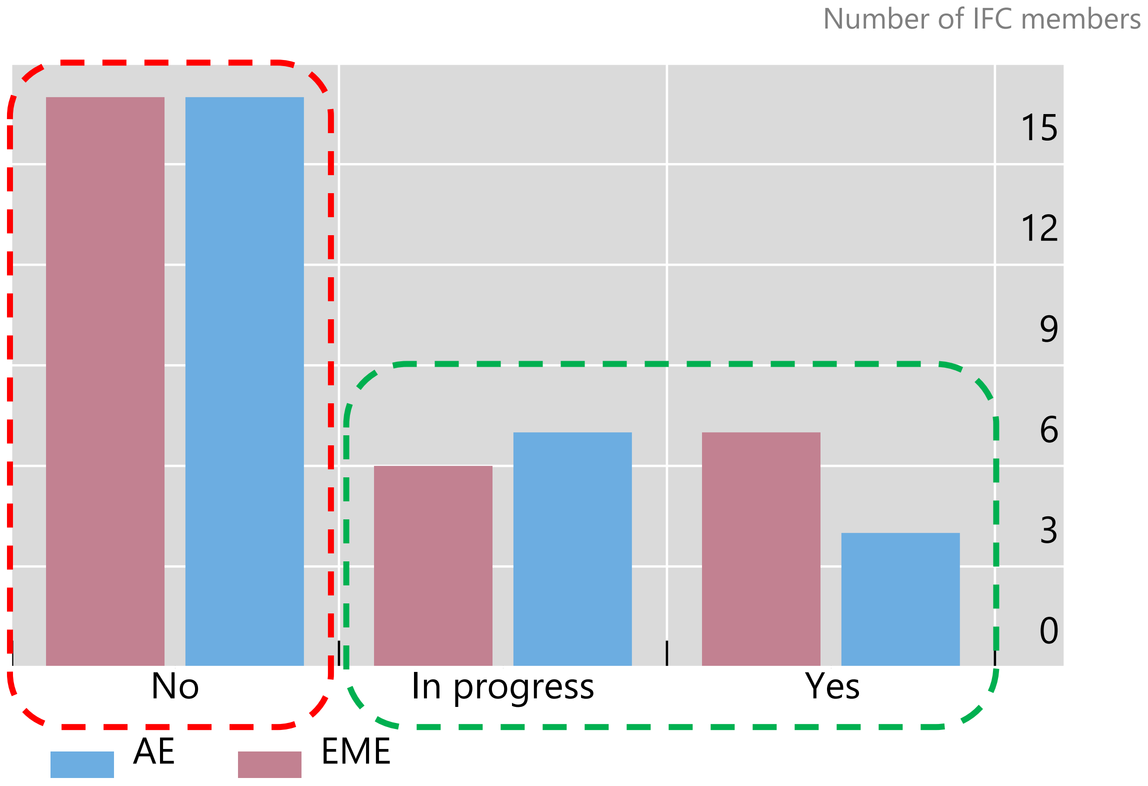
Data challenges



Source: IFC survey

Finding 6: Reporting of data is still at early stages

Established reporting process for financial firms



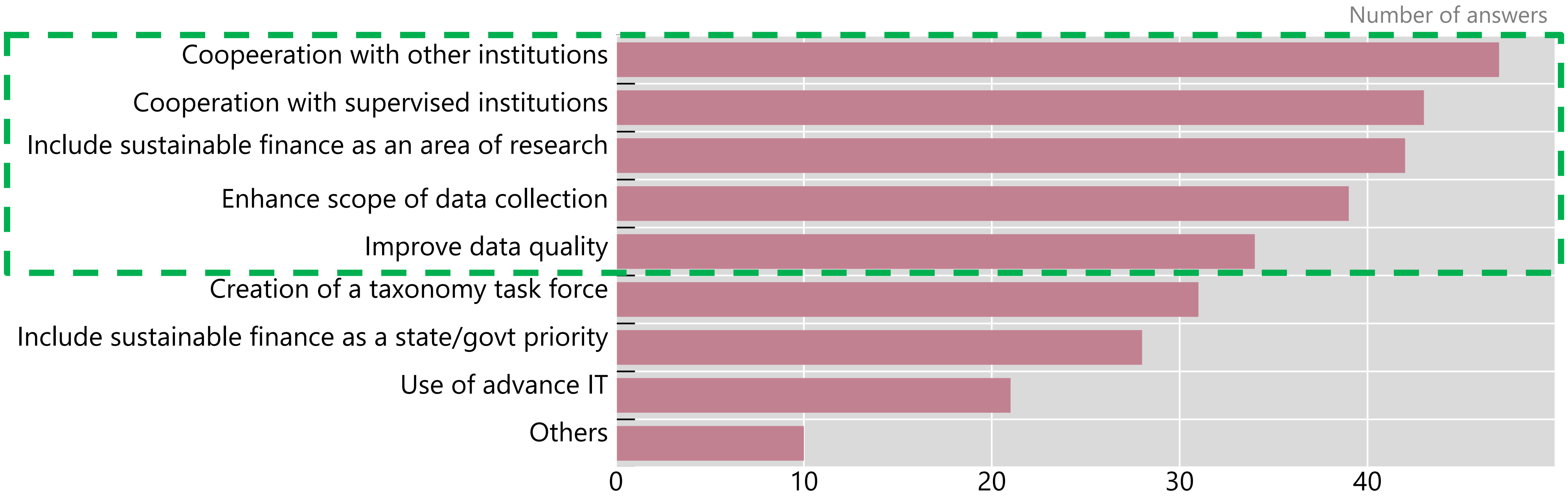
Source: IFC survey

- **More than half of IFC members do not have an established process for the reporting of sustainable finance data to CBs** or other relevant stakeholders
- **Many advanced economy Central Banks are leading by example** by reporting on their own sustainability data.

Finding 7: Central Banks identify different approaches to close data gaps

- Cooperation among public sector entities and private sector (eg taxonomy task force) are most promising to Central Banks
- Complemented by new data collection initiatives and use of advanced IT

Measure to close information gaps

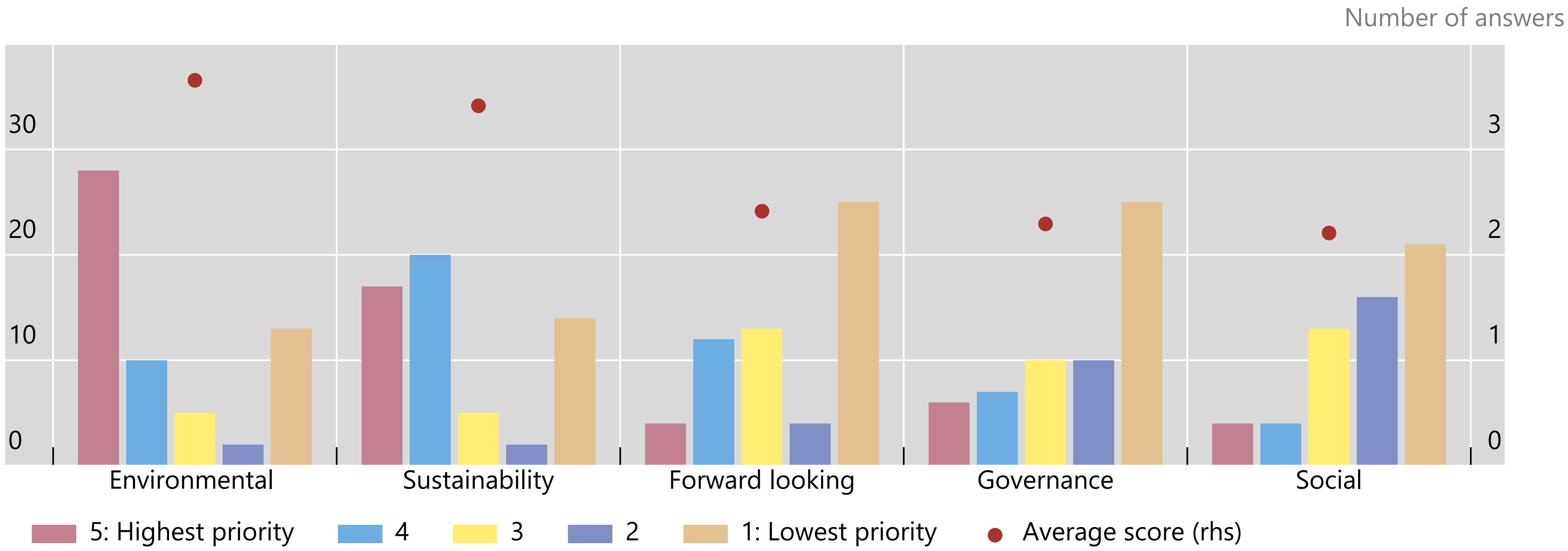


Source: IFC survey

Finding 8: Environmental indicators are most important to IFC members

- Environmental indicators are reported as being most relevant.
- Having a standard definition or taxonomy in place boosts the importance central banks place on governance and social indicators

Key sustainable finance metrics identified by Central Banks

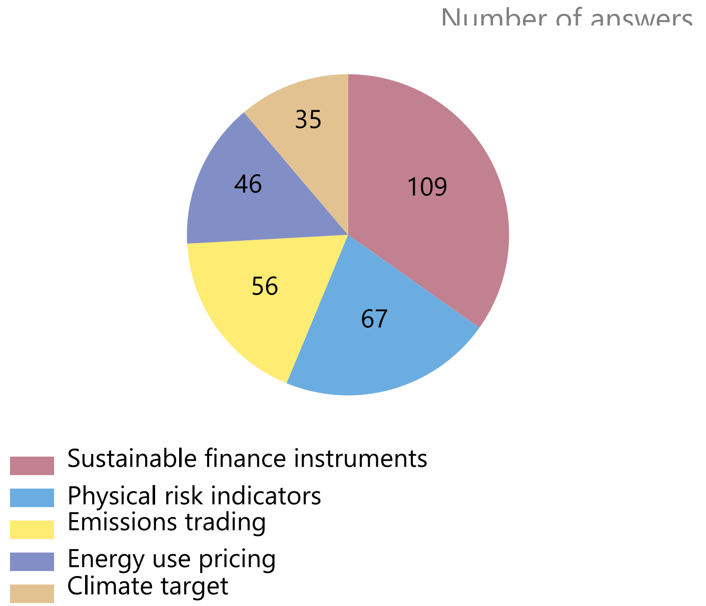


Source: IFC survey

Finding 9: Indicators on financial instruments, physical risk and emission trading are considered most relevant

- The most important indicators include **sustainable financial instruments and environmental indicators on physical risk and emission trading,** followed by energy use / pricing and climate targets, eg
  - Emissions footprint indicators
  - Green / Sustainable lending and bond holdings / issuance
  - ESG ratings
- Macro data is available for some of these areas, but many indicators tend to rely on micro data, which is often not publicly available (ie granular public data and vendor data)
- Members seek to close data gaps – for instance by combining different data sources (eg Colombia's approach to physical risk indicators)

Top 5 actively-used indicators

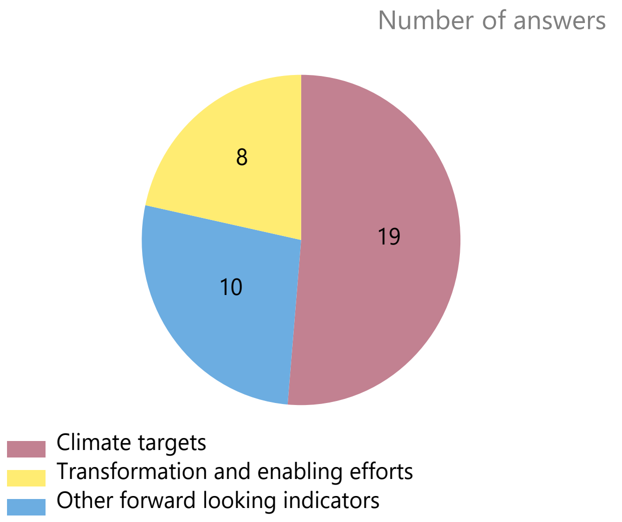


Source: IFC survey

Finding 10: Remaining indicator groups seem to be a newer area of analysis

- **Forward looking indicators: climate target indicators for Greenhouse Gas Emissions / for firms of highest priority**
  - Forward-looking indicators are not yet used widely, but initiatives are underway (focussing on country and firm-level climate target data)
- **The use of social and governance indicators is limited for now**
  - The most relevant **social indicators** relate to **financial inclusion** as well as **working conditions and human rights**
  - Transparency and disclosure as well as board diversity are top **governance indicators**

Top forward-looking indicators



Source: IFC survey

Recommendations

- **Central banks will have to advance in identifying data needs (ie key metrics to be collected)** to pursue relevant sustainable policy objectives
  - Definitions and taxonomies have to be established, overarching concepts developed, working closely with key stakeholders, including non-traditional stakeholder
- **Closing data gaps remains a top priority** and requires concerted efforts by all stakeholders:
  - There is a need for enhanced cooperation among key stakeholders (CBs, national statistics offices and government agencies, international organisations, vendors and reporting firms)
  - Working with firm level (including vendor) data poses operational challenges which need consideration and creative solutions (eg using advanced data techniques)
- It is important to **use established data** for policy purposes and **coordinate efforts**:
  - International coordination of various initiatives is key (for macro and micro data – eg IMF / NGFS / BIS / FSB)

International Conference on "Statistics for Sustainable Finance", co-organised with the Banque de France and the Deutsche Bundesbank

14-15 September 2021, Paris, France, hybrid format

Assessing the effectiveness and impact of central bank and supervisory policies in greening the financial system across the Asia-Pacific[1]

Sylvain Augoyard and Adrian Fenton, WWF Singapore;
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1 This presentation was prepared for the conference. The views expressed are those of the authors and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

Assessing the Effectiveness and Impact of Central Bank and Supervisory Policies in Greening the Financial System across the Asia-Pacific

Findings from the Second APAC Central Bank Sustainability Survey 2021

Sylvain Augoyard,[1] Aziz Durrani,[2] Adrian Fenton,[3] Ulrich Volz[4]

Abstract

This article presents the findings from the second Asia-Pacific (APAC) Central Bank Sustainability Survey, shedding light on (i) details of sustainable finance measures that have been implemented by central banks and financial supervisors (CBFS) in the region; (ii) the rationales and processes underpinning their adoption; (iii) whether and how CBFS assess the effectiveness, efficiency, and equity of adopted measures; and (iv) the capacity building needs of CBFS in APAC. A growing number of CBFS across APAC are paying due attention to climate change and other environmental risks. Many have already started to develop or implement various sustainable finance measures, or are planning to do so going forward. For the time being, most activities pertain to their own governance and strategy as well as micro-prudential supervision. Most CBFS plan to scale up their sustainable finance activities across a range of areas. While the majority of CBFS have started to assess the effectiveness of the implemented measures, a more systematic assessment is held back by a self-perceived lack of expertise and data availability constraints. CBFS cited a number of training needs with respect to achieving climate and environmental objectives with respect to their institutional mandates.

Keywords: sustainable finance, central banks, financial regulators, financial supervision, Asia and the Pacific, climate change, nature loss

JEL classification: G1, G2, G3, Q01, Q5

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views expressed in this article are those of the authors alone and do not necessarily reflect the views of SEACEN or its member institutions.

Contents

1. Introduction

The macroeconomic and financial impacts and risks associated with climate change and nature loss have been widely recognised. A consensus has emerged among central banks and financial supervisors (henceforth "CBFS") that they need to address climate and other sustainability risks and support the scaling up of sustainable finance (e.g., NGFS, 2019, 2021a). It is also acknowledged that doing so is part of their mandate (Dikau and Volz, 2021). CBFS have a potentially large number of monetary, prudential and other tools at their disposal to affect sustainability outcomes (Dikau et al., 2020a, 2020b).

A broader contour of a new framework for mitigating climate-related and environmental risks and governing sustainable finance is emerging. This includes the addressing of data gaps; enhancing market practices and transparency through standards, taxonomies and disclosure; integrating climate-related and environmental risks into financial stability monitoring and micro- and macroprudential supervision; the analysis of climate-related risks through scenario analysis and stress testing; adjusting monetary operations to account for sustainability impacts; and integrating sustainability factors into own-portfolio management. Nevertheless, there is still considerable discussion around the specific sustainable finance policies and instruments that should be used and how exactly they should be implemented. Moreover, given that most CBFS have only very recently started to actually implement sustainable finance policies and instruments, there is a lack of understanding of their effectiveness and impact.

Against this backdrop, this article seeks to shed light on the factors that have led CBFS across the Asia-Pacific (APAC) region to adopt (or consider adopting) specific sustainable finance measures; if and how they assess the impact of the adopted measures; and what the potential training needs of CBFS are. The article presents the main findings from the second APAC Central Bank Sustainability Survey.[5] The survey was jointly carried out by the South-East Asian Central Banks (SEACEN) Research and Training Centre; the Centre for Sustainable Finance at SOAS, University of London; and WWF-Singapore between June and August 2021 with financial support from the International Network for Sustainable Financial Policy Insights, Research, and Exchange (INSPIRE), a research partner of the Network of Central Banks and Financial Supervisors for Greening the Financial System (NGFS). The survey was sent to the 35 central banks and monetary authorities that are members, associate members or observers of the SEACEN Centre and two other monetary and financial authorities in APAC.[6] The survey had a response rate of 70%. The aim of this second survey was to better understand (i) details of sustainable finance measures that have been implemented; (ii) the rationales and processes underpinning their adoption; (iii) whether and how CBFS assess the effectiveness, efficiency, and equity of adopted measures; and (iv) the capacity building needs of CBFS in the region.

The survey data indicates that most CBFS across the APAC region have implemented or are starting to implement sustainable finance measures to achieve climate and environmental objectives associated with their institutional mandates.

[5] A first sustainable finance survey among was conducted among APAC CBFS in 2019. See Durrani et al. (2020).

[6] The SEACEN Centre was established in 1982 with a membership of eight central banks/monetary authorities. It has since grown to 19 members, eight associate members and eight observers.

The data also indicates the number of measures that will be implemented will grow in the future. It highlights that more than a third of the 26 CBFS participating in the survey are to some extent measuring the efficacy of implemented sustainable finance measures. This progress is notable considering the difficult context within which many CBFS in the APAC region operate. Many suffer from capacity and resource constraints and are attempting to address the impacts of climate and environmental risks on financial stability while also implementing Basel III recommendations. Despite the progress, however, the advances being made are insufficient considering escalating climate risks within APAC countries from both a physical and transition risk perspective, as well as other accelerating nature-related risks such as biodiversity and natural capital loss. Progress needs to be expedited, notably to prevent or limit a build-up of these risks that would have severe consequences on economic and financial stability.

The remainder of the article is structured as follows. Section 2 will present the main survey findings. Section 3 will discuss the survey results and make recommendations for policy makers to improve the design and implementation of existing and new sustainable finance measures as well as on data gathering aspects to allow for a systematic evaluation of the effectiveness of sustainable finance measures that will enhance the capacity of CBFS to manage climate- and sustainability-related financial risks and promote sustainable finance. Section 4 concludes.

2. Survey results

The survey was sent to the 35 central banks and monetary authorities across APAC that are members, associate members and observers of the SEACEN Centre and two other monetary and financial authorities. Of SEACEN's 19 full members, 16 responded, an 84% members response rate. Another 10 associate members and observers and other CBFS responded, making a total of 26 responses among central banks, regulatory agencies and monetary authorities. The overall response rate was therefore 70%. This is a significant response rate and hence allows us to draw conclusions across the region. In some cases, certain respondents skipped a particular question and did not submit a response, in which case we considered this as a nil response for that question. In such cases, and where relevant, percentages were therefore still calculated based on the total of 26 respondents.

2.1. Measures implemented

According to the survey data, CBFS across APAC demonstrate a range of efforts to address climate and environmental objectives, utilising the full breadth of their institutional mandates (see Table 1). The survey asked respondents to report which sustainable finance measures they are currently employing, and which measures they are planning to implement in the future. The measures were organised by 'intervention areas', corresponding to the nature and main objectives of these measures (e.g. monetary policy, micro-prudential supervision).

Number measures implemented, by intervention area

Table 1

Type of intervention area	Total # of measures currently implemented	Number of associated CBFS	Total # of measures to be implemented in the future	Number of associated CBFS	Total # of measures implemented either currently or in the future	Number of associated CBFS
Macro-prudential instruments	15	11	20	14	25	16
Micro-prudential instruments	52	17	51	15	72	19
Portfolio management	16	10	17	11	26	14
Credit allocation instruments	18	10	19	9	24	11
Own governance and strategy	117	24	107	23	135	24
Dev. / eval. of gov. policies and measures[1]	23	12	19	10	23	12
Monetary policy	25	14	22	11	29	14
Standard setting for sustainable finance	27	17	34	18	41	18

[1] Involvement in the development / evaluation of government-led policies and measures

How to interpret Table 1: *In total, 11 central banks and/or financial supervisors are currently implementing macro-prudential measures, for a total of 15 distinct measures. In addition, 14 central banks and/or financial supervisors are planning to implement such measures in the future, for a total of 20 distinct measures. The total number of macro-prudential measures either currently implemented or planned is 25, involving 16 central banks and/or financial supervisors.*

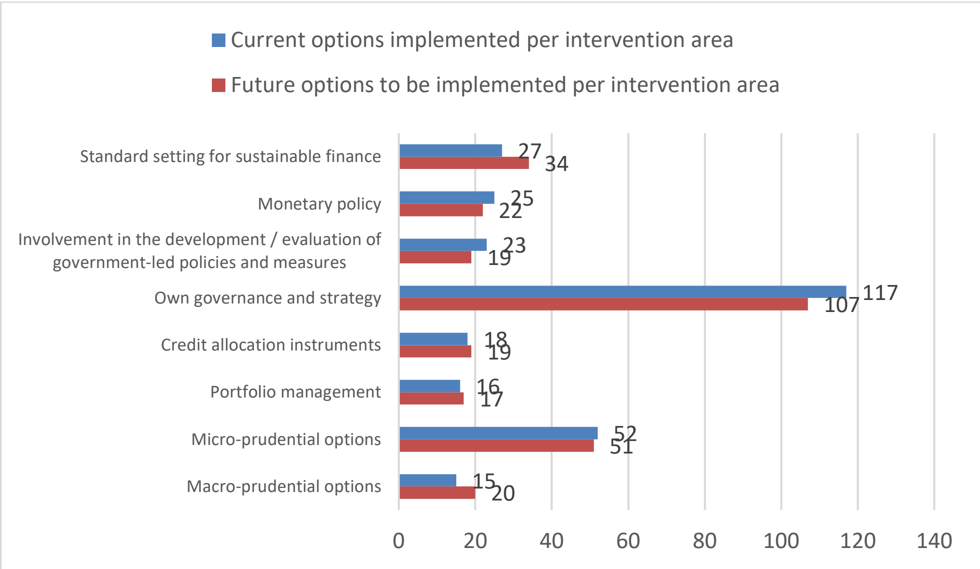
The intervention area in which the highest number of sustainable finance measures are currently being implemented and planned to be implemented in the future is 'own governance and strategy'. This is not surprising because many measures within this group, such as developing a climate change strategy, participating in international initiatives, or supporting capacity building among financial institutions, would naturally be implemented in the early phases of addressing climate and environmental objectives. It also contains a greater variety of measures relative to most other intervention areas.

Fewer CBFS have or are currently implementing measures from intervention areas such as macro-prudential policy or credit allocation. Depending on the perspective adopted, this is either problematic given how climate and environmental risks are rising and the resulting imperative to urgently address these risks; or it is understandable given the complexities involved in implementing measures from these and related intervention areas and the need for these measures to be based on high-quality data and analysis which requires expertise.

Micro-prudential measures have been or are currently being implemented to a higher degree than macro-prudential measures. This could indicate a greater focus of CBFS on microprudential tools; however, it may also reflect that CBFS are not yet ready to apply macroprudential instruments to address climate and other sustainability risks. Understanding why specific intervention areas have been utilised more than others could be a future research topic.

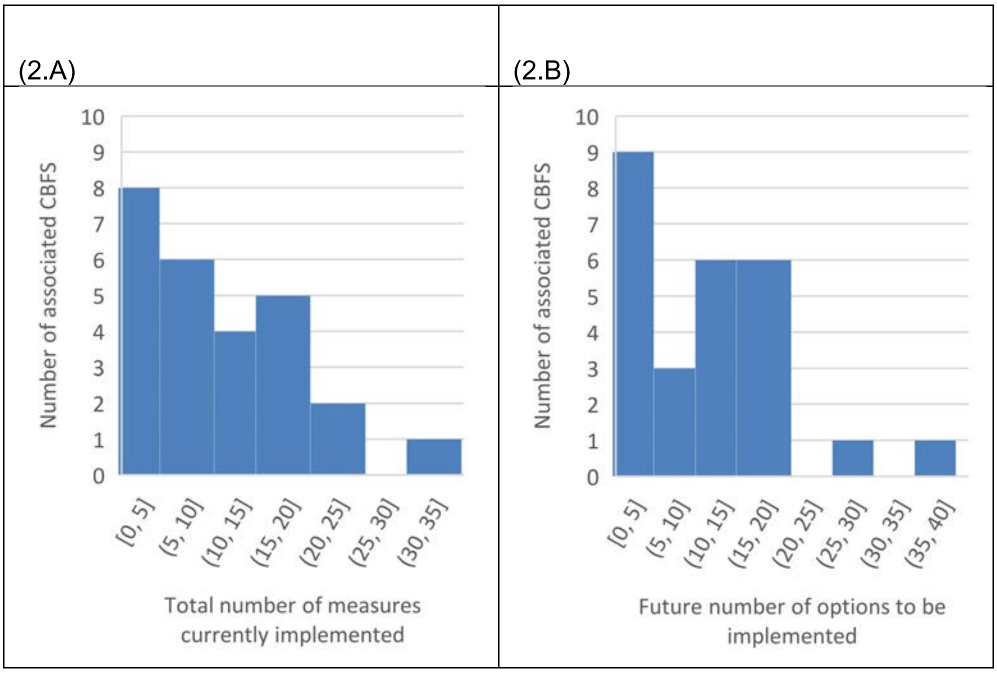
Figure 1 shows the total number of measures currently implemented as well as expected to be implemented in the future by all CBFS across each intervention area. For instance, while 'own governance and strategy' remains the most popular intervention area, it becomes relatively more popular, with over twice as many implemented measures compared to the next intervention type.

Figure 1: Total number of current and future measures to be implemented by all CBFS intervention area



The distribution of sustainable finance measures currently implemented or to be implemented in the future by a CBFS with respect to achieving climate and environmental objectives is positively skewed with almost half of CBFS implementing only between 1 and 10 measures (see Figure 2). The spread of measures implemented differ between CBFS: the lowest number of measures currently being implemented by an individual institution is 1 and the largest is 33. Looking at measures to be implemented in the future, this range is expected to increase slightly, with the lowest number of measures being 1 and the largest being 37. This clearly shows a split emerging between more active and less active CBFS. Figure 2 shows a bi-modal distribution emerging with respect to future total measures that are to be implemented.

Figure 2: Histogram of total measures implemented by CBFS with respect to climate and environmental objectives



The most commonly cited action to achieve climate and environmental objectives is participation in international initiatives, cited by 21 of 26 CBFS (Table 2). This alludes to the important role these initiatives – most importantly the NGFS but also the Sustainable Banking Network – have in driving important debates and in sharing good practices and finding solutions. The top three actions undertaken are from the category of CBFS's own governance and strategy: participation in international initiatives, supporting capacity building for the financial industry, and developing an official strategy. The issuance of regulations or supervisory expectations for financial institutions also features prominently, with 12 CBFS currently have such a measure in place.

Top 12 measures implemented by CBFS to achieve climate and environmental objectives

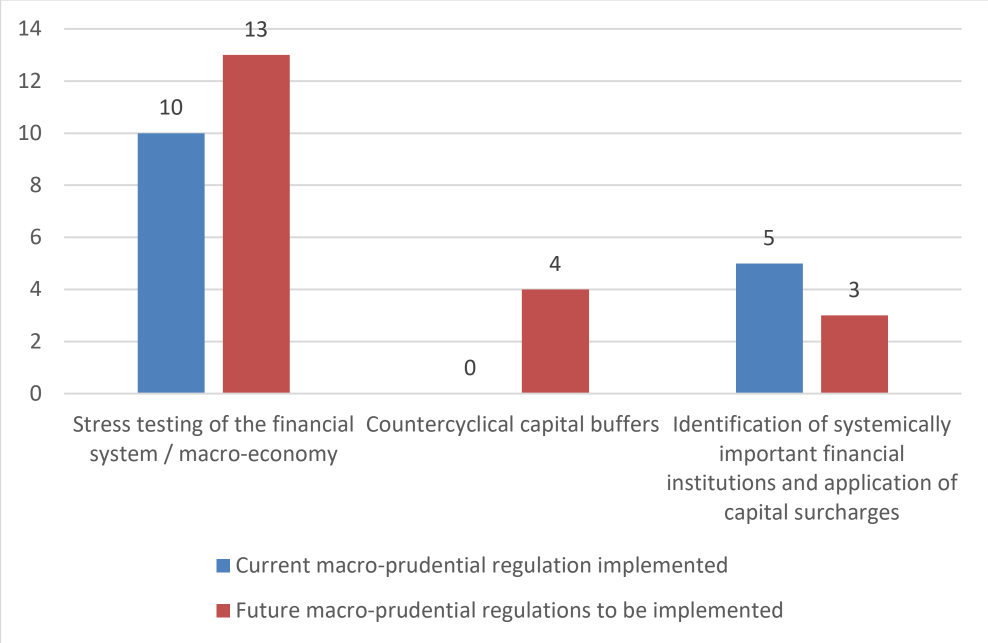
Table 2

Intervention area	Specific measure	Number of times it is implemented
Own governance and strategy	Participation in international initiatives (e.g. NGFS, IFC SBN, other)	21
Own governance and strategy	Support of capacity building efforts for the financial industry	17
Own governance and strategy	Development of an official strategy for your own institution, in line with existing mandates	13
Micro-prudential measures	Sustainable finance regulations (principle-based, covering governance, policies and risk management practices of financial institutions)	12
Own governance and strategy	Creation of multi-stakeholder initiatives (involving financial regulators, financial institutions, industry associations and other relevant stakeholders)	12
Own governance and strategy	Conduct and publication of research relevant to the financial sector and on potential policy response	12
Dev. / eval. of gov. policies and measures[1]	Ex ante policy evaluation and design	12
Monetary policy	Management of foreign exchange reserves	12
Dev. / eval. of gov. policies and measures[1]	Ex post policy monitoring and evaluation	11
Standard setting for sustainable finance	Development of taxonomies for (un)sustainable economic activities	11
Macro-prudential measures	Stress testing of the financial system / macro-economy	10
Own governance and strategy	Coordination with national climate planning processes	10

[1] Involvement in the development / evaluation of government-led policies and measures

For those CBFS with a mandate for macro-prudential regulation, macro-level stress-testing is currently implemented or starting to be implemented by 40% of CBFS (10 of 25 relevant CBFS). Going forward, this is bound to increase to 52% of CBFS (13 of 25 relevant CBFS). No CBFS is currently utilising countercyclical capital buffers and only 3 of 25 relevant CBFS are currently identifying systemically important financial institutions and capital surcharges. In the future, more CBFS are expected to look towards countercyclical capital buffers (4 of 25 relevant CBFS) (see Figure 3).

Figure 3: Current and future macro-prudential measures to be utilised by relevant CBFS



These figures will be considered by some as too low given the continued escalation of physical climate risks and growing political momentum to address it through policy and climate-emergency declarations (i.e. escalation of transition risks). However, climate risk-based stress-testing is still a relatively new and technically demanding process requiring expertise and data which need to be developed. An important question is how CBFS intend to use the results of macro-level stress-testing, such as whether it will be used as the basis for implementing further sustainable finance measures, such as credit allocation instruments or micro-prudential tools.

For those CBFS with a mandate for micro-prudential regulation or supervision, the preferred measure is the issuance of sustainable finance regulations or supervisory expectations,[7] with 52% (12 out of 23 relevant CBFS) of the relevant institutions currently implementing or starting to implement them (Figure 4). Other relatively common measures are setting out disclosure requirements or guidelines (35% or 8 of 23 relevant CBFS), expecting financial institutions to conduct stress-testing (30% or 7 of 23 relevant CBFS), and utilising capital requirements or add-ons (26%, 6 of 23 relevant CBFS). Some CBFS do not associate climate and environmental objectives with their micro-prudential mandate (8 of 23 relevant CBFS). Once these are removed from the calculations, the figures increase: sustainable finance regulations (80%), setting out disclosure requirements (53%), expecting financial institutions to conduct stress-testing (47%), and utilising capital requirements or add-ons (40%).

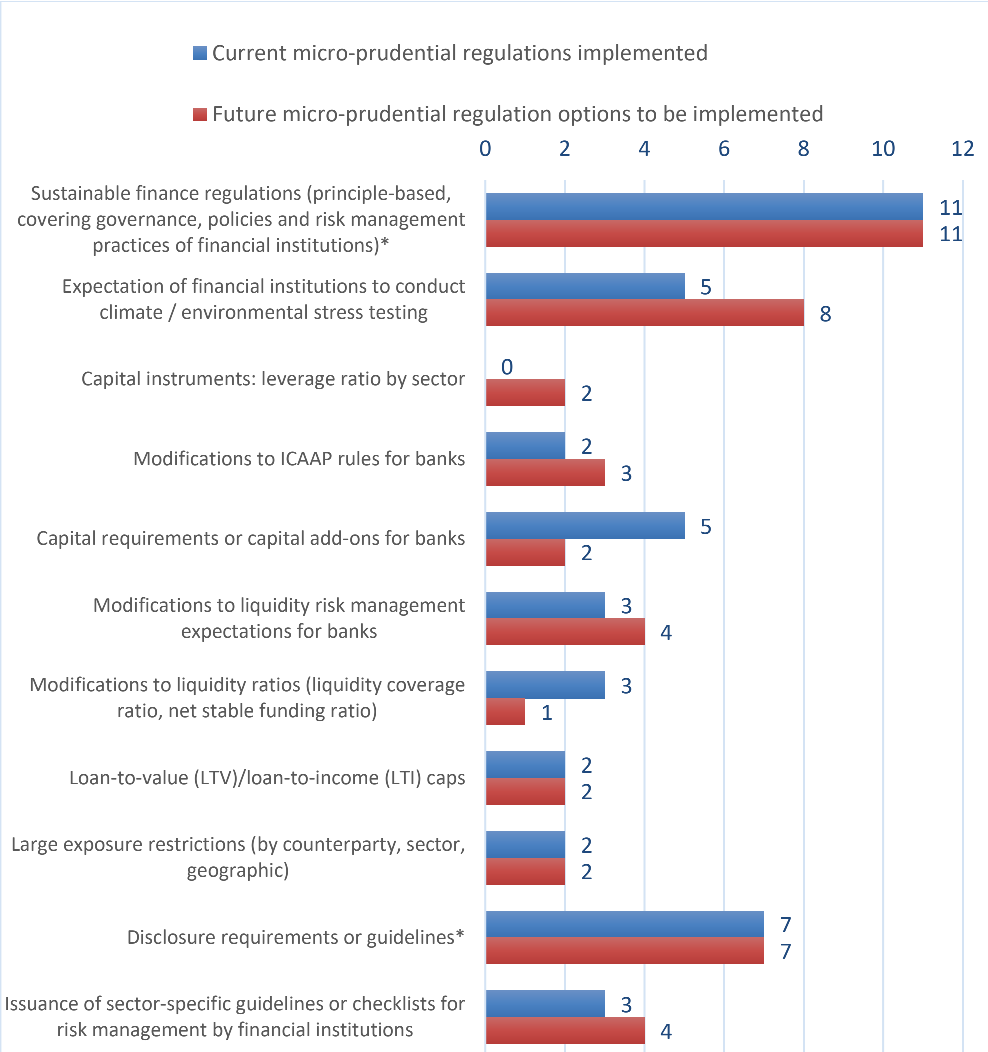
The relatively large number of CBFS which do not associate climate and environmental objectives with their micro-prudential mandate complicates the interpretation of results. Why CBFS are less likely to associate climate and

[7] Principle-based, covering governance, policies and risk management practices of financial institutions.

environmental objectives with their micro-prudential mandate than with their macro-prudential mandate should be a focus for future research.

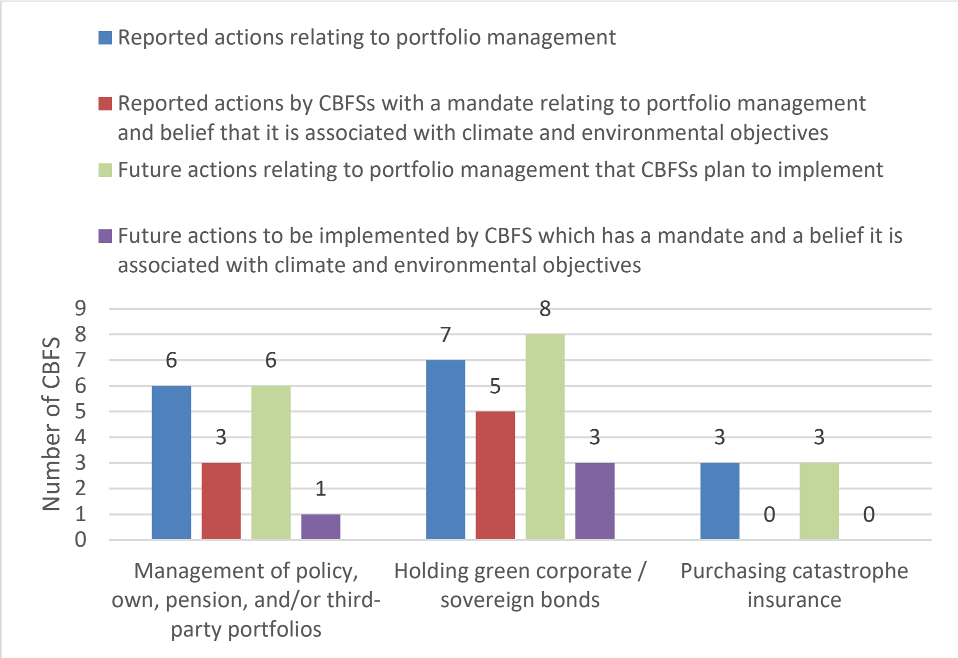
Overall, there is little difference between the measures CBFS currently implement and those which they plan to implement in the future. The measure most commonly expected to be implemented in the future remains sustainable finance regulations. However, expectations for financial institutions to conduct stress-testing increase from 7 to 9 CBFS, and capital requirements or add-ons for banks reduces from 6 to 3 CBFS. The reasons behind and the implications of a potentially reduced use of capital requirements and add-ons could be a focus for future research.

Figure 4: Current and future micro-prudential regulation measures implemented/to be implemented by relevant CBFS



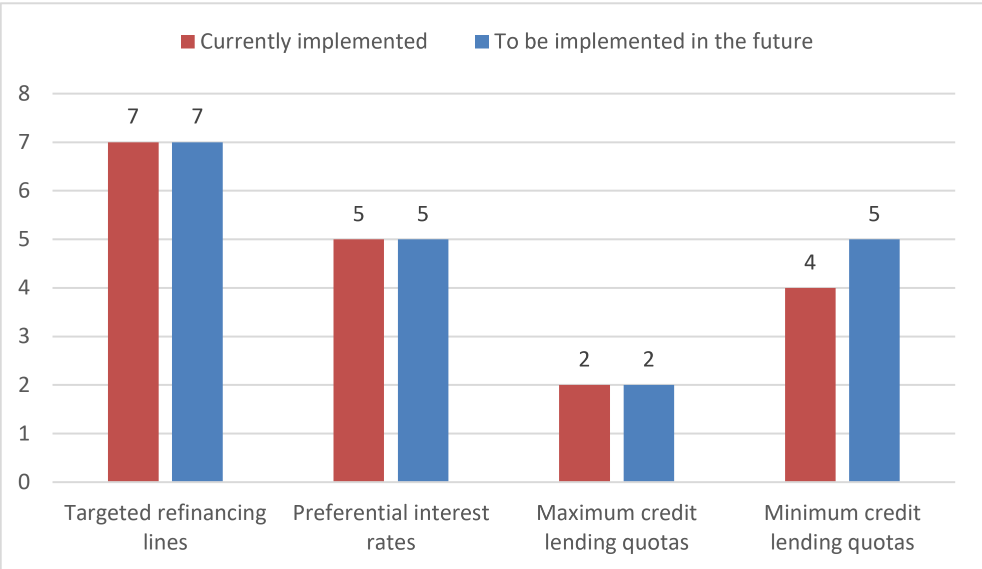
The results related to portfolio management are complex to understand. A number of respondents indicated they are implementing actions despite stating that they do not believe climate and environmental objectives are relevant to their portfolio management mandate (Figure 5). Specifically, many CBFS report that they hold green corporate / sovereign bonds and alter the management of policy, own, pension, and/or third-party portfolios.

Figure 5: Current and future actions relating to portfolio management to be implemented by CBFS



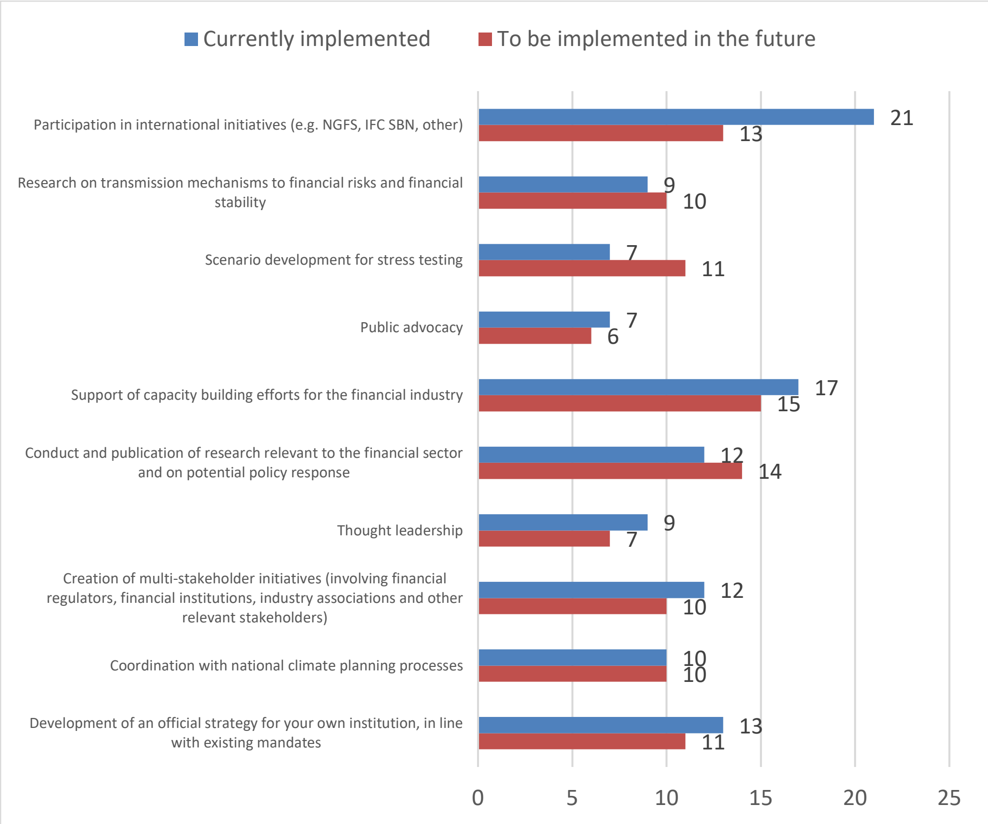
Several CBFS reported the use of some credit allocation instruments (see Figure 6). The most commonly reported tool was targeted refinancing lines, reported by 7 out of 26 CBFS. The utilisation of credit allocation instruments appears unlikely to change in the future. For instance, the same CBFS which currently offer targeted refinancing lines reported that they will continue to do so in the future. This perhaps indicates a cultural element to choosing what actions to implement or whether credit allocation tools might suit some contexts better than others.

Figure 6: Number of CBFS currently implementing or planning to implement specific credit allocation instruments



'Own governance and strategy' is the most common intervention area from which CBFS adopt sustainable finance measures. Within it, 'participation in international initiatives' and 'support for capacity building for financial institutions' are the most popular measures (see Figure 7). The least implemented is public advocacy, and it is expected to remain this way in the future, which seems like a missed opportunity for central banks to use the influential role granted by their role and statutory independence to call for more robust and ambitious government policies. The measure which is expected to see the highest growth is scenario development for stress-testing (increasing from 7 to 11 of 26 CBFS). This indicates that stress-testing is likely to become more important for APAC CBFS when looking to achieve climate and environmental objectives in the future.

Figure 7: Number of CBFS currently implementing or planning to implement specific measures in the "Own governance and strategy" intervention area



A particularly important measure appears to be the development of an official climate change strategy, which 13 out of 26 CBFS reportedly have or are currently developing. Where a CBFS has an official climate change strategy, on average it is associated with implementing or planning to implement more sustainable finance measures across every intervention area (see Table 3). The intervention area where the proportional difference is the largest is credit allocation instruments. The intervention area with the largest absolute difference in the number of measures implemented is micro-prudential tools.[8]

The influence of participating in international initiatives appears less relevant. It is however worth noting that CBFS that are participating in an international initiative have a significantly higher number of measures in place within the "internal governance and strategy" category. This might show the influence of initiatives such as the NGFS in supporting CBFS to define and start implementing a strategy. As these initiatives are relatively recent, it is likely that a clearer distinction will materialise between CBFS that participate in these and those that do not.

erage number of relevant sustainable finance measures per CBFS currently ng implemented, depending on having a climate change strategy (or not), and rticipating in international initiatives (or not), by intervention area

Table 3

	Macro-prudential tools	Micro-prudential tools	Portfolio managemen t	Credit allocation instruments	Internal governance and strategy	Dev. / eval. of gov. policies and measures[1]	Monetary policy	Standard setting for sustainable finance
S has a ate change tegy	1.4	4.5	1.5	1.5	7.4	1.5	1.5	2.5
S does not e a climate nge strategy	0.5	1.1	0.5	0.3	3.0	0.3	0.8	0.7
S is icipating in rnational atives	0.9	3.0	1.1	1.0	6.1	0.9	1.0	1.7
S is not icipating in rnational atives	1.2	1.8	0.6	0.8	1.6	0.8	1.6	1.0

olvement in the development / evaluation of government-led policies and measures

When CBFS have an official climate change strategy they are more likely to have implemented or be implementing key measures frequently considered as critical to climate-related and broader sustainability objectives (Table 4). Similarly, when CBFS participate in international initiatives they are also more likely to be implementing such measures. The influence of participating in international initiatives is actually stronger than that of having an official climate change strategy. It is perhaps unsurprising as these initiatives are often focusing on sharing experience and building capacity on such measures. Furthermore, the wider adoption of these key sustainable finance measures by CBFS participating in international initiatives also indicates that these are not only important in terms of providing a platform for peer learning and the adoption of best practices, but also because they create peer pressure.

[8] Internal governance and strategy would be artificially higher due to the variable 'official climate change strategy' being part of this intervention area.

Number of CBFS implementing key sustainable finance measures depending on having a climate change strategy (or not), and participating in international initiatives (or not)

Table 4

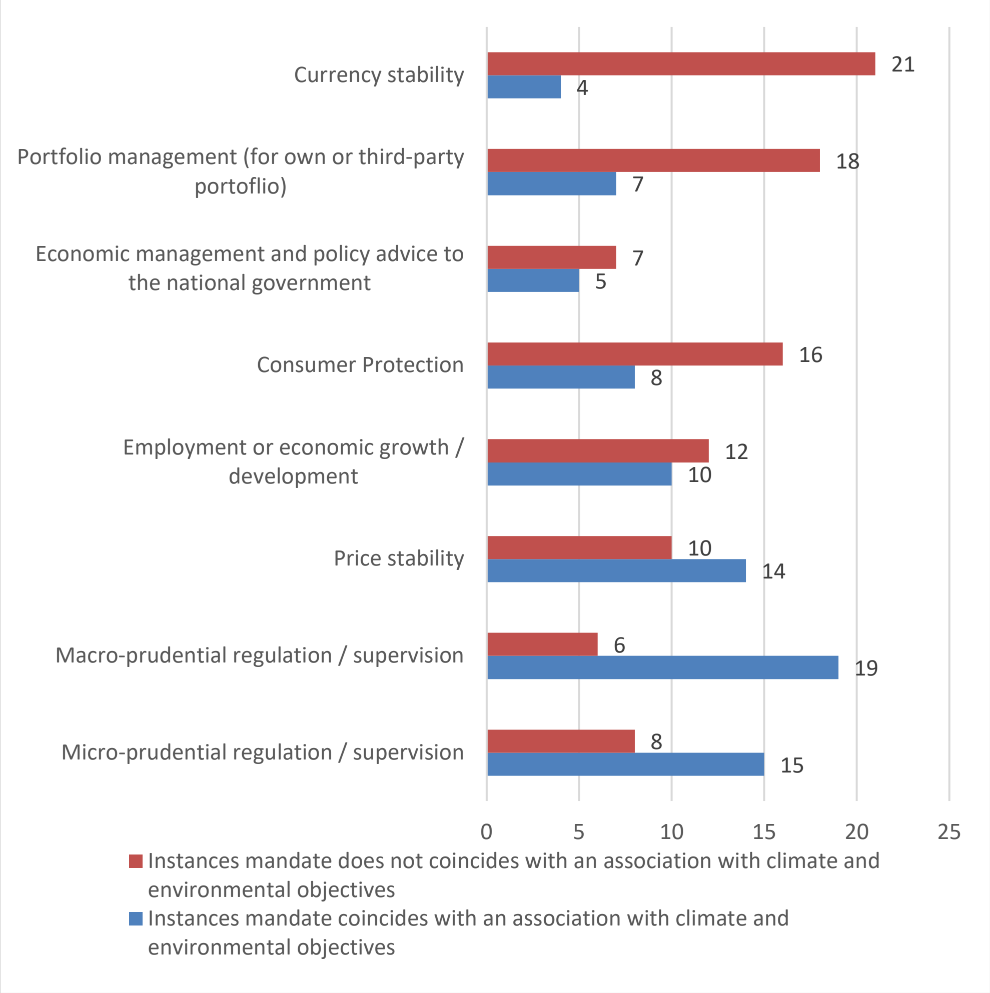
	Stress testing of the financial system / macro-economy	Expectation of financial institutions to conduct climate / environmental stress testing	Development of taxonomies for (un)sustainable economic activities
Number of CBFS with a climate change strategy implementing the measure	11	9	12
Number of CBFS without a climate change strategy implementing the measure	4	2	4
Number of CBFS participating in international initiatives implementing the measure	12	10	14
Number of CBFS not participating in international initiatives implementing the measure	3	1	2

2.2. Factors considered

CBFS reported a variety of decision-making factors for implementing measures to achieve climate and environmental objectives. The most cited reason behind choosing such measures is the institutional mandate, which would be expected from CBFS as public institutions.

The survey results demonstrate that CBFS often associate climate and environmental objectives with their respective institutional mandates. The frequency with which these linkages are recognised differs across mandates (Figure 8). Relatively fewer CBFS recognise linkages with currency stability, portfolio management, and consumer protection mandates. Instead, more CBFS associate climate and environmental objectives with macro-prudential regulation, micro-prudential regulation, and price stability. There are only two instances whereby a CBFS associated climate and environmental objectives with neither of these mandates.

Figure 8: Number of CBFS associating climate and environmental objectives with their mandates



The association with climate and environmental objectives frequently does not hold between mandates which have conceptual linkages. For instance, the scientific reasoning behind why climate and environmental objectives are associated with macro-prudential regulation is likely to mean these objectives should be also associated with the mandate of providing economic policy advice to national governments. Other instances are listed in Table 5. Understanding why CBFS recognise climate and environmental objectives as being associated with some but not others should be a focus of future research, especially if efforts to address climate and environmental risks require measures to be implemented in these intervention areas, which is likely the case.

Related mandates and their association with climate and environmental objectives Table 5

Mandate #1	Mandate #2	% of relevant CBFS which associate climate and environmental objectives to both mandates	% of relevant CBFS which only associate climate and environmental objectives with one mandate	% of relevant CBFS which associate climate and environmental objectives to neither mandate
Macro-prudential regulation	Currency stability	12% (3 of 25)	68% (17 of 25)	20% (5 of 25)
Macro-prudential regulation	Economic advice to national government	33.33% (4 of 12)	50% (6 of 12)	16.67% (2 of 12)
Macro-prudential regulation	Employment or economic growth / development	36.36% (8 of 22)	45.45% (10 of 22)	18.18% (4 of 22)
Macro-prudential regulation	Micro-prudential regulation	61.9% (13 of 21)	23.8% (5 of 20)	14.3% (3 of 20)
Micro-prudential regulation	Portfolio management	18.18% (4 of 22)	54.55% (12 of 22)	27.27% (6 of 22)

*Results only shown for central banks and financial supervisors which have mandate over both areas.

Other relatively commonly cited reasons for choosing measures to achieve climate and environmental objectives are measures being implemented in other countries, an internal assessment determining the need for such measures, and the assessed capacity of financial institutions. The reasons least mentioned are the opinions from other stakeholders, recommendations stemming from academic research, and national government requests (see Figure 9).

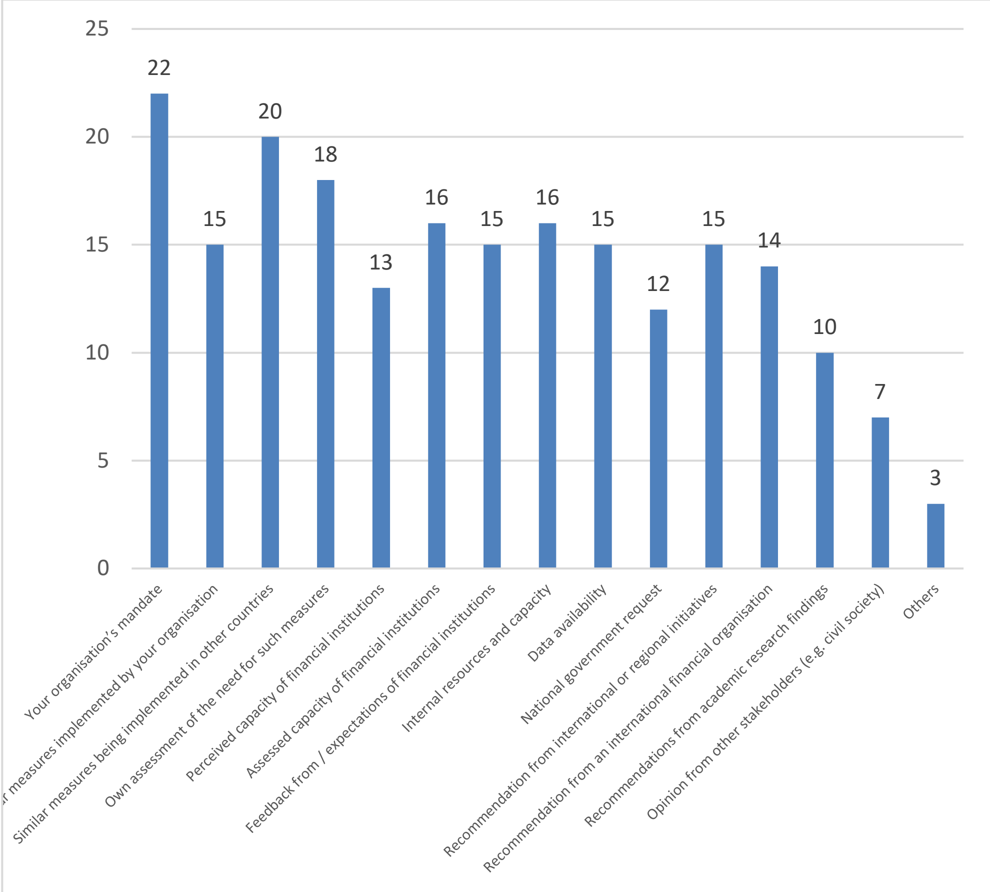
The influence of measures being implemented in CBFS in other countries indicates that CBFS might see an ability to justify or determine their behaviour based on their peer group. In contrast, CBFS seem not to place much importance on the views of other external stakeholders, notably civil society and academia, but also international financial organisations. Why this is the case should be a focus for subsequent research. A significant amount of data and knowledge on climate and environmental risks as they relate to the financial system is being created by these stakeholders. Many would consider effective collaboration between these stakeholders and CBFS as being fundamental to expedite efforts to address climate and environmental risks and achieve key international targets.

Basing decisions on the capacity of financial institutions might be problematic, particularly if financial institutions only develop capacity based on their perceived needs, which are driven by signals sent by CBFS. To avoid creating a vicious circle that would run counter to sustainability objectives, CBFS may need to pre-emptively communicate with financial institutions about forthcoming sustainable finance measures for them to develop capacity, ahead of changing regulatory/supervisory conditions. It should be noted that assessed capacity was cited more often than perceived capacity in terms of choosing which measures to implement in order to achieve climate and environmental objectives, potentially highlighting the importance of established frameworks for supporting capacity assessment.

16 CBFS highlighted internal resources and capacity as a factor behind the adoption of specific measures. As will be discussed later, CBFS cited a number of training needs with respect to achieving climate and environmental objectives. This is important as it highlights where CBFS are experiencing difficulties with respect to

achieving their climate and environmental objectives. It also gives indications as to their future intentions.

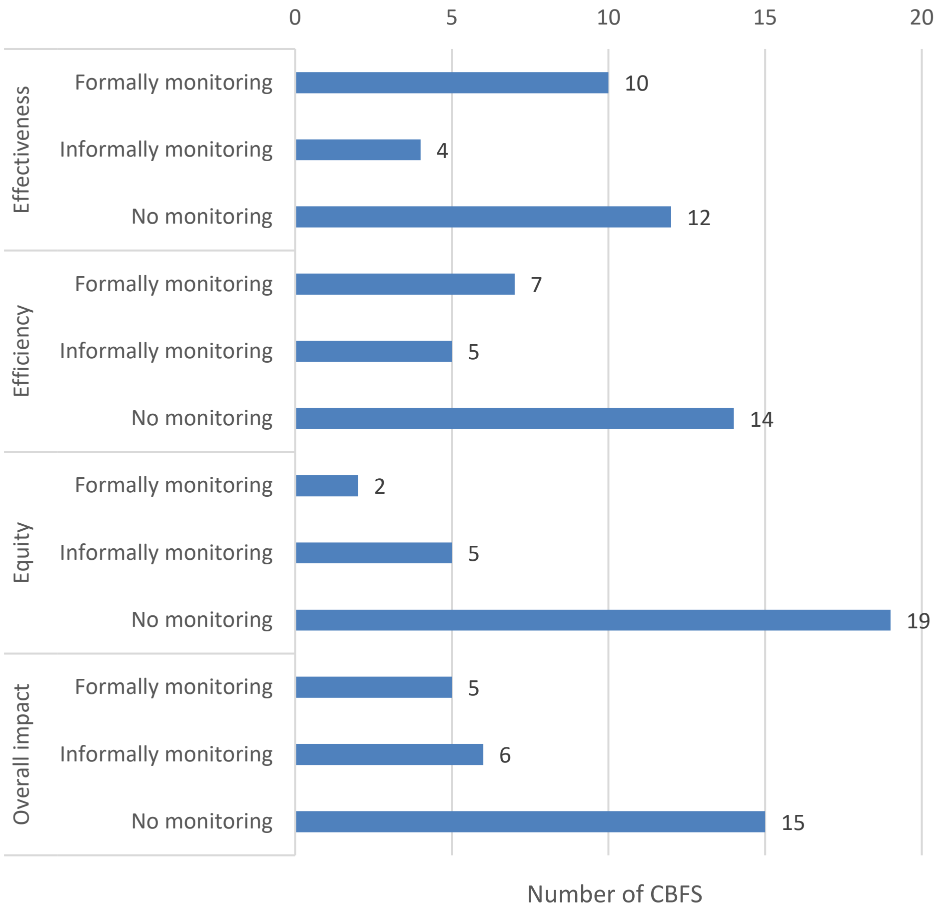
Figure 9: Number of CBFS citing specific reasons behind the adoption of measures to achieve climate and environmental objectives



2.3. Assessing performance of implemented measures

Currently, a non-negligible number of CBFS are monitoring the results of their sustainable finance measures in some manner (see Figure 10). The most common way sustainable finance measures are monitored is in terms of 'effectiveness', with 10 (38%) and 4 (15%) of 26 CBFS either formally or informally tracking this aspect of performance respectively. The least common way sustainable finance measures are monitored is in term of 'equity' with only 2 (8%) and 5 (19%) of 26 CBFS either formally or informally tracking this aspect of performance respectively.

Figure 10: Number of CBFS that are measuring the performance of their sustainable finance measures, and nature of monitoring performed

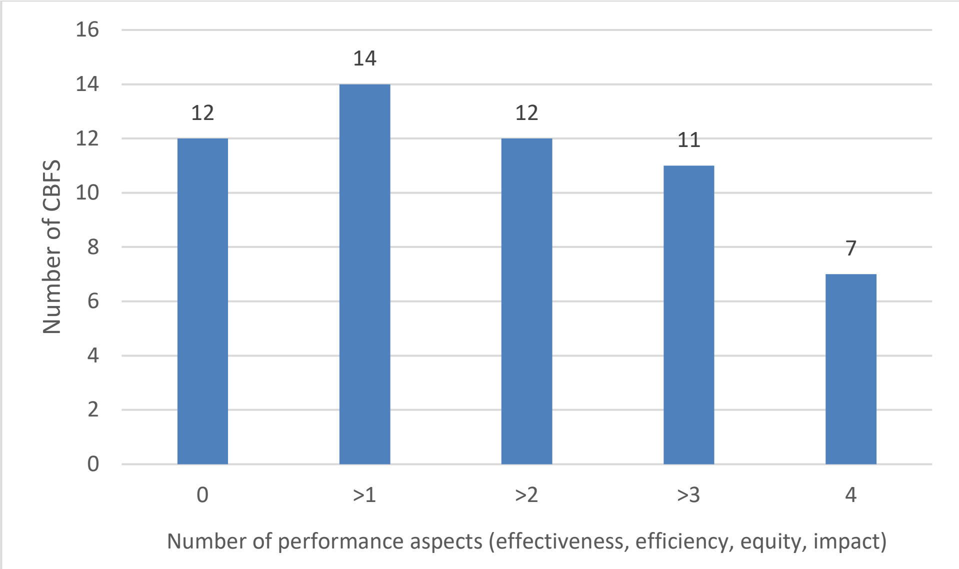


Note: Effectiveness is about whether a specific measure achieves its intended goals. Efficiency is about whether a specific measure achieves its intended goals at reasonable cost. Equity is about whether the benefits and costs of a specific measure is distributed in a just and fair manner. Impact is when a specific measure leads to changes in the practices of targeted financial institutions that result in positive climate and environmental outcomes, such as contributing towards the transition to a low-carbon, climate-resilient and more sustainable economy.

While several CBFS are monitoring multiple aspects of performance (Figure 11), only 7 (27%) of 26 CBFS indicated that they are monitoring the effectiveness, efficiency, equity, and impact of implemented sustainable finance measures. However, considering the contemporary and fast evolving nature of sustainable finance many would consider this to be good progress. Yet, 12 (46%) of 26 CBFS indicated that they are yet to monitor any aspect of performance. The appropriateness of these measuring systems should be a focus of future research, especially regarding the capacity and data availability issues raised by respondents.

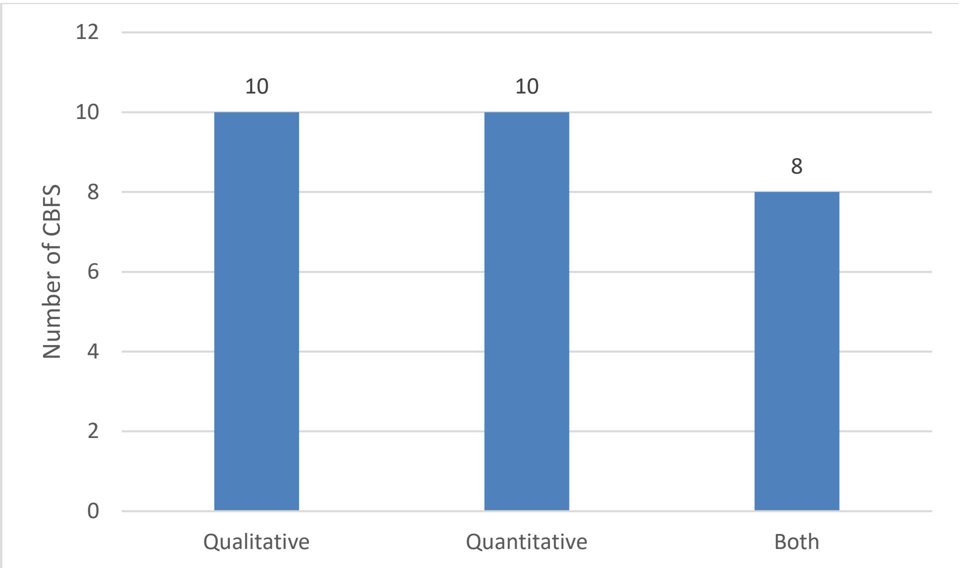
Interestingly, there does appear to be a pattern to the way CBFS monitor the performance of implemented sustainable finance measures. If CBFS are to monitor only one aspect of performance, it is effectiveness rather than any other. Efficiency comes second, followed by impact. The component of performance which CBFS monitor the least is equity. It should be noted that the concept of equity is important for sustainability debates and even enshrined within international climate and environmental negotiations under the concept of 'just transition'.

Figure 11: Extent to which CBFS monitor the performance of sustainable finance measures implemented, across several components



Data collection to monitor the performance of implemented sustainable finance measures comprises both qualitative and quantitative data (see Figure 12). Most efforts at monitoring performance involve data collection. Interestingly, frequently both are collected (8 of 14 relevant CBFS) with only 2 instances where only qualitative or quantitative data is collected respectively. Regarding types of data that CBFS are using to assess the effectiveness, efficiency, equity or overall impact of implemented sustainable finance measures, 19% said that they were using new data and collection systems specific to the enacted measure(s), 8% relied on pre-existing data and collection systems, and 27% relied on both. 46% did not respond to the question.

Figure 12: Number of CBFS that collect data to monitor performance of implemented sustainable finance measures



Few CBFS reported that they have a system in place to integrate the learnings into the design and implementation of future sustainable finance measures (Figure 13). Various reasons were cited why this was the case (Figure 14). The most frequently cited factors are 'lack of expertise' (13 of 25 relevant CBFS), 'lack of clear mandate or request to do so' (12 of 25 relevant CBFS), and 'data availability constraints' (11 of 25 relevant CBFS). It is interesting to note that these reasons would technically also inhibit current efforts to monitor the performance of implemented sustainable finance measures, opening up questions regarding the suitability or quality of current monitoring efforts. Other factors cited were raised with much less frequency, despite the possibility of linkages with the most cited reasons. For instance, 'high costs' are associated with expertise and data availability, as obtaining required expertise and ensuring adequate data collection will involve costs. Additionally, the lack of a clear mandate to monitor performance would be associated with a lack of defined budget category. Among the CBFS that do not yet have a system in place to integrate learnings from the efficacy of existing measures into the design and implementation of future ones, 13 intend to develop such a system in the future, while 2 stated that they had no such intentions.

It is interesting that CBFS appear to believe there is a disconnect between having a mandate to achieve climate and environmental objectives with respect to institutional mandates and having a mandate or request to monitor the performance of such efforts. The establishment of monitoring and evaluation systems should be a critical component of ensuring mandates are being realised. Greater understanding of this disconnect should be a focus of further research, including whether CBFS need an explicit mandate or request to monitor the performance of their sustainable finance measures to achieve their climate and environmental objectives.

Figure 13: Responses to the question "Do you have a system to integrate the learnings into the design and implementation of future sustainable finance measures?"

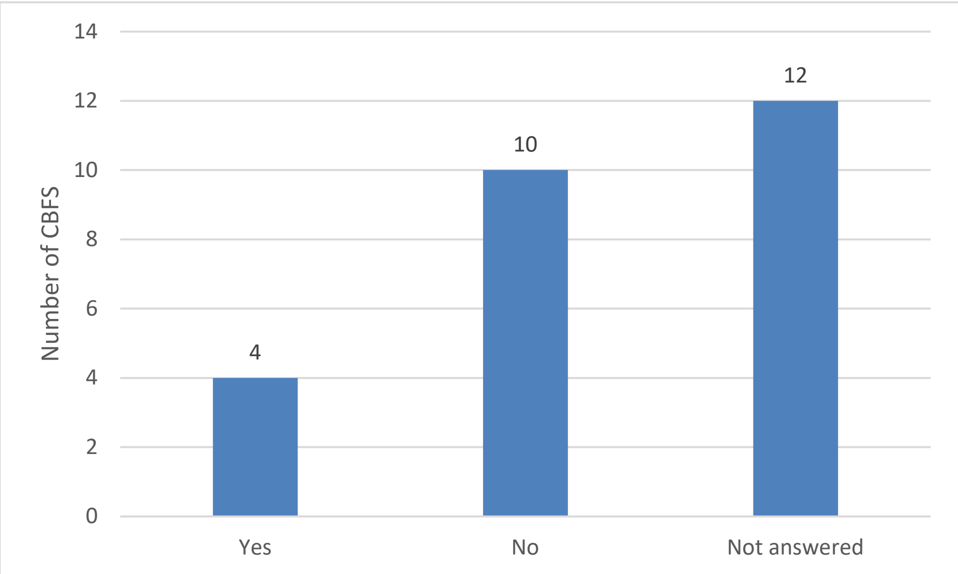
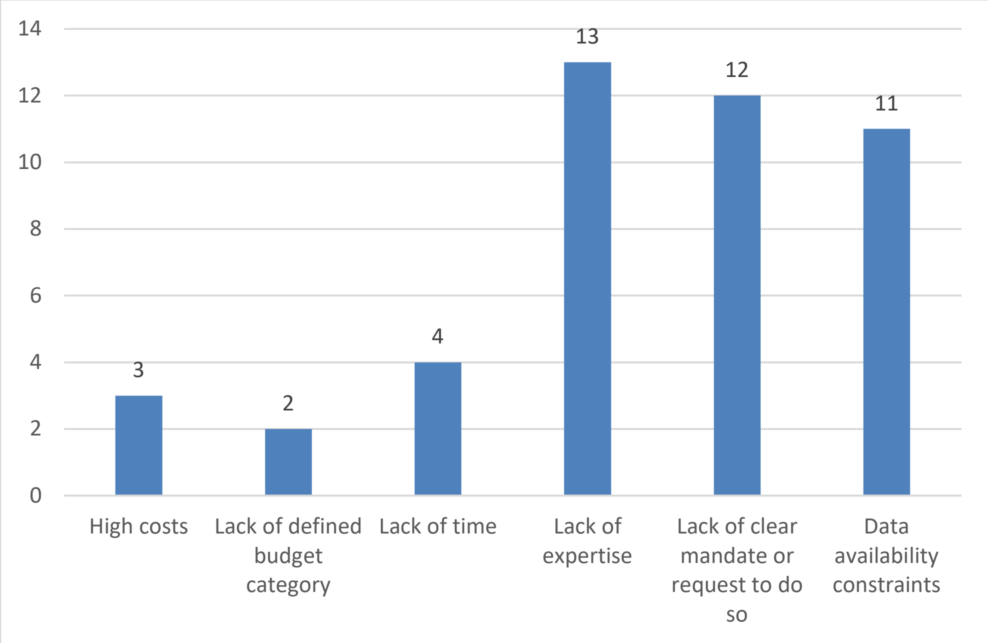


Figure 14: Reasons cited for not developing a monitoring and evaluation system (number of CBFS)



Asked about the kind of data that CBFS would like to be able to collect in order to evaluate the performance of their sustainable finance measures, a broad range of responses were recorded, ranging from data on the amount of green lending and green bond issuance, data on lending to unsustainable businesses, the carbon footprint of credit, corporate governance data on sustainability, data on climate and other ESG risk, and the climate alignment of lending and investment portfolios.

Understanding who receives the findings of performance monitoring systems is problematic as many respondents did not answer this question (13 of 26 CBFS). Those which did respond indicated the results are mostly kept for internal purposes, with relatively fewer communicating the results to the national government, other monetary or financial authorities, the financial industry, or the general public (Table 6).

Communication of performance monitoring results — Table 6

Number of CBFS reporting that they communicate results					
Internal	**National government**	**Other monetary or financial authority**	**Financial industry**	**Public**	**Other stakeholders**
10	5	4	4	3	0

The relatively low number of CBFS communicating results to other monetary or financial authorities is likely due to respondents often being integrated financial regulators. However, the lack of communication on results would be a concern for those who see transparency as a fundamental driver of behavioural change and good governance. Though a counter argument can be made that until performance monitoring and communication plans are fully developed, there is a risk of miscommunication and interpretation of the results.

However, many will consider the low number of CBFS communicating results to national government as especially problematic, even in the short term. The results of macro-level climate risk stress-testing would have utility for many national ministries as well as sub-national governments, whether they relate to transition or physical risk,[9] and many of the CBFS reported they have a mandate to support government policy making. Understanding how the results of monitoring systems for sustainable finance measures can support government policy could be a future research topic.

Asked whether there were any climate, environmental or sustainability-related policies and measures that the CBFS has enacted that it would recommend others in the region to also enact, 10 CBFS responded positively. Recommendations included to first develop a sustainable finance taxonomy that can be synergised to economic activities in the national account; developing a sustainable finance roadmap/framework or green/sustainable banking guidelines/principles; and issuing guidelines for environmental and social risk management. Setting clear supervisory expectations for financial institutions on managing climate-related and environmental risk was highlighted by several CBFS as an important first step to get financial institutions to integrate considerations of these risks in their decision making and risk management processes.[10] Some CBFS also mentioned the development of a disaster rehabilitation and disaster containment facility and related initiatives to complement government disaster management efforts.

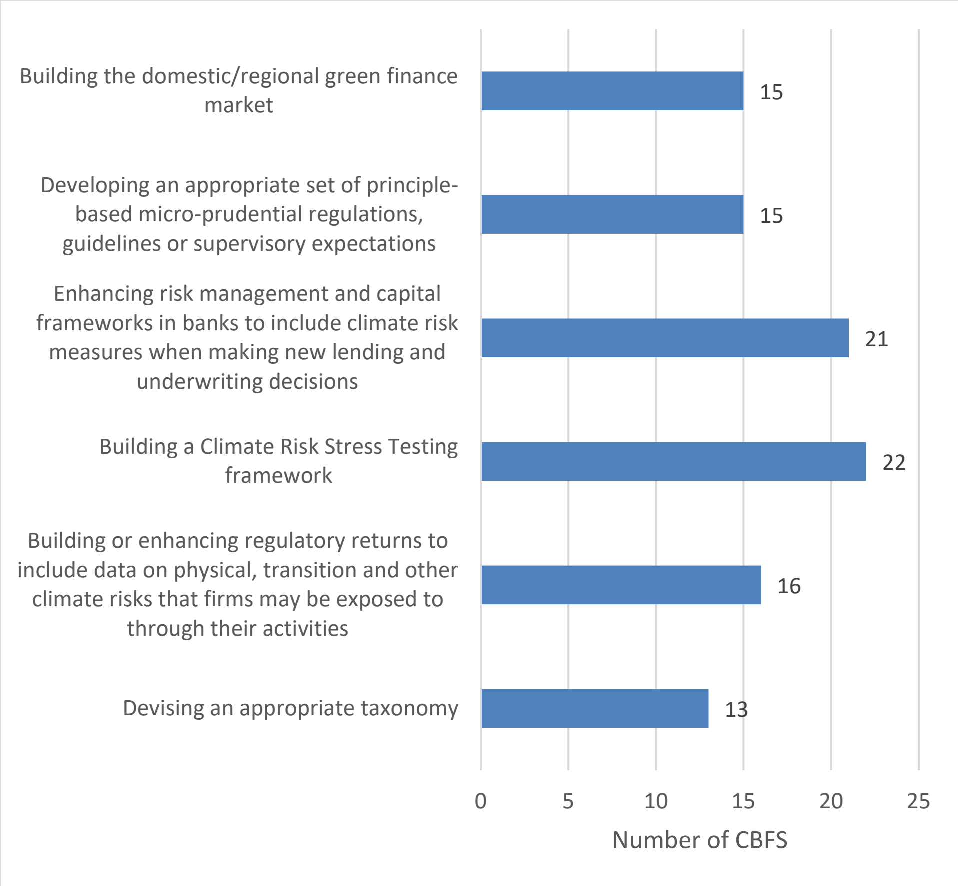
2.4. Capacity building needs

The final question asked in which key areas CBFS would require additional technical assistance and training (Figure 15). 85% said they would require additional assistance on building a climate risk stress-testing framework, whilst 81% said they also wanted assistance in enhancing the risk and capital management frameworks of banks to better reflect climate-related risks. Help was also requested on developing an appropriate regulatory or supervisory framework on climate risks; enhancing reporting to include climate risk data; and on developing domestic/regional green finance markets. These are encouraging signs that CBFS in APAC are keen to start requiring more stringent climate-related risk management measures from banks, while also stimulating financial markets to better capture the opportunities commonly associated with the low-carbon transition.

[9] These would support the development of Nationally Determined Contributions, a Low-Emissions Development Strategy, and a National Adaptation Plan, widely considered as the three main components of climate change planning at national-level

[10] One CBFS referred to the NGFS (2020) publication "Guide for Supervisors – Integrating climate-related and environmental risks into prudential supervision" as a useful and comprehensive guide for supervisors to kick-start the process to do so.

Figure 15: Answers to the question "Which of these key areas would you like more detailed training or technical assistance on, in relation to the design and implementation of sustainable finance measures?"



The fact that 22 CBFS highlighted the need for support to develop a climate risk stress-testing framework is interesting, as only 10 (13) CBFS reported that they are currently implementing (planning to) implement macro-level climate risk stress-testing, and only 7 (8) CBFS reported that they currently (intend to) expect financial institutions to conduct stress-testing. Overall, a total of 7 CBFS highlighted a need for technical support or training for building a climate risk stress-testing framework, even though they reported no current or future intention to implement macro-level climate risk stress-testing themselves or require financial institutions to conduct climate stress-testing. This indicates that they recognise the importance of climate risk stress testing but consider their current and near future ability as inadequate for implementing such measures. This would then support the argument that actually a much larger number of CBFS would be wanting to implement or mandate climate risk stress-testing than what has been indicated here – but they are just waiting until they have the proper capacity and resources to be able to do so.

The lowest reported training need was on 'support to devise an appropriate taxonomy' (13 of 26 CBFS). This figure is also interesting as many would consider an appropriate taxonomy to be fundamental to efforts to make financial flows more sustainable due to its importance in defining what can be and cannot be classified as sustainable, yet few taxonomies have been developed in the countries covered by the survey. This could be because CBFS feel sufficient support is already available. This might be the support offered by other CBFS, due to the relative lack of influence of external stakeholders mentioned previously.[11] There are also a number of projects to develop taxonomies within various countries in Asia, and CBFS may also take the view that it is for other institutions to develop the taxonomies that they, and the firms they regulate, will be the end users of.

There were a range of additional comments and requests from the respondents on which areas and types of assistance they required in building out their sustainable finance related capabilities. Areas most frequently highlighted included technical training on developing sustainable finance strategies and roadmaps; climate risk analysis including scenario analysis and stress-testing; developing and implementing prudential frameworks and instruments; taxonomy development; and developing disclosure frameworks.

3. Discussion and recommendations

The survey results show that CBFS across the APAC region are starting to address climate change and other pressing sustainability challenges, but that most of them are in the early stages of doing so. They also illustrate the benefits of international co-operation and exchange, which can help develop a better understanding of what measures to adopt and also support efforts to implement key measures such as climate risk stress-testing and developing taxonomies. Issues such as a lack of capacity and resources (including perceived) clearly inhibit efforts to address climate and environmental risks. Specific strategies need to be developed to address these issues to ensure that progress in achieving climate and environmental objectives is not frustrated.

The survey data indicates that CBFS have implemented or are starting to implement a wide range of sustainable finance measures to achieve climate and environmental objectives associated with their institutional mandates. The data also indicates that the number of measures implemented should grow in the future. It highlights that many CBFS are to some extent measuring the performance of implemented sustainable finance measures. Monitoring and evaluation systems are vital to understanding whether implemented sustainable finance measures are achieving climate and environmental objectives. Specialised data collection and analysis systems are likely to be required, along with communication strategies so that relevant stakeholders receive clear guidance.

The progress made to date is welcomed considering the difficult context within which many CBFS within APAC operate. Indeed, many suffer from capacity and resource constraints and are attempting to address the impacts of climate and environmental risks on financial stability while also implementing Basel II and III recommendations. It is arguable, however, that the progress being made is insufficient considering escalating climate risks within these countries from both a physical and transition risk perspective, as well as other escalating nature-related risks such as biodiversity and natural capital loss.

Progress needs to be expedited and CBFS need to take much more comprehensive action in line with their mandates given the potentially severe

[11] E.g. civil society, academia, and international financial institutions.

implications of these mounting risks to economic and financial stability. The Intergovernmental Panel on Climate Change and the United Nations Framework Convention on Climate Change were created and signed almost thirty years ago. Under the Paris Agreement signed in 2015, countries not only agreed to expedite efforts to address the causes and impacts of climate change but also under Article 2.1c to align financial flows with these efforts. Nevertheless, very few CBFS in APAC can be said to have made substantive progress.

CBFS need to strengthen their effort given the crucial role they ought to play in ensuring that financial flows are channelled towards more sustainable outcomes. CBFS need to implement sustainable finance measures faster and ensure monitoring and evaluation efforts are increased to ensure they are achieving the intended climate and environmental objectives. Steps have been undertaken in that direction, but many are either informal or data is insufficient to comprehensively assess progress. Efforts need to be more systematic and communication plans made so that the information is received by the various stakeholders to address climate and environmental risks within their jurisdictional mandates.

To this end, CBFS will need to increase capacity and develop a strategy to deal with factors which inhibit progress, such as lack of data. If CBFS are to meet the urgency required to address climate and environmental risks, collaborative efforts will be needed whereby the work of civil society, academia, development financial institutions, and domestic financial institutions supports the efforts by CBFS, as is the case with other financial stakeholders addressing climate and environmental risks. Building on the survey responses, in the following we highlight four areas in which APAC CBFS should strengthen their efforts: climate risk stress-testing, climate risk reporting and governance, developing a regulatory framework on climate risk management, and capacity building and training.

3.1. Climate risk stress-testing

As shown in the survey, climate risk stress-testing is clearly a key consideration for CBFS across APAC, with 10 CBFS in the region having already introduced it or having made formal announcements. One of the clearest ways to signal to financial institutions that they need to take climate risk seriously is for climate risk-based stress-testing to become a part of CBFS's regular oversight activities. The objective would be to test the resilience of the major banks, insurers, asset managers and the overall financial system to different possible climate pathways. Such an exercise would provide a comprehensive assessment of risks facing individual institutions as well as the financial system's exposure to climate-related risks and highlight the macrofinancial vulnerabilities of the economy. It will also allow comparability of climate exposures and results across firms and assess system-wide feedback loops. Importantly, it will provide key insights allowing regulators and supervisors to adapt capital charges and liquidity risk management requirements, among other supervisory measures. The existence of such an exercise will force financial institutions to start to collect the relevant data from their own counterparties, factor climate risk in lending and underwriting decisions and build the necessary systems and frameworks to assess and mitigate their exposures to climate risk.

A comprehensive climate risk stress-testing programme is also a good way for CBFS to build internal capacity and create synergies between various relevant departments. The NGFS has published useful guidance including a set of climate scenarios that can serve as a template (NGFS, 2021b), albeit they will need to be adapted to suit the specificities of the individual economies.

Whilst a few financial supervisors in APAC such as the Monetary Authority of Singapore and the Hong Kong Monetary Authority are already relatively advanced in planning for such exercises, the majority of CBFS in the region still need to develop such frameworks. The implementation of such stress-tests has also been somewhat delayed due to the Covid-19 crisis. In Europe, the Bank of England has incorporated climate scenarios in its 2021 biennial exploratory scenario and has previously run a high-level climate risk stress-test for the insurance sector. The European Banking Authority is also developing a climate risk stress-test which will be implemented by the European Central Bank, whilst the Dutch central bank was one of the earliest to run a climate stress-test in 2018, and also conducted an assessment of their financial system's exposure to biodiversity loss in 2020.

3.2. Climate risk reporting and governance

In the survey, 11 CBFS stated that they have already implemented or started working on the development of taxonomies for (un)sustainable economic activities, and a further two envisage doing so in the future. Overall, taxonomies are seen as a key component of regulatory frameworks on sustainable finance. Under the recently issued Taxonomy Regulation, EU financial institutions and non-financial corporates have to report on their alignment with activities considered as sustainable by the Taxonomy. This taxonomy also underpins new and proposed regulations on financial instruments and products, notably limiting greenwashing risks. Such taxonomies, when extended from only sustainable activities to also cover unsustainable activities, can provide a more complete picture of the risk profile of companies (financial or non-financial). There are already efforts to develop taxonomies across Asia Pacific. The recent report on the Roles of ASEAN Central Banks in Managing Climate and Environment-related Risks, published in November 2020 (Anwar et al., 2020), sets out the intention to adopt a principles-based ASEAN-wide taxonomy for green and transitional activities, as well as to develop ASEAN green lending principles and guidelines. For instance, Bank Negara Malaysia has published its Climate Change and Principles-based Taxonomy in April 2021.

The ASEAN report also lays out a number of key priorities, which the findings from this survey support. Chief amongst these is to build up the capacity of supervisors to monitor climate risk and integrate it into prudential supervisory frameworks, as well as for central banks to embed ESG standards into their own operations and strategies and to take the lead in working with other domestic government agencies to grow the supply of green / sustainable finance. Looking more globally, Europe is leading in this area, with the European Central Bank having set out an ambitious supervisory programme laying out expectations relating to climate risk disclosure and risk management (ECB, 2020). This clearly states out how the supervisory assessment process should evolve to include climate risk assessments, looking at business models, governance, risk appetite setting and climate risk disclosures as well as risk management assessments incorporating credit, market and liquidity risk and climate risk-based stress testing. Our strong recommendation is that similar frameworks should be rolled out across Asian CBFS.

We recommend that CBFS in the APAC region set clear guidelines and requirements for the firms they regulate to have clear transition plans, with targets set to align their portfolios with global agreements, supported by concrete action plans with short- and medium-term milestones. The board and senior management of these institutions need to be overseeing and monitoring progress, and there should be a clear link to executive compensation based on reaching sustainability targets. Asset managers and banks should have similar expectations for the companies they invest in / lend to. Public disclosure of these plans and of the progress made against them will allow market participants to allocate capital towards activities that are more sustainable and to those that meaningfully support the transition.

In order to properly analyse the extent of the climate risk issues facing each country, and to be able to carry out climate risk stress-tests, firms should coherently and accurately report their climate risk related exposures, calling for more widespread and harmonised mandatory disclosure requirements. The Task Force on Climate-related Financial Disclosures (TCFD) recommendations provide a good basis for such disclosure frameworks. However, it will be important that CBFS make the disclosure of climate-related financial risks mandatory and that they provide firm guidance on they expectations to financial firms. Also, prospectively, disclosure needs to go beyond climate-related financial risks and also cover other environment-related financial risks. A Task Force on Nature-related Financial Disclosures has been launched in 2021 to make recommendations to this effect.

An additional recommendation is that once CBFS begin collecting such climate risk-based information, they should use it to develop climate transition loss and physical risk data maps showing the extent and type of physical and transition risks that their countries are exposed to. This could include, for example, how much lending and collateral is associated with 'dirty' assets or what is the share of mortgage books that are backed by energy-inefficient housing. Monitoring tools can then be set up to measure these risks for the economy based on what domestic lending institutions are exposed to, and to take steps to address these risks. In addition, climate related loss history can be collected and the insurance protection gap can be monitored. This will then greatly help the various policy initiatives geared towards mitigating climate risks and developing sustainable finance measures.

3.3. Climate risk regulatory framework

81% of survey respondents stated that they would like more training and capacity building support on enhancing risk management and capital frameworks for the banks they regulate, to ensure that those banks include climate risk measures when making lending and underwriting decisions. A key issue for central banks and regulators is that the current risk management framework that is used to calculate capital requirements (the latest iteration of which is Basel III), typically considers short time horizons and relies on historical loss data to estimate the severity and frequency of potential future risks and losses. Given the non-linearity of climate change, current backward-looking models are not able to adequately assess climate risks and so cannot quantify them appropriately. Our current economic system is also inherently biased towards high carbon industries since many externalities are either not priced in or insufficiently so. An area of discussion by regulators is therefore the potential for a requirement to add-in a forward-looking climate-based factor when making lending, investing or insurance decisions. This would either increase or decrease the risk rating (and pricing) for these transactions. Similarly, there is also significant debate around whether green-supporting and dirty-penalising factors should be implemented in banks' capital calculations. This could boost green lending, reducing the cost of borrowing for those sectors relative to loans granted to carbon intensive activities. Such a framework is already being applied by the People's Bank of China, in conjunction with a number of additional measures taken to establish a national taxonomy and framework for climate risk disclosures as well as expanding the domestic green finance market (Yi, 2020).

In order to support the development of such a regulatory framework as well as climate risk stress-testing, CBFS should set up an internal governance structure and build internal capacity to better manage and mitigate climate-related financial risk. Over time, CBFS should aspire to undertake bottom-up deep dive reviews into the major financial institutions within the country, to assess their whole climate risk framework, governance, risks, gaps and feasibility of the actions they are taking. Such reviews should extend to banks, insurance firms and asset managers. The findings should feed into climate risk stress-testing assumptions and judgements, and, in due course, capital requirements and add-ons.

3.4. Capacity building and training

As can be seen from various responses to the survey, and in particular the final question asking about training needs of the respondents, there is a substantial need for capacity building and training to enable CBFS in APAC to adequately respond to the climate and environmental crises we are collectively facing. 92% of 26 survey respondents answered the question on the various areas of training and capacity building support they required for the design and implementation of sustainable finance measures.

Training needs have been expressed across areas such as climate risk stress-testing (85% of respondents); enhancing risk management and capital framework (81%); enhancing climate risk data returns (62%); developing climate risk principle-based micro-prudential regulations or guidelines (58%); developing the sustainable finance and green bond market (58%); and developing appropriate taxonomies (50%). Other comments also included the need to help develop an internal governance structure and building capacity to ensure the proper design and implementation of the above measures.

Building the appropriate in-house capacities is critical. Only when CBFS have sufficient expertise will they be able to develop and implement targeted policies that will help to effectively mitigate climate- and other environment-related financial risks and scale up sustainable finance. Capacity building should therefore be a key priority in order to make sure that CBFS can play the critical role they need to assume in aligning the financial system with sustainability.

4. Conclusions

The APAC region is significantly exposed to climate change and environmental degradation. CBFS across the region face significant challenges in mitigating the associated risks posed to macroeconomic and financial stability, and in supporting the scaling up of sustainable finance. The results of the second APAC Central Bank Sustainability Survey presented in this article show that most CBFS in the region are paying considerably more attention to sustainability challenges compared to 2019, when the first survey was conducted. Most CFBS have now either implemented or are starting to implement various sustainable finance measures to achieve climate and environmental objectives associated with their institutional mandates. The survey responses also reveal that the number of measures that will be implemented should grow in the future. The roll-out of sustainable finance measures is notable and reflects growing concern among policymakers regarding the climate and environmental crises.

Interestingly, more than a third of the 26 CBFS participating in the survey are already measuring the performance of implemented sustainable finance measures to some extent. This is relevant, as an appropriate monitoring and evaluation of these measures is crucial for making sure that CBFS achieve the desired outcome through their chosen measures without creating unintended distortions. However, few CBFS stated that they have a system in place to integrate the learnings into the design and implementation of future sustainable finance measures, citing a lack of expertise and data availability constraints as some of the main bottlenecks. Going forward, it will be critical that assessment of sustainable finance measures is routinely integrated into policy frameworks.

Perhaps not surprisingly, the survey reveals major needs for capacity building and training to enable CBFS in APAC to adequately respond to the sustainability challenge. Developing the appropriate expertise among CBFS staff will be key to ensuring that the right measures will be implemented and that CBFS can play their crucial role in safeguarding macroeconomic and financial stability and support the transition to a low-carbon, resilient and more sustainable economy.

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The low-carbon transition, climate disclosure and firm credit risk[1]

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The low-carbon transition, climate commitments and firm credit risk*

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Abstract: This paper explores how the need to transition to a low-carbon economy influences credit risk. It develops a novel dataset covering firms' greenhouse gas emissions over time alongside information on strategies for managing transition risk, including climate disclosure practices and forward-looking emission reduction targets. It assesses how such metrics influence firms' credit ratings and their market-implied distance-to-default. High emissions tend to be associated with higher credit risk. But disclosing emissions and setting emission reduction targets are associated with lower credit risk, with the effect somewhat stronger for more ambitious climate commitments. After the Paris agreement, firms most exposed to transition risk also saw their ratings deteriorate relative to otherwise comparable firms, with the effect larger for European than US firms, probably reflecting differential climate policy expectations. These results have policy implications for corporate disclosures and strategies around climate change, and the treatment of climate-related transition risk in the financial sector.

JEL classification: C58, E58, G11, G32, Q51, Q56
Keywords: climate change; transition risk; disclosure; net zero; green finance; credit risk

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1 Introduction

Climate change is one of the biggest challenges of our time. Urgent action is needed to rapidly reduce greenhouse gas (GHG) emissions if the world is to avert the catastrophic consequences of significant global warming (IPCC, 2021). Meeting the goals of the 2015 Paris Agreement to limit global warming to well below 2 degrees Celsius compared to pre-industrial levels, and preferably to 1.5 degrees Celsius, is crucial in this regard. To achieve these objectives, global GHG emissions need to be substantially reduced by 2050. With this in mind, European countries and the US have pledged to reduce GHG emissions to zero in net terms by this date. But achieving net-zero emissions by 2050 requires much sharper annual reductions in GHG emissions than those which have been observed since 1990.

It is therefore essential that every firm in the economy substantially reduces its GHG emissions in the coming years, at least in net terms. Firms that fail to do so will fail the planet. But they may also endanger their own medium-term survival. In particular, firms which do not adapt sufficiently may be left with stranded assets such as unusable coal mines, or remain exposed to heavily carbon-intensive technologies that may eventually attract punitive taxation given the growing appetite of governments to introduce tougher policies to catalyse the transition to a low-carbon economy. Such firms may also see an increase in their financing costs if they face changing market sentiment and growing investor pressure. Early signs of this can be seen both in the rapid growth of green finance and in several recent initiatives of investor groups that aim to foster the low-carbon transition[1]. All of these factors present significant transition risk for firms that have to reduce their GHG emissions. And if they reduce a firm's ability to service and repay its debt, the credit risk associated with this firm will increase (BCBS, 2021). As such, a firm with a higher carbon footprint today is more exposed to transition risk and may have higher credit risk either now or in the future, especially if it has no credible plan to transition towards the low-carbon economy or it fails to adapt in a timely fashion. Partly

[1] Notably, Climate Action 100+ is a global investor-engagement group that calls upon companies with highest greenhouse gas (GHG) emissions to set decarbonisation targets, disclose their climate-related risks, and improve governance around those risks. More recently, the Glasgow Financial Alliance for Net Zero (GFANZ) encompassing large parts of the financial system has been created to mobilise the necessary capital to build a global net zero emissions economy and deliver on the goals of the Paris Agreement.

linked to these considerations, S&P and Moody's signed the Principles for Responsible Investment (PRI) in 2016, committing to account for climate change related aspects in their assessments of creditworthiness.

In light of these developments, this paper assesses whether and how two key measures of firm-level credit risk – credit ratings issued by rating agencies and the market-implied distance-to-default – are influenced by firms' climate-related transition risk. Importantly, we go beyond considerations of firms' actual current GHG emissions and emission intensities, which are the focus of most existing research, to assess how realised performance in reducing emissions, climate-related disclosure practices, and forward-looking emission reduction targets may all influence credit risk.[2] Although actual emissions proxy a firm's current exposure to climate-related transition risk, we have in mind that past performance, disclosure practices and the existence of forward-looking emission reduction targets and plans may reflect the firm's commitment and strategy to reduce such risk.

We first develop a novel firm-level dataset covering the non-financial corporations included in the S&P 500 and STOXX Europe 600 indices. This provides a rich picture of firms' climate-related transition risk and their strategies to manage such risk, alongside standard financial variables which typically influence credit risk. We then apply panel regressions and a difference-in-difference approach exploiting the Paris agreement to assess how such climate-related metrics influence credit risk.

In our panel analysis, we find that high emissions and emission intensities tend to be associated with higher credit risk as assessed by both rating agencies and financial markets. Choosing to disclose emissions is associated with a better credit rating; at the same time, however, rating agencies appear to pay more attention to disclosed emissions than inferred emissions, implying that a firm which discloses high emissions may see an overall worsening in its credit rating. We also find some weaker evidence that disclosing emissions is associated with lower market-implied credit risk. The results relating to realised past reductions in emissions are also more mixed. We find that achieving reductions in emissions is associated with better credit ratings but does not appear to

[2] While cutting the level of emissions is clearly what matters from a societal perspective to transition to a low-carbon economy, emission intensities may also be relevant for an individual firm's credit risk, as we discuss further in Section 2.2 Therefore, throughout our analysis, we consider both of these variables alongside each other when gauging firms' current exposure to transition risk.

influence market-implied credit risk. This result is comparable to the finding of Bolton and Kacperczyk (2021a), who identify based on a sample of US firms that year-on-year changes in emissions are priced in stock returns.

In terms of climate-related commitments, we find strong evidence that firms who have adopted a forward-looking target to cut emissions have lower credit risk under both of our metrics. There is also some evidence that this effect tends to be stronger for more ambitious commitments, both in terms of the percentage reduction in emissions targeted and the targeted speed of reduction. In a supplementary analysis, we also find that firms with emission reduction targets have historically reduced their emissions by more than firms without targets. While this could partially reflect firms committing to targets if they find it easier to cut their emissions, this finding at least provides some assurance that firms which disclose targets do indeed make tangible progress towards meeting the Paris goals.

The magnitude of most of the effects is also economically meaningful. For example, we estimate that committing to an emission reduction target is associated with a firm's credit rating being about half a notch higher, which is almost as much as the effect from a one standard deviation reduction in leverage. Since credit risk metrics may be more sensitive for firms already closer to default, it is also interesting to consider whether our results are stronger for high-yield firms than for those with an investment-grade rating. As might be expected, we find indicative evidence that high current emissions and emission intensities matter primarily for high-yield firms, though the limited sample of such firms makes it challenging to draw strong conclusions. By contrast, transition risk management practices, such as disclosing carbon emissions and announcing forward-looking commitments remain highly relevant for the credit risk of investment-grade firms. These results may reflect that high-yield firms are more vulnerable to immediate transition risks, but that highly-rated firms still face an elevated risk of failure in the medium-term if they lack a credible transition plan.

Taken together, and acknowledging some limitations related to the reliability and comparability of the climate-related metrics, the regression results suggest that high emitters have a higher risk of failure but that strategies to manage transition risk are also crucial. In particular, firms that are better aware of the low-carbon transition – as indicated by their disclosure practices and announcement of forward-looking commitments − have better credit ratings and receive a more favourable market-based credit risk assessment, relative to similar firms that show less preparedness. At the same time, while our results indicate that climate-related transition risk and strategies are somewhat reflected in credit risk metrics, it should be emphasised that the true extent of such risks could still be materially under-estimated by rating agencies and market participants, especially given uncertainties over future climate policies and wider evidence which suggests that climate risks are not very well priced in financial markets (Schnabel, 2021).

Our difference-in-differences analysis attempts to ascribe greater causality to some of our findings. It finds that firms most exposed to climate transition risk by virtue of their emissions or sector saw their credit ratings deteriorate after the Paris agreement, whereas other comparable firms did not. We also find that the impact of transition risk on credit risk was larger for firms domiciled in Europe than in the US after the Paris agreement. This points to different expectations around government climate policy and commitment both after the Paris agreement and across countries. As such, the results are indicative of a causal relationship between some transition risk metrics and credit ratings.

Our results have several policy implications. First, they show the importance of firms' adopting credible strategies to monitor and reduce their GHG emissions for their own long-term viability. This highlights the value of policies to strengthen corporate disclosure of emissions and emissions reduction targets in a consistent manner. Such action would also have the added benefit of helping investors and credit rating agencies to price climate-related risks more accurately, which is crucial given the wider role that financial markets will need to play in financing the transition to a low-carbon economy (see also Lagarde (2021); Schnabel (2021)). Second, they have potential implications for the way that central banks approach climate-related transition risk in their monetary and non-monetary policy operations. Finally, they call for an assessment of whether the climate-related transition risk faced by firms is adequately and consistently reflected in the prudential and supervisory framework for banks and insurance companies given their extensive exposures to the corporate sector.

Our paper is related to a wide literature which investigates the relationship between corporate sustainability, including environmental performance, and financial performance

(Edmans, 2021a,b; Nguyen, Kecskés, and Mansi, 2020; Misani and Pogutz, 2015; Ghisetti and Rennings, 2014; Rexhäuser and Rammer, 2014). Recent work has also focused on the specific link between climate-related transition risk and stock returns (see, for example, Bolton and Kacperczyk (2020, 2021a,b)). This line of research establishes that equity market investors tend to require higher returns for their exposure to firms with higher levels of GHG emissions. Furthermore divestment seems to be the result of exclusionary screening based on direct emission intensity in specific industries. As regards disclosure, disclosing emissions reduces the stock returns that the investors demand for bearing risk.

There is, however, much less empirical research on the relationship between climate-related transition risk and credit risk, and most of it has only considered either environmental scores provided by rating agencies and/or backward-looking environmental metrics, such as GHG emissions, emissions intensities and year-on-year changes in emissions [3]. This line of literature tends to find that firms with higher GHG emissions and/or worse environmental scores exhibit greater credit risk, as measured by bond yield spreads, bond credit ratings, and CDS spreads (Stellner, Klein, and Zwergel, 2015; Höck, Klein, Landau, and Zwergel, 2020; Barth, Hübel, and Scholz, 2020; Seltzer, Starks, and Zhu, 2020). Attig, El Ghoul, Guedhami, and Suh (2013) analyse the relationship between firm credit ratings and ESG scores, including environmental scores, and find that a better environmental score is associated with a better rating. Safiullah, Kabir, and Miah (2021) find a negative, economically meaningful impact of carbon emissions on credit ratings in the US. Finally, further emerging empirical studies covering different geographies suggest that firms with higher GHG emissions levels and/or intensities are associated with a lower distance-to-default (Nguyen, Diaz-Rainey, and Kuruppuarachchi, 2021; Kabir, Rahman, Rahman, and Anwar, 2021; Capasso, Gianfrate, and Spinelli, 2020). Although some of these studies suggest that credit rating agencies and financial market participants account to some extent for environmental performance as proxied by environmental scores, important caveats exist regarding the use of scores. Such metrics are often inconsistent over time, incomparable across firms and sectors, and display a very low correlation when

[3] There is also a brief literature which directly attempts to assess whether credit rating agency methodologies reflect environmental considerations. For example, Kiesel and Lücke (2019) run a textual analysis on the credit rating reports of Moody's published between 2004 and 2015 and suggest that the credit rating agency does account in its decisions albeit to a small extent for the environmental performance of a firm in its rating decisions.

compared across different providers, which may reflect large discretion in methodologies (Berg, Koelbel, and Rigobon, 2019; Billio, Costola, Hristova, Latino, and Pelizzon, 2020; Schnabel, 2020a). As such, environmental scores may not be an adequate proxy for transition risk. By contrast, GHG emissions are likely to be a better proxy and can be effectively exploited under informed methodological choices that acknowledge and address caveats on the availability, reliability, and comparability of such data (see for instance Busch, Johnson, and Pioch (2020) and Kalesnik, Wilkens, and Zink (2020)), noting also the importance of leveraging available data sources despite such caveats (NGFS, 2021; Elderson, 2021). In addition, while acknowledging some reliability and comparability challenges, hard information on firms' climate disclosure practices and forward-looking commitments provides a more direct and consistent read on their forward-looking strategies to manage transition risk than opaquely computed environmental scores.

We contribute to the existing literature in three main ways. First, we move beyond backward-looking measures of GHG emissions and environmental scores to develop a rich, novel firm-level dataset which also covers firms' disclosure practices and quantitative information on forward-looking commitments to reduce emissions. Second, we assess credit risk via both credit ratings and market-implied distance-to-default in a common empirical framework. This provides a more holistic picture than the existing literature focusing on credit risk and it also allows us to explore the differential treatment of climate-related transition risk by rating agencies and financial markets. Third, we exploit the Paris agreement in a novel way to attempt to ascribe greater causality to the link between climate-related transition risk and credit risk in Europe and in the US.

The rest of the paper is organized as follows. Section 2 describes the dataset, with a particular focus on the range of quantitative climate-related metrics that we employ. Section 3 presents the set of hypotheses and our empirical strategies. Sections 4 and 5 present and discuss the results on credit ratings and on distance-to-default, respectively. Section 6 briefly discusses the credibility of emission reduction targets. Section 7 concludes and discusses policy implications.

2 Dataset and variable selection

For constructing our dataset, we consider the non-financial constituents of the stock indices S&P 500 and STOXX Europe 600, that amount to 859 large firms incorporated in Europe and in the US. We collect data on credit ratings and exclude firms that do not have a credit rating issued by S&P or Moody's and obtain a set of 558 firms. For these remaining firms, we further collect data on environmental and financial performance, as well as macroeconomic indicators. In relation to some metrics of financial performance, we apply winsorization to remove the effect of outliers, following Baghai, Servaes, and Tamayo (2014): leverage, debt service, and profitability are winsorized at 99th percentile; debt service and profitability are also winsorized at the 1st percentile; when leverage is negative, we set it equal to zero. The time period spans from 2010 to 2019 and includes the time before and after the signature of the Paris Agreement in 2015 and the signature of the PRI statement by S&P and Moody's in 2016. This allows us to analyse potential changes in the awareness of climate change and related transition risk, as may be reflected in credit ratings and market prices. As the availability of credit ratings changes over time, the resulting dataset is an unbalanced panel. The frequency of the firm-level environmental and firm-financial variables is yearly and the frequency of macroeconomic variables is monthly, reflecting the two complementary measures of firm credit risk that we analyse. The sample composition by year, country and sector is shown in Table 1. In the following we describe the variables employed for the measurement of credit risk and for the measurement of transition risk as well as the set of controls that we employ in the empirical analysis.

Table 1: Sample composition by year, country, and sector.

Notes: The table shows the sample composition for observations with an available S&P or Moody's rating. The definition of the variables year, country, and sector is given in Appendix.

Year	**Obs.**	**Country**	**Obs.**	**Sector**	**Obs.**
2010	432	Austria	30	B-Mining and quarrying	239
2011	442	Belgium	40	C-Manufacturing other than C19	2348
2012	454	Switzerland	172	C19-Manufacture of coke and refined petroleum products	99
2013	469	Germany	295	D-Electricity, gas, steam and air conditioning supply	485
2014	493	Denmark	40	E-Water supply; sewerage, waste management and remediation	70
2015	508	Spain	100	F-Construction	73
2016	522	Finland	60	G-Wholesale and retail trade; repair of motor vehicles	439
2017	531	France	375	H-Transportation and storage	246
2018	546	United Kingdom	457	I-Accommodation and food service activities	127
2019	558	Ireland	91	J-Information and communication	515
		Italy	94	M-Professional, scientific and technical activities	121
		Luxembourg	24	N-Administrative and support service activities	121
		Netherlands	153	O-Public administration and defence; compulsory social security	10
		Norway	43	Q-Human health and social work activities	49
		Poland	10	R-Arts, entertainment and recreation	13
		Portugal	10		
		Sweden	151		
		US	2810		
Obs.	4955	Obs.	4955	Obs.	4955
Firms	558	Firms	558	Firms	558

2.1 Measures of firm credit risk

Two complementary measures of credit risk are analysed. We rely on credit ratings issued by Standard and Poors (S&P) and Moody's, and on the distance-to-default measure calculated using the approach of Merton (1974) and Bharath and Shumway (2008).

Credit ratings constitute a publicly available source of firm specific credit risk information that is based on specialised analysis of default risk performed by the issuing credit rating agency. Firms that need a credit rating procure one from the issuing credit rating agency and the rating is subsequently made public. Fundamental balance sheet analysis, market surveys, as well as quantitative models are used, together with expert judgement, to form and update these rating assessments. Credit rating agencies indicate that they account for environmental and climate factors where such factors materially affect the creditworthiness of the firm (see S&P Global Ratings (2015), S&P Global Ratings (2017b), S&P Global Ratings (2017a)). Moody's Investors Service (2016) describes four primary categories of risk related to the low-carbon transition used in the rating assessment of corporate and infrastructure sectors: 1) policy and regulatory uncertainty regarding the pace and detail of emissions policies; 2) direct financial effects such as declining profitability and cash flows, due to higher research and development costs, capital expenditure and operating costs; 3) demand substitution and changes in consumer preferences; and 4) technology developments and disruptions that cause a more rapid adoption of low-carbon technologies. S&P Global Ratings (2017a) explains that "over the past two years (between July 16, 2015, and Aug. 29, 2017), environmental and climate (E&C) concerns affected corporate ratings in 717 cases, or approximately 10% of corporate ratings assessments". Also, the frequency with which environmental and climate factors have affected corporate ratings has increased over time. The final ratings are issued on a discrete letter scale, as shown in Table 2, with a rating grade equivalent to S&P's AAA reflecting the lowest credit risk.

Table 2: Credit rating scale

Notes: The table shows the rating scale typically expressed as a letter combination {AAA} being the best, i.e. corresponding to an assessment of a very low probability of default, and {CCC} being the worst, i.e. corresponding to a high probability of default. A firm with a rating grade equivalent to S&P's AAA, AA, or A reflects a minimal-to-low credit risk, while a rating grade equivalent to S&P's BBB, BB, or B reflects a moderate-to-high credit risk. The last column shows the ordinal value for each rating grade that we use in the panel regression analysis.

Summary scale	**Rating scale**	**Ordinal value**
IG: minimal credit risk	AAA	7
IG: very low credit risk	AA+, AA, AA-	6
IG: low credit risk	A+, A, A-	5
IG: moderate credit risk	BBB+, BBB, BBB-	4
HY: substantial credit risk	BB+, BB, BB-	3
HY: high credit risk	B+, B, B-	2
HY: very high credit risk	CCC+, CCC, CCC-	1

Credit rating agencies regularly reassess firms' credit risk and, where needed, update the rating assigned to a firm upon consideration of new information. The re-rating is done on a regular basis (e.g. when annual financial and non-financial statements are released) as well as upon specific events. When we use credit ratings as the dependent variable in the empirical specification, we lead the dependent variable by three months to ensure that the information disclosed in the financial and non-financial statements are available to the rating agency when assessing the firm's credit risk as part of the rating process. In addition, leading the dependent variable allows us to mitigate eventual reverse causality concerns. We retrieve credit ratings issued by S&P and Moody's from the proprietary ECB Ratings Database. For our baseline specification, we use the long-term issuer credit ratings provided by S&P, while we assess the robustness of our results by testing our hypotheses on Moody's ratings. For the purpose of our empirical analysis using panel regressions, we operationalise the ratings by grouping them into seven categories and converting to an ordinal scale such that the higher the value, the better the rating, as shown in Table 2. This is in line with the wider approach in the literature (see for instance Doumpos, Niklis, Zopounidis, and Andriosopoulos (2015)). For the purpose of our empirical analysis using difference-in-differences, we employ the alphanumeric mapping of rating grades to values ranging from 1 to 21, without categorization, to capture rating actions such as up- and downgrades.

Ratings play a crucial role for the financial system by providing a generally accepted rating classification with a wide coverage across countries, markets, and sectors. They are the go-to credit risk assessment for investors and official organisation, and often constitute a pivotal role in investment and official policy decisions. For example, the collateral and investment frameworks of public institutions, such as many central banks, depend heavily on ratings for eligibility assessments.

As an alternative to ratings issued by rating agencies, as shown in Table 2, we also consider market-based ratings. Even if it is elusive, a direct mapping can be established between agency issued ratings and the probability of default. At the same time, market prices also contain information about credit risk (and thus probabilities of default). For example, the spread between yields of different companies is typically (among other things) associated to credit risk. We even talk about yield curves predicated by rating scales, e.g. the AAA-yield curve and the CCC-yield curve. In this way there are two sources of available credit risk information: rating agencies and that implied by market prices.

Whereas agency-issued ratings are mapped to a discrete scale and are updated at regular frequencies, or when firm specific events require it, the market implied default probabilities are typically measured on a continuous scale and are updated every time market prices are recorded, as the output of an assumed pricing model. Different models can be used to extract credit risk information from market prices. For example, a simple and easily implementable approach assumes that the yield spread over the reference pricing curve for firm j can be decomposed into the firm's probability of default (PD) and it's loss-given-default (LGD): $S_j = PD_j \cdot LGD$, where S_j is observed in the financial markets and LGD can be approximated using historical default events, allowing the probability of default for firm j to be inferred. However, there are naturally other factors affecting the yield spread of a firm apart from its probability of default, for example idiosyncratic market perturbations, the liquidity and subordination of the bond issue in question. Merton

(1974) represents an approach that relies on balance sheet fundamentals and the equity prices to gauge a firms credit risk. The intuition of the approach is that default occurs when the value of a firm's assets falls below the value of its liabilities. In this case the value of the firm's equity is negative, and the firm is hence in a state of default. To implement this idea, Merton applies contingent claims analysis on the summary positions of the firms balance sheet. Using the put-call parity from option pricing theory (Stoll, 1969), and following the Black-Scholes-Merton option-pricing approach (Merton, 1973 and Black and Scholes, 1973), Merton (1974) treats the firm's equity as a call option on the firm's assets with the exercise value equal to the present value of the firm's debt, if it was risk free. The put-option (from the parity) thus has an economic interpretation as the credit risk taken by the firm. The put-call parity is written as:

$$\textit{Underlying Asset} + \textit{Put} = \textit{Call} + \textit{PV(X)}, \tag{1}$$

which can be applied to the firm's balance sheet as:

$$\begin{aligned} &\textit{Firm Asset} + \textit{Credit risk} = \textit{Equity} + \textit{Risk-free debt} \\ &\Updownarrow \\ &\textit{Equity} = \textit{Firm Asset} + \textit{Credit risk} - \textit{Risk-free debt}. \end{aligned} \tag{2}$$

With this set-up, it is possible to use the option pricing formula for an American call option to extract market based estimates of the firm's credit risk expressed as a statistical measure of the distance the assets are from falling below the value of the firm's debt at a given point in time, using only information available in capital markets and from the firm's accounts. Annex B shows how we implement this approach.

2.2 Measures of firms' climate-related transition risk

We focus on GHG emissions-related variables as our key measures of transition risk, covering both backward-looking and forward-looking metrics (see Tables 3 and 4, respectively). The backward-looking variables exploit GHG emissions data from Urgentem.[4]

[4]We also collect data on emissions from Refinitiv and Eurostat for further robustness analysis as well as the EU ETS carbon price from ICE.

We distinguish between Scope 1, 2 and 3 GHG emissions in line with the GHG protocol for accounting and reporting purposes. Scope 1 corresponds to the direct emissions of the firm from owned or controlled sources. Scope 2 relates to the emissions associated with the consumption of purchased energy. Scope 3 includes all emissions that occur in the value chain of the firm, excluding Scope 2; this generally represents the highest emissions category as it includes, among others, the emissions stemming from the usage of products sold by the firm.

We consider GHG emissions both in absolute terms, i.e. in levels, and in relative terms scaled by revenues, i.e. emissions intensity (see also Bolton and Kacperczyk (2021b) for a discussion on this). Cutting the level of emissions is clearly what matters from a societal perspective to transition to a low-carbon economy and so it is evident that firms with high levels of current emissions are likely to be more vulnerable. GHG emissions in levels are also more straightforward in distinguishing high-carbon firms and sectors and arguably less prone than emission intensities to window-dressing or being conflated with cost-efficiency issues. At the same time, GHG emission intensities may reflect the carbon-efficiency of a firm. From the perspective of individual firms, those which are more carbon-efficient in generating revenues may be better placed than their competitors to withstand policy changes to tackle global warming, such as higher carbon taxes. Such firms may, therefore, also have lower credit risk.[5] In view of this, we consider both emissions levels and emissions intensities alongside each other throughout our analysis.

Since past GHG emissions may be either disclosed or inferred by third-party data providers, we also compile a dedicated dummy variable indicating whether Scope 1, 2, and/or 3 GHG emissions, whether in absolute or relative terms, are self-disclosed (see also Busch, Johnson, and Pioch (2020) and Kalesnik, Wilkens, and Zink (2020) regarding consistency of disclosed and inferred emissions). We classify a firm as disclosing if any of the three Scope emissions are self-reported, though in the most recent data the vast majority, i.e. over 80%, of disclosing firms disclose all three Scopes. Finally, we construct a variable capturing realised year-on-year changes in self-disclosed Scope 1 and 2 GHG emissions

[5]To see the potential importance of considering emission intensities from another perspective, consider the hypothetical example of a merger between two identical firms with the same revenues and emission intensities. The merged firm will have the same emission intensity as each individual firm but double the level of emissions. From a credit risk perspective, however, it is not clear that the merged firm would face substantially greater climate-related risks than each individual firm.

in both absolute and relative terms.[6] This provides a gauge on whether the emissions trajectory of a firm has been moving in the right direction in the past and may also give a signal of the firm's commitment and ability to continue reducing emissions in the future.

The forward-looking transition metrics focus on firms' commitments to reduce emissions. A dedicated dummy variable indicates whether the firm discloses an emission reduction target or not. Two further variables consider the ambitiousness of commitments in quantitative terms: the percentage by which the firm commits to reduce GHG emissions and the number of years by which the firm commits to reduce emissions. Given the emerging state of forward-looking information, the latter two variables are available only for the time period starting 2015. Finally, given the limitations regarding the quality and availability of such data, we collect this type of data from two alternative data sources: Refinitiv and the Carbon Disclosure Project (CDP) data retrieved from Bloomberg. By comparison with Refinitiv data, the CDP data provides additionally the base year to which the emission reduction target refers and the absolute level of emissions in the base year against which the target is set, allowing us to construct the targeted absolute emission reduction and the implied targeted average annual absolute emission reduction.

We also employ two dummy variables proxying the validation of the reliability of emissions reduction targets and of emissions figures: SBTi and audit. A science-based target indicates whether the self-disclosed target is aligned with the Paris Agreement 2050-temperature goal. Where firms disclose emissions and emission reduction targets, this disclosure is typically included in the non-financial statement. While the auditing of non-financial statements is not mandatory, firms may ask an auditor to assure their quality, including the climate-related information. Auditing increases the likelihood that emissions reported in non-financial statements are verified, but does not necessarily imply that this is the case.

Figure 1 shows that the share of firms disclosing data on GHG emissions and committing to emission reduction targets has increased over time. But despite having similar trends, the firm-level correlation between the two variables is only 47% (see also Table 20),

[6] This variable is most meaningful for firms that consistently disclose emissions in consecutive years and is subject to greater measurement challenges for firms for which it can only be computed by relying on inferred emissions (see Busch, Johnson, and Pioch (2020) and Kalesnik, Wilkens, and Zink (2020)).

Table 3: Backward-looking transition-risk metrics

Variable	Description	Source
Scope 1 GHG intensity	Scope 1 GHG emissions of a firm Expressed in million tonnes of eCO2 per million unit of revenue. May be self-disclosed or 3rd-party-estimated.	Urgentem
Scope 2 GHG intensity	Scope 2 GHG emissions of a firm Expressed in million tonnes of eCO2 per million unit of revenue. May be self-disclosed or 3rd-party-estimated.	Urgentem
Scope 3 GHG inten sity	Scope 3 GHG emissions of a firm Expressed in million tonnes of eCO2 per million unit of revenue. May be self-disclosed or 3rd-party-estimated.	Urgentem
Scope 1 GHG level	Scope 1 GHG emissions of a firm Expressed in million tonnes of eCO2. May be self-disclosed or 3rd-party-estimated.	Urgentem
Scope 2 GHG level	Scope 2 GHG emissions of a firm Expressed in million tonnes of eCO2. May be self-disclosed or 3rd-party-estimated.	Urgentem
Scope 3 GHG level	Scope 3 GHG emissions of a firm Expressed in million tonnes of eCO2. May be self-disclosed or 3rd-party-estimated.	Urgentem
DiscloseGHG dummy	Dummy indicating whether a firm's Scope 1, 2, and/or 3 GHG emissions are self-disclosed	Urgentem
Disclosed intensity change	Year-on-year change in self-disclosed Scope 1 and 2 GHG emissions intensity of a firm	Constructed
Disclosed level change	Year-on-year change in self-disclosed Scope 1 and 2 GHG emissions level of a firm	Constructed
EU ETS Carbon Price	EUA (EU ETS) Futures Price	ICE
Top CO2 NACE	Dummy indicating top 3 carbon polluting NACE1 sectors in EU-27+UK	Eurostat
Top CH4 NACE	Dummy indicating top 3 methane polluting NACE1 sectors in EU-27+UK	Eurostat

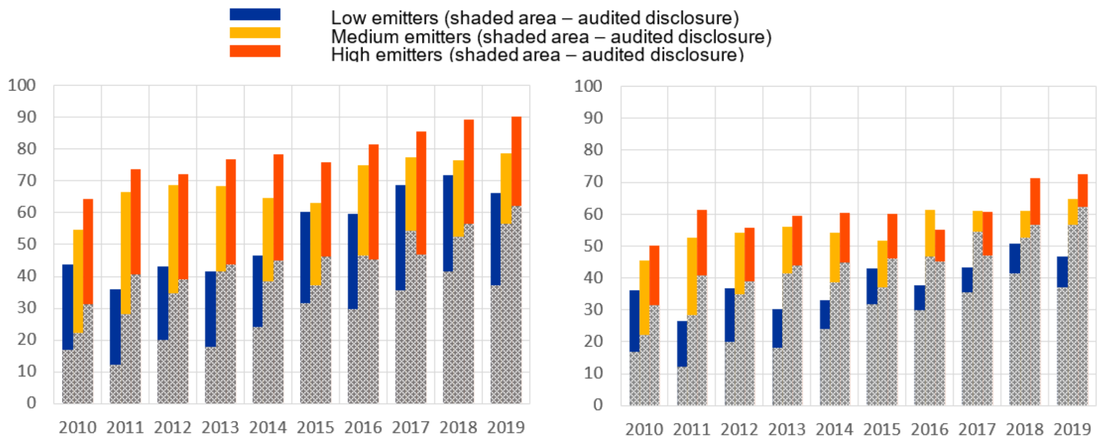
clearly making them of independent interest. The chart also shows that a large fraction of disclosures are audited and that high emitters consistently disclose the most. The latter is in line with the observation of Marquis, Toffel, and Zhou (2016) that more environmentally-damaging firms who are exposed to greater scrutiny choose to disclose more climate-related information.

Table 4: Forward-looking transition-risk metrics

Variable	Description	Source
DiscloseCommit dummy	Dummy indicating whether a firm self-discloses a forward-looking commitment to reduce GHG emissions	Refinitiv
TargetPerc Ref	Percentage by which the firm commits to reduce GHG emissions	Refinitiv
TargetYear Ref	Number of years until reaching the target year by which firm commits to reduce GHG emissions	Refinitiv
TargetPerc CDP	Percentage reduction from the base year that the most ambitious absolute emissions reduction target relates to. The information is directly from the company's response to the CDP climate change information request.	Bloomberg
TargetBaseYear CDP	Base year of the most ambitious absolute emission reduction target. The information is directly from the company's response to the CDP climate change information request.	Bloomberg
TargetYear CDP	Number of years until reaching the target year of the most ambitious absolute emissions reduction target. The information is directly from the company's response to the CDP climate change information request.	Bloomberg
SBTi	Dummy indicating whether the firm's target is aligned with the Paris Agreement goal	SBTi
Audited	Dummy indicating whether the non-financial statement of the firm has been audited	Refinitiv

Figure 1: Disclosure of backward-looking GHG emissions and forward-looking emissions reduction targets

Notes: Left panel: Disclosure of GHG emissions by emitters class. Y-axis: Percentage of firms in each emitters class disclosing GHG emissions out of a sample of 859 non-financial firms. X-axis: Time in years. Right panel: Disclosure of GHG emission reduction targets by emitters class. Y-axis: Percentage of firms in each emitters class disclosing emission reduction targets out of a sample of 859 non-financial firms. X-axis: Time in years. Firms are classified as high, medium, or low emitters based on the terciles of the distribution of firm-level aggregate Scope 1, 2 and 3 in 2010. Sources: Urgentem, Refinitiv, and authors' calculations.

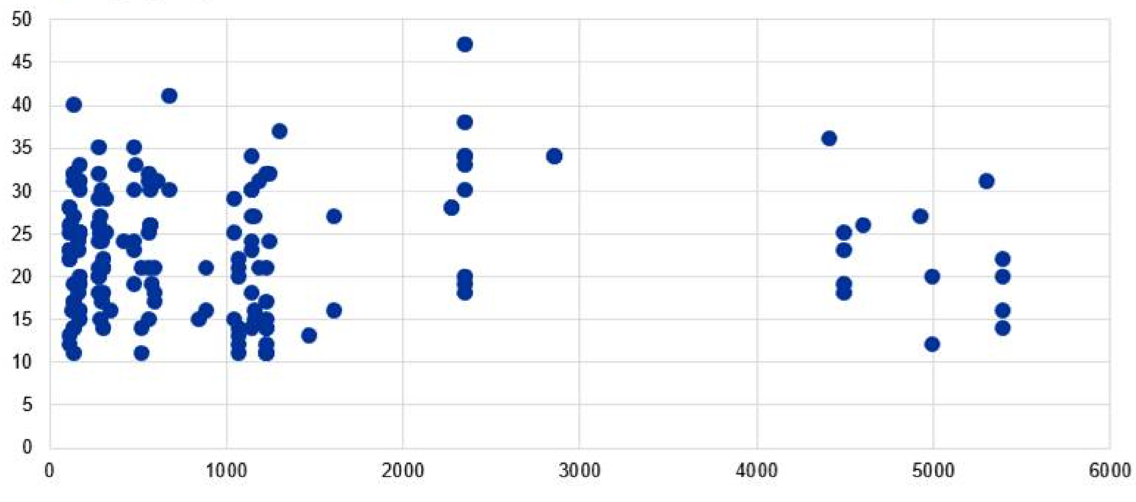


In addition to the assumption establishing the link between GHG emissions/intensities and firms' backward-looking exposure to transition risk, we use the forward-looking variables as proxies of firms' management of such risk. The disclosure variable, albeit being backward-looking, plays a dual role. On one hand, it provides evidence of firms' commitment on being transparent concerning their transition risk exposure. It also serves a signalling role, when considered vis-a-vis non-disclosing peers, whereby firms engaging in this practice convey the image of being more aware of the risks inherent with the transition to a greener economy. As discussed in the introduction, the existing caveats on environmental scores lead us to not include these variables in our baseline analysis.

Climate-related risks include transition risk and physical risk. These two types of risks are different in nature and are likely to affect a firm's credit risk through very different transmission channels. At the same time, if a firm's physical risk is correlated with its transition risk, it would be important to control for physical risk in an empirical analysis of transition risk. Figure 2 shows that this is not the case for European firms. A similar finding is documented by S&P Global, Trucost ESG analysis (2019) for US firms, who additionally note that variation in climate risk exposures for physical versus transition risk does not appear to conform to clear sectoral patterns. For example, the majority of S&P500 utility sector firms have a high climate-related transition risk but significantly variable physical risk dependent on the location of their operations. In view of all this, we focus only on climate-related transition risks in this paper, while recognising that the link between physical risk and credit risk is an important topic for future research.

Figure 2: Relation of firm-level physical risk to transition risk for European firms

Notes: Y-axis: Firm-level physical risk score provided by 427 for the year 2018. X-axis: Firm-level transition risk metric proxied by scope 1, 2, and 3 GHG emissions in tons of eCO2 relative to revenues provided by Urgentem for the year 2018. Data source: 427 and Urgentem from Alogoskoufis, Dunz, Emambakhsh, Hennig, Kaijser, Kouratzoglou, Muñoz, Parisi, and Salleo (2021)



2.3 Controls

Firm-level financial variables and macroeconomic variables are included as controls for credit risk, with the latter group being implemented only for specifications run on distance-to-default (see Table 19 in the Appendix). We select the firm financial variables considering prior literature on credit ratings (Baghai, Servaes, and Tamayo, 2014; Doumpos, Niklis, Zopounidis, and Andriosopoulos, 2015; Jones, Johnstone, and Wilson, 2015) and market practices of credit rating agencies. These variables include: profitability proxied by return on equity; firm size proxied by book total assets; leverage proxied by the ratio between the sum of short-term and long-term debt and EBITDA; debt service capacity proxied by the ratio between EBIT and interest expenses; solvency proxied by the ratio between PPE and total assets, and governance score. As profitability should reduce default risk, we expect a negative sign between profitability and credit risk. The larger the firm, the better its ability to ensure debt repayment in normal as well as adverse economic circumstances. More leveraged firms are typically associated with higher credit risk, whereas higher debt service capacity is associated with lower credit risk. The more solvent the firm, the lower should be its credit risk. A firm's governance score, which is provided by Refinitiv on a 0 to 100 scale at sectoral level, yields a relative ranking of firms operating in the same economic sector where an higher score corresponds to better managed firms. This variable is particularly relevant for our analysis, as better management may well be correlated with better environmental practices and higher awareness towards transition risk. We also collect data on the economic sector and the country of main activity of the firm, considering the country of registration and the country of incorporation. Finally, several control variables that proxy for the state of the economy on the macroeconomic level are included in the setup of the analysis on the market-implied distance-to-default. These variables are market return, return on oil spot price, inflation change, industrial production, return on gold, rates of treasury bills and implied market volatility.

2.4 Descriptive statistics

Summary statistics on ratings, GHG emissions-related variables and firm-level financial variables are provided in Table 5. Pooled correlations of main variables are shown in the appendix in Table 20.

Table 5: Summary statistics of firm-level variables

Notes: The definition of all variables is given in Appendix.

Variable	Observations	Mean	Median	Standard deviation	Minimum	Maximum
Rating S&P	4762	4.21	4	0.82	1	7
Rating Moody's	4365	4.12	4	0.83	1	7
Size	4944	35761087	17278500	55151427	422868	751216000
Governance	4841	61.47	64.84	21	0	98
Solvency	4936	0.29	0.22	0.23	0	1.39
Leverage	4931	2.83	2.32	2.20	0	13.48
Profitability	4811	20.27	14.98	28.22	-42.2	191.93
Debt service	4923	14.08	7.091	41.91	-16.39	969
Scope 1 GHG intensity	4865	0.000354	0.000019	0.000966	0.0000001	0.010127
Scope 2 GHG intensity	4759	0.000054	0.000029	0.000088	0.0000002	0.001418
Scope 3 GHG intensity	4759	0.004730	0.001256	0.016818	0.000031	0.103110
Scope 1 GHG level	4745	5.55	0.28	17.36	0.000162	178.65
Scope 2 GHG level	4745	1.27	0.29	5.03	0.000948	161.48
Scope 3 GHG level	4745	40.55	8.09	113.88	0.035471	1993.62
Disclosed Scope 1-2 intensity change	4408	0.03	0	0.72	-1	35.08
Disclosed Scope 1-2 level change	4276	0.18	0	5.10	-0.99	326.22
TargetYear	945	5.75	3	5.62	0	33
TargetPerc	898	31.21	25	22.21	0.28	100
DiscloseGHG dummy	4955	0.68	1	0.46	0	1
DiscloseCommit dummy	4955	0.65	1	0.47	0	1
TargetPerc CDP	1257	42.36	30	33.34	0	100
TargetBaseYear CDP	1269	2012	2014	4.75	1990	2020
TargetYear CDP	1268	15.48	11	12.61	0	60
TargetAnnualLevel CDP	771	0.06	0	0.36	0	3.90
TargetLevel CDP	772	1.03	0	7.22	0	121.35
SBTi dummy	4955	0.05	0	0.21	0	1
Audited dummy	4955	0.46	0	0.49	0	1

3 Hypotheses and empirical specifications

As described in Section 2, we consider two measures of firm credit risk for our dependent variable: credit ratings and the market-implied distance-to-default.

The two measures metrics reflect slightly different pricing mechanisms of transition risk. The market-implied distance-to-default reflects transition risk through its potential to disrupt the future earnings and hence dividends of a firm. Credit ratings speak rather to a firm's ability to continue servicing its debt, whereby transition risks may present a greater near-term challenge for firms who already have low ratings but are likely to represent a medium-term challenge for all firms. Despite these differences, we adopt a broadly common empirical framework for both metrics as this allows us to compare results in a more straightforward way. But we acknowledge some of these issues in an extension to our credit rating analysis where we distinguish high yield from investment grade firms.

We test three hypotheses to explore how the various climate-related metrics discussed in section 2 may influence our measures of firm credit risk. First, we note that uncertainties surrounding the timing and speed of the transition to a low-carbon economy, government policy, technological change and market sentiment can represent a source of transition risk for firms with high current GHG emissions. In particular, if these drivers significantly increase the costs of a firm with high emissions and reduce its ability to repay and service its debt, they may increase its probability of default. For this reason, we investigate whether:

H1. There is a positive relationship between a firm's exposure to transition risk, as proxied by GHG emissions, and its credit risk.

Data on GHG emissions are either disclosed by firms or inferred by data providers using proprietary estimation methods. Listed firms are often required to disclose on environmental matters, but they can choose which standards to adopt and through this which information to disclose, thus potentially engaging in selective disclosure. Where firms do not disclose, GHG emissions are inferred by special-purpose data providers, although these data may be significantly less effective than firm self-reported data (Kalesnik, Wilkens, and Zink, 2020).

Against this background, we investigate the effect of disclosure on credit risk. Reporting environmental information can be perceived by rating agencies and market participants as a positive effort of the firm to convey its exposure to transition risk (see e.g. Eliwa, Aboud, and Saleh (2019) for firms' ESG practices). Furthermore, higher level of disclosure is linked to lower information asymmetry between markets, rating agencies and firms, and hence lowers credit risk. In particular, the disclosure of forward-looking targets can convey not only that a firm is aware of the transition risk to which it is exposed, but also that has an active plan to manage these risks. At the same time, disclosed data allow for monitoring the actual performance and effectiveness of the firm in reducing GHG emissions over time. Depending on this performance, disclosure of backward- and forward-looking environmental information can have a moderating effect on the relationship between transition and credit risk. In this context, we test two hypotheses:

H2. The interaction between firms' GHG emissions and its decision to disclose GHG emissions has a significant impact on credit risk estimates.

H3. There is a negative relationship between firm's management of transition risk, as proxied by GHG emission reduction targets and actual GHG emission reduction, and credit risk estimates.

Our empirical strategy consists of two approaches, each applied to the two different credit risk measures. First, a panel regression examines the relationship between firm transition risk and credit risk and how that relationship is affected by firms' disclosure of environmental variables and adoption of targets. Then a difference-in-differences analysis identifies potential causal relationships after the Paris agreement and differences between European and US companies. The next subsections describe in more detail the empirical specifications.

3.1 Panel regressions

Depending on the hypothesis, we employ three specifications for each measure of firm credit risk, with the same set of controls, but with different metrics of transition risk: (i) current GHG intensities and GHG emissions, (ii) as (i) but distinguishing between disclosed and inferred GHG intensities/emissions, (iii) as (ii) but also including year-on-year change in GHG emissions, a dummy indicating the existence of a forward-looking commitment, and the ambitiousness of this commitment.

In the first hypothesis, we analyse the direction and the significance of the relationship between the firm credit risk measures, and Scope 1, 2 and 3 GHG intensities or GHG emissions, which proxy its current exposure to climate-related transition risk. The model is summarised in Equation 3. The dependent variable is the measure of firm credit risk, either the rating or the distance-to-default. $Scope1_{i,t}$, $Scope2_{i,t}$ and $Scope3_{i,t}$ are the corresponding GHG intensities/emissions. The $Controls_{j,i,t}$ vector includes the variables described in the section 2.3 and is common throughout the different specifications. Finally, we account for unobserved variation at sectoral, time and country level through fixed-effects.

$$\begin{aligned} CreditRisk_{i,t} = &\alpha + \beta_1 Scope1_{i,t} + \beta_2 Scope2_{i,t} + \beta_3 Scope3_{i,t} + \Sigma_{j=1}^{N} \gamma_j Controls_{j,i,t} + \\ &\rho SectorFE_i + \tau TimeFE_t + \sigma CountryFE_i + \epsilon_{i,t} \end{aligned} \tag{3}$$

To test the second hypothesis, we introduce a dummy variable $DiscloseGHG_{i,t}$ for disclosure of GHG emissions, as described in 2.2. The model is summarised in Equation 4. The coefficient of interest is the interaction term of the dummy and the level of GHG intensities/emissions. The coefficient on the disclosure dummy itself is also relevant, as it shows how the act of disclosing GHG emissions affects the relationship between transition risk and credit risk.

$$\begin{aligned} CreditRisk_{i,t} = &\alpha + \beta_0 DiscloseGHG_{i,t} + \beta_1 Scope1 + \beta_2 Scope2_{i,t} + \beta_3 Scope3_{i,t} + \\ &\beta_4 DiscloseGHG_{i,t} \times Scope1_{i,t} + \beta_5 DiscloseGHG_{i,t} \times Scope2_{i,t} + \\ &\beta_6 DiscloseGHG_{i,t} \times Scope3_{i,t} + \Sigma_{j=1}^{N} \gamma_j Controls_{j,i,t} + \rho SectorFE_i + \\ &\tau TimeFE_t + \sigma CountryFE_i + \epsilon_{i,t} \end{aligned} \tag{4}$$

Finally, for the third hypothesis, we augment the model specification by adding the past year-on-year change in Scope 1 and 2 intensities/emissions, $DisclosedLevelChange_{i,t} = (Scope1and2_{i,t} - Scope1and2_{i,t-1})$, and any information on the forward-looking emission reduction target of a firm, as described in Equation 5. The vector of variables $Target$ has two different specifications, that we test separately: (i) a dummy variable for disclosure of a target $DiscloseCommit_{i,t}$ and (ii) quantitative information reflecting its ambitiousness, i.e. the targeted percentage of emission reduction $TargetPerc_{i,t}$ and the targeted year $TargetYear_{i,t}$. While the dummy variable is well-populated in our dataset, the quantitative information is available only starting 2015.

$$\begin{aligned}CreditRisk_{i,t} =& \alpha + \beta_0 DiscloseGHG_{i,t} + \beta_1 Scope1 + \beta_2 Scope2_{i,t} + \beta_3 Scope3_{i,t} + \\ & \beta_4 DiscloseGHG_{i,t} \times Scope1_{i,t} + \beta_5 DiscloseGHG_{i,t} \times Scope2_{i,t} + \\ & \beta_6 DiscloseGHG_{i,t} \times Scope3_{i,t} + \beta_7 DisclosedLevelChange_{i,t} + \\ & \Sigma_{k=1}^{N} \psi_k Target_{k,i,t} + \Sigma_{j=1}^{N} \gamma_j Controls_{j,i,t} + \\ & \rho SectorFE_i + \tau TimeFE_t + \sigma CountryFE_i + \epsilon_{i,t}\end{aligned} \tag{5}$$

Within this empirical setup, we attempt to tackle potential endogeneity concerns throughout, though, as discussed below, we also attempt to confront this issue via a complementary difference-in-difference exercise. In particular, alongside standard firm-level controls for credit risk, the design of our panel regressions considers governance as a control variable as this may clearly be a common factor which explains both credit risk and climate-related disclosures and commitments. The inclusion of country fixed-effects allows us to control for country-level differences concerning climate disclosure policies. Finally, when ratings are the dependent variable, we lead the variable by three months to capture rating adjustments performed following the publication of firms' annual reports, while for the market-based distance-to-default credit metrics, we assume that the markets are efficiently reflecting the relevant disclosures at the time of their publication. Hence, we are deferring the information contained in the annual reports to the end of the month following the publication date, while for the inferred climate information and forward-looking commitments collated by external climate data providers, we lag the data by 6 months, which in our view conservatively approximates the publication lag of this relevant data group, too. In various robustness exercises, which are discussed in section 5.2 we also repeat the analysis on a sample excluding high-emitters and use firm fixed-effects as opposed to sector and country ones.

3.2 Difference-in-differences approach

A firm's exposure to climate-related transition risk depends on the environmental performance of the firm, but also on government policy as an acknowledged risk driver for the climate-related transition (BCBS, 2021). Employing a quasi-experimental research design, we exploit the Paris Agreement as a shock that increases the climate-related regulatory risk faced by firms without changing their environmental profiles. The Paris Agreement has been adopted in December 2015, signed in April 2016, and ratified in November 2016, by a group of countries including the US and all European countries in our sample. This represents an exogenous event that may have shifted the assessment of credit rating agencies (see for example Moody's Investors Service (2016), S&P Global Ratings (2017a)) and the perception of market participants around climate-related transition risk, since it reflected a tightening of the commitment of governments to reduce GHG emissions. At the same time, the impact may have been different across jurisdictions. Before the Paris Agreement, European countries already had an up and running carbon market, the EU Emissions Trading System (ETS). And although the US signed the Paris Agreement, the credibility of the government commitment to reduce emissions was limited by the election of Donald Trump in November 2016, Trump's announcement in June 2017 of withdrawal from the Paris Agreement, and the filing for withdrawal in November 2019. Resenting these differences, we run a difference-in-differences regression to test the relationship between credit ratings and measures of GHG emissions or intensities, around the date of the Paris Agreement, for European countries and for the US separately.

Specifically, first we compare changes in credit ratings for high polluting firms operating in the Europe versus other European firms, both before and after the Paris Agreement, as described in Equation 6. Second, we compare changes in credit ratings for high polluting firms operating in Europe versus other European firms and versus US firms, as described in Equation 7.

$$\begin{aligned} CreditRating_{i,t} =& \alpha + \beta_0 Treatment_i \times postParis_t + \\ & \Sigma_{j=1}^{N} \gamma_j Controls_{j,i,t} + \rho FirmFE_i + \tau TimeFE_t + \epsilon_{i,t} \end{aligned} \tag{6}$$

The indicator variable *Treatment* is defined for each firm i and has three different specifications: (i) top GHG NACE; (ii) top GHG intensity; (iii) top GHG level. The treatment top GHG NACE (corresponding to dummy variable *TopGHGNACE*) refers to firms in the top polluting economic activities in terms of carbon dioxide and methane emissions, based on data we collect from Eurostat for the period 2010-2019 (dummy variables *TopCO2NACE* and *TopCH4NACE*). The treatment top GHG intensity (corresponding to dummy variable *TopGHGintensity*) refers to firms with values of GHG emissions intensity (Scope 1[7]) in the top quartile of the distribution of GHG emissions intensity. The treatment top GHG level (corresponding to dummy variable *TopGHGlevel* refers to firms with values of GHG emissions levels (Scope 1) in the top quartile of the distribution of GHG emissions levels. The 75th percentile for determining the quartile is set based on the values as of end-2014. We include the set of controls, described in the section 2.3, firm and time fixed-effects and, for European firms, the EU ETS carbon price to account for the EU carbon market.

In addition, we separately investigate whether credit rating agencies assess firms in European countries differently by comparison with firms in the US. European countries have a low-carbon transition policy including the EU ETS carbon market since 2005, whereas the US do not have a low-carbon transition policy. We do this by employing a triple difference-in-differences specification, which includes the dummy *TransitionPolicy*, equal to 1 for European countries, as described in Equation 7.

$$
\begin{aligned}
CreditRating_{i,t} = &\alpha + \beta_0 Treatment_i \times TransitionPolicy_i \times postParis_t + \\
&\beta_1 Treatment_i \times postParis_t + \\
&\beta_2 TransitionPolicy_i \times postParis_t + \\
&\Sigma_{j=1}^{N} \gamma_j Controls_{j,i,t} + \rho FirmFE_i + \tau TimeFE_t + \epsilon_{i,t}
\end{aligned}
\tag{7}
$$

[7]By comparison with Scope 2 and Scope 3 GHG emissions, Scope 1 GHG emissions are the ones with the highest degree of data availability and credibility to market participants. The quality of data for firm-level Scope 1 GHG emissions benefits from the data that firms have to mandatory report since 2009 to the Environmental Protection Agency (EPA) for selected facilities in the US and to the EU Transaction Log under the EU ETS for selected installations since 2005. We consider Scope 1 in line with the panel regression results where we test the relationship between credit risk and GHG-emissions-variables.

4 Credit ratings

4.1 Results of regression analysis

Given the categorical nature of credit ratings, when considering ratings as the dependent variable, we employ both standard ordinary least square estimators as well as ordered logit ones in line with Baghai, Servaes, and Tamayo (2014)[8], controlling for traditional fixed-effects. To assess the overall impact of both backward- and forward-looking metrics on ratings we also compute the average marginal effects stemming from the logistic regression.

The first set of results uses the specification presented in Equation 3 to address the relationship between firms' exposure to transition risk, in levels, and their credit rating. We present the results in Table 6.

[8]In line with Baghai, Servaes, and Tamayo (2014), we consider ordered logit estimators suitable for our research question. Given the categorical nature of ratings, ordered logit does not assume that moving from for example BB to BBB is equivalent to moving from AA to AAA. We also report OLS estimators since some of our specifications employ firm fixed-effects to control for unobservable firm-specific heterogeneity, and estimating ordered response models with firm fixed-effects would result in biased and inconsistent point estimates.

Table 6: Panel regression for credit ratings and emissions, Testing H1 from 2010-2019

Notes: The table shows the result of the panel regression relevant for H1, see Equation 3, where the relationship between GHG emissions − expressed in intensity (Models 1 and 2) and in levels (Models 3 and 4) − and credit ratings is tested for the full data sample covering the period from 2010 to 2019. We employ both OLS (Models 1 and 3) and ordered logit estimators (Models 2 and 4). Firm-level clustered standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Variable	**(1 - int., OLS)**	**(2 - int., logit)**	**(3 - levels, OLS)**	**(4 - levels, logit)**
Scope 1 GHG intensity	-66.6**	-194**		
	(29.4)	(93.0)		
Scope 2 GHG intensity	259	900		
	(283)	(918)		
Scope 3 GHG intensity	-2.01**	-6.26**		
	(0.86)	(2.71)		
Scope 1 GHG level			-0.0037***	-0.012***
			(0.0012)	(0.0038)
Scope 2 GHG level			0.0017	0.0058
			(0.0023)	(0.0073)
Scope 3 GHG level			-0.000093	-0.00024
			(0.00016)	(0.00050)
Profitability	0.00044	0.0021	0.00045	0.0021
	(0.00046)	(0.0030)	(0.00046)	(0.0031)
Size	4.2e-09***	1.3e-08***	4.2e-09***	1.3e-08***
	(8.0e-10)	(2.4e-09)	(8.1e-10)	(2.5e-09)
Leverage	-0.13***	-0.40***	-0.13***	-0.41***
	(0.012)	(0.042)	(0.012)	(0.043)
Solvency	-0.18	-0.46	-0.21	-0.53
	(0.13)	(0.41)	(0.13)	(0.39)
Debt servicing capacity	0.0012**	0.0050**	0.0012**	0.0050**
	(0.00052)	(0.0025)	(0.00052)	(0.0025)
Governance	0.0039***	0.011***	0.0038***	0.010***
	(0.0011)	(0.0036)	(0.0012)	(0.0036)
Constant	4.21***		4.22***	
	(0.091)		(0.091)	
Controls	Y	Y	Y	Y
Time fixed-effects	Y	Y	Y	Y
Sectoral fixed-effects	Y	Y	Y	Y
Country fixed-effects	Y	Y	Y	Y
Observations	4,201	4,201	4,194	4,194
R-squared	0.343	0.1697	0.343	0.1698

Results suggest an overall negative relationship between GHG emissions, intensities and credit ratings, with more carbon intensive firms having on average lower ratings. The main drivers of this association are Scope 1 emissions and the corresponding intensity. We also find a negative relationship for Scope 3 GHG intensities, although this variable is more sensitive than Scope 1 emissions to the set of environmental metrics included in the specification. This variation is likely to be explained by the existing limitations on the proper accounting and disclosure of Scope 3 emissions, which ought to encompass all emissions related to the value-chain of a firm's products. On the non-environmental metrics, we do find an higher governance score to be associated with better credit ratings. Controlling for this effect is particularly relevant given the theoretical arguments on the relationship between the management structure of a firm, its environmental practices and credit risk. Among the remaining control variables we find results in line with the literature concerning the sign and significance of the relationships.

Turning to our second hypothesis, we present results for the specification in Equation 4 in Table 7. It is immediately evident that we find strong results on the relevance of the act of self-disclosing GHG intensities. Firms which disclose such information do report better credit ratings than their non-disclosing peers as reflected in the coefficients on the dummy variable in the first row of the table. As we discuss further below these results are also economically significant. In addition to the standalone effect of being a disclosing firm, we find a significant difference in how GHG emissions/intensities are associated with ratings depending on whether emissions are self-reported or inferred by third-party data providers. In particular, the interaction term between the disclosure dummy and Scope 1 intensity is found to be significantly negative. By contrast, inferred intensities do not seem to be reflected in credit ratings and, in contrast to the first set of results in Table 6, Scope 3 emissions are found to be significantly reflected in lower ratings when disclosed. As discussed later in this section, there is a trade-off between the benefit coming from the act of disclosing GHG emissions and the negative impact that the level of disclosed emissions and emission intensities has on credit ratings. The net effect of these two factors depends crucially on the scale of carbon emissions/intensities. Still, it is clear that disclosure has a significant bearing on credit ratings and our results appear to confirm the effect of this variable similarly to what has been documented by Bolton and Kacperczyk (2020)

Table 7: Panel regression for credit ratings and emissions, Testing H2 from 2010-2019

Notes: The table shows the result of the panel regression relevant for H2, see Equation 4, where the relationship between disclosure, its interaction with GHG emissions and credit ratings is tested for the full data sample covering the period from 2010 to 2019. Model 1 shows the OLS results considering GHG emission intensity, while model 2 shows the corresponding ordered logit results. Model 3 shows the OLS results considering GHG emission level, while model 4 shows the ordered logit results. Firm-level clustered standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Variable	(1 - int., OLS)	(2 - int., logit)	(3 - levels, OLS)	(4 - levels, logit)
DiscloseGHG dummy	0.26***	0.84***	0.23***	0.73***
	(0.067)	(0.21)	(0.052)	(0.16)
DiscloseGHG x Scope 1 GHG intensity	-113**	-359**		
	(46.2)	(149)		
DiscloseGHG x Scope 2 GHG intensity	196	460		
	(939)	(3,168)		
DiscloseGHG x Scope 3 GHG intensity	-2.49	-5.69		
	(1.61)	(4.66)		
DiscloseGHG x Scope 1 GHG level			0.0021	0.0045
			(0.0031)	(0.0095)
DiscloseGHG x Scope 2 GHG level			-0.0034	0.0087
			(0.017)	(0.055)
DiscloseGHG x Scope 3 GHG level			-0.00048*	-0.0015**
			(0.00026)	(0.00075)
Inferred Scope 1 GHG intensity	42.8	150		
	(51.7)	(162)		
Inferred Scope 2 GHG intensity	-294	-661		
	(936)	(3,185)		
Inferred Scope 3 GHG intensity	-1.03	-4.09		
	(1.13)	(3.50)		
Inferred Scope 1 level			-0.0049*	-0.014
			(0.0028)	(0.0086)
Inferred Scope 2 level			0.0015	0.0035
			(0.0026)	(0.0083)
Inferred Scope 3 level			0.00064***	0.0019***
			(0.00023)	(0.00070)
Governance	0.0034***	0.0084**	0.0032***	0.0077**
	(0.0012)	(0.0036)	(0.0012)	(0.0036)
Constant	3.98***		4.00***	
	(0.097)		(0.095)	
Firm-level controls	Y	Y	Y	Y
Time fixed-effects	Y	Y	Y	Y
Sectoral fixed-effects	Y	Y	Y	Y
Country fixed-effects	Y	Y	Y	Y
Observations	4,381	4,381	4,373	4,373
R-squared	0.344	0.1753	0.341	0.1746

The third hypothesis, which we formally test via the specifications in Equation 5, relates to the potentially moderating impact of transition risk management on the negative relationship found between current carbon emissions/intensities and credit risk. Table 8 presents the results for past year-on-year changes in (disclosed) emission levels/intensities and the forward-looking commitment dummy in . In addition, we present the results for forward-looking commitment dummy. Table 9 presents the results for variables speaking to the ambitiousness of commitments in quantitative terms in place of the forward-looking commitment dummy, on the more restricted sample for which we have the necessary data.

Table 8: Panel regression for credit ratings and emissions, Testing H3 from 2010-2019

Notes: The table shows the result of the panel regression relevant for H3, see Equation 5, where the relationship between quantitative backward and qualitative forward-looking metrics (commitment to reduce emissions) and credit ratings is tested for the full data sample covering the period from 2010 to 2019. Model 1 shows the OLS results considering GHG emissions intensity, while model 2 shows the corresponding ordered logit results. Model 3 shows the OLS results considering GHG emissions level, while model 4 shows the ordered logit results. Firm-level clustered standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Variable	**(1 - int., OLS)**	**(2 - int., logit)**	**(3 - levels, OLS)**	**(4 - levels, logit)**
DiscloseGHG dummy	0.21***	0.68***	0.18***	0.57***
	(0.067)	(0.21)	(0.053)	(0.17)
DiscloseGHG x Scope 1 GHG intensity	-108**	-359**		
	(52.3)	(171)		
DiscloseGHG x Scope 2 GHG intensity	-36.5	40.2		
	(941)	(3,145)		
DiscloseGHG x Scope 3 GHG intensity	-1.42	-3.46		
	(1.54)	(4.92)		
Disclosed intensity change	-0.015	-0.049*		
	(0.0089)	(0.026)		
DiscloseCommit dummy	0.14***	0.44***	0.14***	0.44***
	(0.050)	(0.16)	(0.051)	(0.16)
DiscloseGHG x Scope 1 GHG level			0.0031	0.0081
			(0.0036)	(0.011)
DiscloseGHG x Scope 2 GHG level			-0.0051	0.0067
			(0.017)	(0.058)
DiscloseGHG x Scope 3 GHG level			-0.00046*	-0.0015*
			(0.00027)	(0.00081)
Disclosed level change			0.00061	0.0025
			(0.0014)	(0.0037)
Governance	0.0030**	0.0076**	0.0029**	0.0072*
	(0.0012)	(0.0038)	(0.0012)	(0.0037)
Constant	3.93***		3.96***	
	(0.10)		(0.097)	
Firm-level controls	Y	Y	Y	Y
Time fixed-effects	Y	Y	Y	Y
Sectoral fixed-effects	Y	Y	Y	Y
Country fixed-effects	Y	Y	Y	Y
Observations	3,984	3,984	3,962	3,962
R-squared	0.349	0.1781	0.348	0.1774

In all specifications, the results indicate that committing to a forward-looking emission reduction target is clearly associated with better credit ratings.[9] The magnitude of this effect is comparable to that for the act of disclosure. And noting that making a forward-looking commitment is only partially correlated with the act of disclosing emissions (see Table 20), the wider results in Table 8 imply that the act of disclosure itself is also independently beneficial for a firm's credit rating. In addition, although there appears to be no meaningful relationship between changes in emission levels and credit ratings,

[9]We also run an additional specification to account for a possible moderating effect of making a commitment on the adverse effect associated with high emissions. The main results are confirmed. Setting a forward-looking target remains associated with better credit ratings and the interacted terms (DiscloseCommit X Scope 1 GHG level and DiscloseCommit X Scope 1 GHG intensity, respectively) remain both negatively associated with credit ratings. The results suggest that disclosing a commitment may mitigate the exposure to transition risk that is proxied through emissions.

realised reductions in emission intensities do appear to be associated with better ratings in some specifications. Taken together, these results highlight how a range of transition risk management strategies can help to offset the negative effect on credit ratings coming from exposure to high emissions levels and and intensities.

We also find that among the sample of firms who disclose quantitative targets and related timelines, credit ratings appear strongly related to the ambitiousness of firms' in terms of the percentage of emissions to be cut. By contrast, the timing concerning the fulfilment of the quantitative targets is not found to be significantly associated with ratings. This difference might be explained by the stronger information content of the percentage reduction targets, which might summarize the overall commitment of a firm towards reducing its transition risk. Despite the relevant shrinkage in sample size, which is due to the scarcity of quantitative forward-looking information, it would seem that the ambitiousness of firms in reducing their exposure to transition risk, through cuts in their current emissions, is associated with more favourable credit assessments.

Table 9: Panel regression for credit ratings and emissions, Testing H3 from 2010-2019

Notes: The table shows the result of the panel regression relevant for H3, see (5), where the relationship between quantitative backward and, where available, quantitative forward-looking transition metrics and credit ratings. Model 1 and 2 show the OLS estimates considering GHG emissions intensity and quantitative forward-looking metrics from Refinitiv and from CDP, respectively. Model 3 and 4 show the OLS estimates considering GHG emissions level and quantitative forward-looking metrics from Refinitiv and from CDP, respectively. Ordered logit estimators lead to similar conclusions and are not reported here for brevity. Firm-level clustered standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Variable	**(1 - int., OLS)**	**(2 - int., OLS)**	**(3 - levels, OLS)**	**(4 - levels, OLS)**
Scope 1 GHG intensity	-66.0	-49.6		
	(42.0)	(88.4)		
Scope 2 GHG intensity	66.7	-21.5		
	(271)	(516)		
Scope 3 GHG intensity	5.58	27.6*		
	(12.2)	(16.1)		
Disclosed intensity change	0.023	-0.014***		
	(0.036)	(0.0049)		
Scope 1 GHG level			-0.0033**	-0.0044
			(0.0017)	(0.0039)
Scope 2 GHG level			0.0076	0.018
			(0.0086)	(0.023)
Scope 3 GHG level			0.00045	0.00045
			(0.00039)	(0.00031)
Disclosed level change			0.0013**	0.0014***
			(0.00049)	(0.00053)
TargetPerc Ref	0.0036**		0.0036**	
	(0.0015)		(0.0015)	
TargetYear Ref	-0.0024		-0.0025	
	(0.0066)		(0.0064)	
TargetPerc CDP		0.0032**		0.0031**
		(0.0014)		(0.0015)
TargetYear CDP		0.0027		0.0031
		(0.0042)		(0.0041)
TargetBaseYear CDP		-0.014*		-0.013
		(0.0083)		(0.0084)
Constant	4.80***	11.2	4.80***	6.72
	(0.21)	(19.7)	(0.21)	(21.2)
Firm-level controls	Y	Y	Y	Y
Time fixed-effects	Y	Y	Y	Y
Sectoral fixed-effects	Y	Y	Y	Y
Country fixed-effects	Y	Y	Y	Y
Observations	815	1,116	808	1,111
R-squared	0.335	0.395	0.333	0.394

4.2 Differential effects of transition risk across investment-grade and high-yield firms

Credit ratings may be more sensitive to changes in risk for firms which are already closer to default. It is, therefore, interesting to consider whether our results depend on the existing credit-worthiness of firms – in particular, on whether they are stronger for riskier high-yield (HY) firms than for those with an investment-grade (IG) rating. To explore this, we define an indicator variable allocating firms to either the HY or IG category based on their credit rating, as defined in Table 2. This results in 84% of the observations belonging to IG firms and 16% to HY. We then re-run the regressions related to H1 and H3, focusing on the interaction of our main transition risk metrics with the two credit quality groups.

Table 10 presents the results related to H1. We find that higher Scope 1 GHG levels and intensities are associated with worse ratings for HY firms but that this is not the case for IG firms. The post-estimation test for both specifications also confirms that estimates of scope 1 GHG levels and intensities for the group of observations with HY ratings differs in a statistically significant manner from those estimates corresponding to IG observations. These results suggest that firms which have worse credit ratings do indeed exhibit stronger sensitivity to their current exposure to transition risk than firms which are IG, though the limited sample of HY firms makes it challenging to draw strong conclusions.

Table 10: Panel regression for credit ratings by credit quality: IG vs HY and emissions, Testing H1 from 2010-2019

Notes: The table shows the result of the panel regression relevant for H1, see Equation 3, where the relationship between GHG emissions − expressed in intensity (Models 1 and 2) and in levels (Models 3 and 4) − and credit ratings is tested for the full data sample covering the period from 2010 to 2019. The results are shown for two groups of credit quality: investment grade and high yield. We employ both OLS (Models 1 and 3) and ordered logit estimators (Models 2 and 4). Firm-level clustered standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Variable	**(1 - int., OLS)**	**(2 - int., logit)**	**(3 - levels, OLS)**	**(4 - levels, logit)**
Scope 1 GHG intensity				
HY	-140***	-653***		
	(47.3)	(205)		
IG	-18.1	-66.3		
	(27.3)	(91.4)		
Scope 2 GHG intensity				
HY	-7,279***	-39,401***		
	(1,122)	(9,579)		
IG	367	997		
	(226)	(752)		
Scope 3 GHG intensity				
HY	-3.78*	-19.2		
	(1.97)	(12.0)		
IG	0.078	-0.36		
	(0.85)	(2.80)		
Scope 1 GHG level				
HY			-0.013***	-0.049***
			(0.0041)	(0.017)
IG			-0.0015	-0.0057
			(0.0014)	(0.0042)
Scope 2 GHG level				
HY			-0.028	-0.47
			(0.042)	(0.52)
IG			0.00057	0.0015
			(0.0026)	(0.0089)
Scope 3 GHG level				
HY			-0.0020	-0.0046
			(0.0014)	(0.0045)
IG			0.00058***	0.0017***
			(0.00020)	(0.00061)
Controls	Y	Y	Y	Y
Time fixed-effects	Y	Y	Y	Y
Sectoral fixed-effects	Y	Y	Y	Y
Country fixed-effects	Y	Y	Y	Y
Observations	4,381	4,381	4,373	4,373

Turning to consider past performance in reducing emissions, disclosure practices and climate commitments, Table 11 presents key results for H3 on GHG intensities and GHG emission levels. Strikingly, we find that the credit ratings of IG firms – who are further away from default – remain sensitive to practices related to transition risk management. In particular, there is strong evidence across specifications that committing to an emission-reduction target is positively associated with better credit ratings for IG firms. There is also some evidence that disclosure and realised performance in cutting emissions are associated with better ratings for IG firms. While post-estimation tests provide only limited evidence that the IG estimates are statistically significantly different from the HY ones, the results clearly dismiss the idea that transition risk only matters for the credit risk of firms which are already close to default. This may be because credit rating agencies maintain a strong focus on the management of medium-term transition risks for relatively credit-worthy firms even if, in contrast to HY firms, they are less concerned about their immediate vulnerability to transition risks.

Table 11: Panel regression for credit ratings by credit quality: IG vs HY, Testing H3 from 2010-2019

Notes: The table shows the result of the panel regression relevant for H3, see Equation 5, where the relationship between disclosure, its interaction with GHG emissions, disclosed change in emissions, forward-looking commitment and credit ratings is tested for the full data sample covering the period from 2010 to 2019. The results are shown for two groups of credit quality: investment grade and high yield. We employ both OLS (Models 1 and 3) and ordered logit estimators (Models 2 and 4). Firm-level clustered standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Variable	**(1 - int., OLS)**	**(2 - int., logit)**	**(3 - levels, OLS)**	**(4 - levels, logit)**
DiscloseGHG dummy				
HY	0.023	-0.45	0.037	0.087
	(0.060)	(0.93)	(0.053)	(0.99)
IG	1.40***	58.7	1.38***	153
	(0.055)		(0.052)	(182)
DiscloseGHG x Scope 1 GHG intensity				
HY	74.6	531		
	(60.8)	(953)		
IG	-81.3*	-331*		
	(43.9)	(194)		
Disclosed intensity change				
HY	0.029*	0.42		
	(0.016)	(1.07)		
IG	-0.016**	-0.075*		
	(0.0074)	(0.041)		
DiscloseGHG x Scope 1 GHG level				
HY			0.0068	-1.01
			(0.0061)	(1.98)
IG			0.0048	0.014
			(0.0036)	(0.014)
Disclosed level change				
HY			0.00052	0.012
			(0.0077)	(0.11)
IG	0.0012	0.0044*		
			(0.00074)	(0.0023)
DiscloseCommit dummy				
HY	-0.049	-0.18	-0.049	-0.58
	(0.058)	(1.00)	(0.057)	(1.06)
IG	0.099**	0.45**	0.11**	0.47***
	(0.041)	(0.18)	(0.042)	(0.18)
Constant	3.08***		3.06***	
	(0.064)		(0.062)	
Firm-level controls	Y	Y	Y	Y
Time fixed-effects	Y	Y	Y	Y
Sectoral fixed-effects	Y	Y	Y	Y
Country fixed-effects	Y	Y	Y	Y
Observations	3,984	3,984	4,373	4,373
R-squared	0.613	0.477	0.611	0.469

4.3 Robustness checks

To further assess the reliability of the results discussed in section 4.1, we perform two further robustness exercises. We first repeat the analysis on a sample excluding high-emitters, defined as those firms belonging to the top tercile of the Scope 1 and 2 GHG intensities' distribution. The main rationale for excluding such firms is that high-emitters, which are more environmentally damaging and therefore exposed to greater scrutiny, choose to disclose more (Marquis, Toffel, and Zhou, 2016), a finding also confirmed in our own sample by their higher disclosure rate of GHG emissions and their greater propensity to commit to emission-reduction targets (see Figure 1). This could have particular implications for our results relating to H3. But as Table 21 shows, the key results relating to disclosure and forward-looking commitments being associated with better credit ratings continue to hold in this sub-sample.

Second, we re-run our panel regressions using firm fixed-effects as opposed to sector and country ones. The results corresponding to H3 are summarized in Table 22. While some results continue to hold, it is evident that some key variables – including those related to the act of disclosure and the commitment to an emission-reduction target – lose their significance under firm fixed-effects. It should be noted, however, that firm fixed-effects require a large amount of degrees of freedom in the estimation and that within-firm variation on the environmental metrics might not be sufficient, especially given the yearly nature of our environmental data. As such, the firm fixed-effects setup has strong limitations to its applicability, which is why we use time, sector and country fixed-effects in our baseline specification and place significantly more weight on those results.

4.4 Economic significance

In the previous section, we have documented how both backward and forward-looking environmental metrics related to transition risk seem to be reflected in credit ratings. We now aim to provide quantitative indications on the magnitude and economic significance of the estimated coefficients. To do so, given the ordinal nature of our ratings variable, we follow two approaches. First, we compute the impact of a one standard-deviation change in continuous environmental metrics on credit rating notches and compare it with the corresponding impact from changes in leverage. We then also consider two dummy variables on disclosure of GHG intensities and the commitment to a forward-looking emission reduction target, for which the impact is purely determined by the magnitude of the coefficient. Formally, we have

$$Impact\ on\ credit\ rating\ notch = 3 * \beta_i * \sigma_i \tag{8}$$

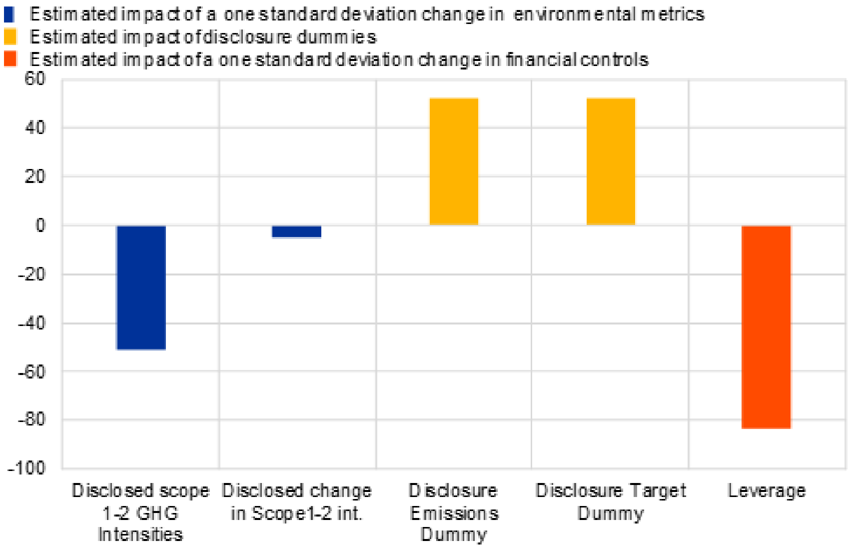
where β_i is the relevant coefficient and σ_i is the standard-deviation of continuous metrics. We multiply by a factor of 3 as the credit rating variable used in the regressions groups 3 credit notches into one categorical value. The results are presented in Figure 3.

As is clear, the impact of the level of Scope 1 and 2 intensities is particularly economically significant, especially when one considers the wide distribution of this variable. In particular, a one standard-deviation increase in intensities is associated with a reduction of more than half a credit notch. By way of comparison, an equivalent increase in leverage decreases credit ratings by approximately 80% of a credit notch. The stand-alone effect of disclosing GHG intensities or making forward-looking commitments to reduce emissions is also material at around half a rating notch for each variable, and has the potential to partially offset the negative effect stemming from the level exposure to transition risk, especially for the average firm in the sample. It is important to highlight however that for highly carbon-intensive firms, such as those from the utilities sector, the effect from disclosed Scope 1-2 intensities will be larger than what computed in this exercise, out-weighting the decrease in credit risk yielded by the act of disclosing.

While the quantitative evidence resulting from the exercise based on OLS estimates has the merit of giving simple indications on the magnitude of the effects of different transition risk metrics´ on credit rating, we also compute in a more rigorous setting the average marginal effects of relevant transition risk variables. Following Alali, Anandarajan, and Jiang (2012), we undertake some data transformation to facilitate the interpretation of the marginal effects. First, we standardize all continuous transition risk variables and

Figure 3: Magnitude of transition risk metrics on credit ratings vis-a-vis leverage.

Notes: left-hand axis: percentage of a credit notch. The first two columns represent the estimated magnitude of a one standard-deviation increase in disclosed Scope 1 and 2 GHG intensities and disclosed changes in Scope 1 and 2 GHG intensities respectively. The third and fourth columns reflect the impact of the decision to disclose of GHG emissions and make a forward-looking commitment respectively. The fifth column shows the impact of a one standard-deviation increase in leverage. The coefficients on the two dummies and leverage are significant at the $p<0.01$ level. Coefficients for disclosed GHG intensities and changes in intensities are significant at the $p<0.05$ level.



controls used in equation 5. Second, we employ as the dependent variable a transformed binary version of credit ratings, taking the value of 1 for $Rating = AAA, AA, A$ and 0 for $Rating = BBB, BB, B$. In this way, we are able to interpret the marginal effects as being the change in likelihood of being in the rating group associated with minimal-to-low credit risk (see Table 2) relative to the rating group associated with moderate-to-high credit risk. Results of both the ordered logistic regression and the corresponding average marginal effects are presented in Table 12.

Even with the additional data transformation steps, which increase the variation within the two broad rating groups, we obtain significant positive estimates for the disclosure and forward-looking commitment dummies. Changes in disclosed Scope 1 and 2 intensities retain modest significance. Turning to the average marginal effects, we find the act of disclosing GHG emissions increasing the likelihood of firms having lower credit risk by approximately 5%, i.e. the firm belonging to the AAA, AA, A group. The effect is even stronger for firms making a forward-looking commitment related to emissions reduction, who are 10% more likely to have a better rating.

Table 12: Testing the economic significance of H3: ordered logit and average marginal effects

Notes: The table shows the results of the ordered logit estimation and the corresponding marginal effects based on equation 5, while employing a binary dependent variable. Firm-level clustered standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Variable	Ordered Logit- Binary rating dependent variable	Average Marginal Effect
Disclosure	0.35***	0.0529**
	(0.15)	
Disclose x Scope 1 and 2 GHG int.	-0.46	-0.0387
	(0.28)	
Disclosed change in Scope 1-2 GHG int.	-0.14*	-0.0078
	(0.081)	
Disclose x Scope 3 GHG int.	-0.091	-0.303*
	(0.13)	
Forward-looking commitment	0.56***	0.0940***
	(0.19)	
Time fixed-effects	Y	Y
Sectoral fixed-effects	Y	Y
Country fixed-effects	Y	Y
Observations	3,810	2,175
R-squared	0.223	

4.5 Results of difference-in-differences analysis

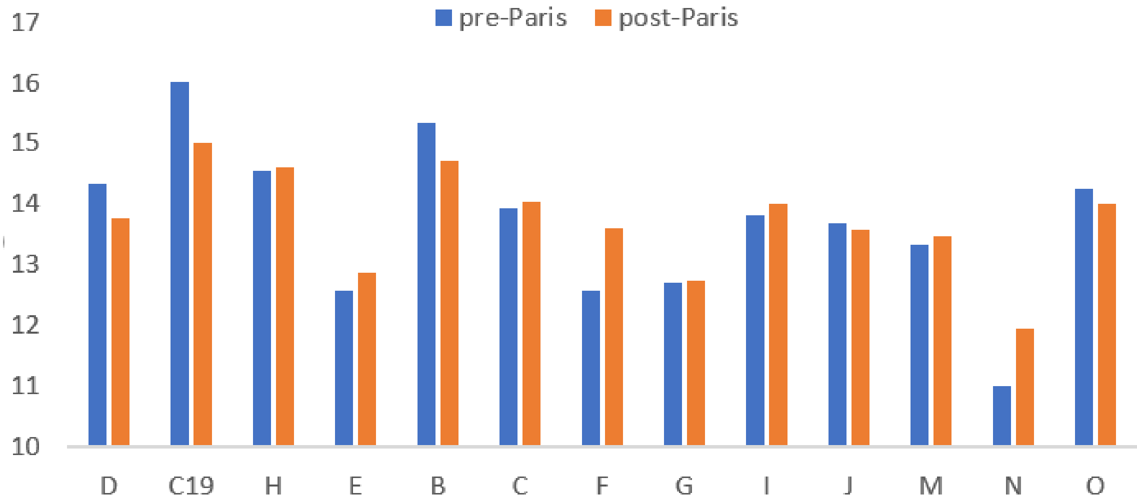
In this section, we present results from the difference-in-differences analysis around the date of the Paris Agreement, as described in Section 3.2.

We start our analysis by presenting panel regression results on the subsample of European firms and on the subsample of US firms to illustrate our primary that the relation between GHG emissions and ratings differs across these two geographies (see results in 7). Scope 1 GHG intensity and Scope 3 GHG intensity are negatively associated with credit ratings for European firms, but not for US firms. Similarly, when considering GHG emissions levels instead of GHG emissions intensity, Scope 1 GHG level is negatively associated with credit ratings for European firms, but not for US firms. For regressions on European firms, we further integrate the EU ETS carbon price reflecting the EU carbon market. The carbon price is negatively associated with credit ratings: a high carbon price is associated with worse credit ratings. The results suggest that a causal relationship between the low-carbon transition and credit ratings may exist for European firms, but not for US firms. We test the existence of such a causal relationship by the means of a difference-in-differences methodology.

Having confirmed our intuition of an associative relationship between GHG emissions and credit ratings depending on the geography (Europe versus US), we define the dataset for difference-in-differences setup. We consider a balanced panel with the same number of firms observed throughout the whole period: before the event, i.e. ex-ante (2011, 2012, 2013, 2014), and during and after the event, i.e. ex-post (2015, 2016, 2017, 2018, 2019). The *CreditRating* variable is mapped to a granular rating scale of ordinal values ranging from 1 to 21, such that a higher ordinal value indicates a better rating. The more granular rating scale suits better the difference-in-differences approach as it allows us to capture all up- and downgrades undertaken by the credit rating agency. We focus first on the sample of European firms, as presented in section 3.2, and present the US comparison later. We start with a descriptive analysis of changes in credit ratings for high polluting firms operating in the Europe versus other European firms, both before and after the Paris Agreement. Figures 4 and 5 show the average rating for each type of treatment[10] before and after the Paris Agreement.

Figure 4: Average rating of European firms before and after the Paris Agreement in 2015 by NACE1-sector.

Notes: The top polluting sectors, as per Eurostat data for carbon dioxide and methane for EU27+UK, are shown first: Electricity, gas, steam and air conditioning supply (D), Manufacturing (C – and in particular Manufacture of coke and refined petroleum products (C19)), Transportation and storage (H), Mining and quarrying (B), Water supply, sewerage, waste management and remediation activities (E). Y-axis: Alphanumeric rating grade following the mapping of the rating scale to ordinal values ranging from 1 to 21, such that a higher ordinal value indicates a better rating. X-axis: NACE1-sector. Sources: Eurostat, Orbis, ECB Ratings Database, and authors' calculations.



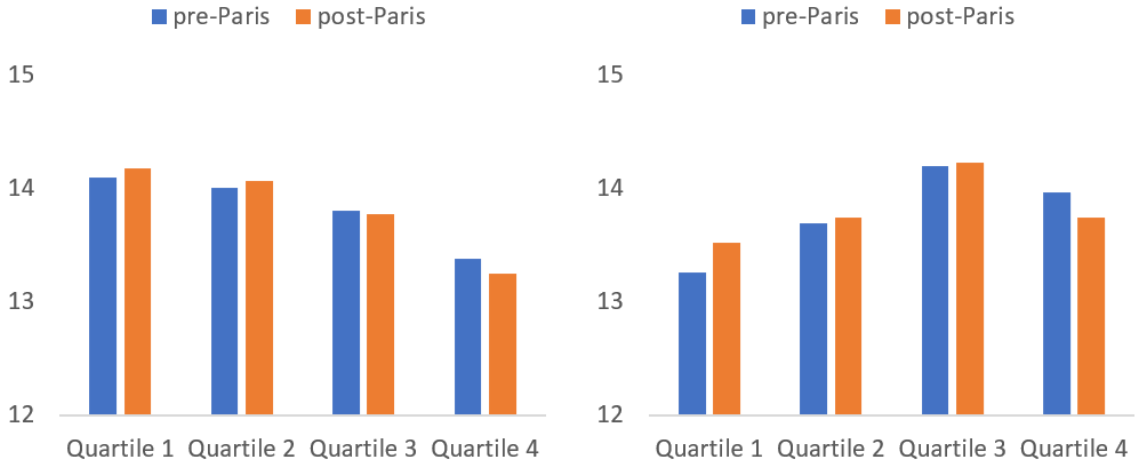
On average, ratings decreased for firms in the top polluting NACE economic activities Electricity, gas, steam and air conditioning supply (D), Manufacture of coke and refined petroleum products (C19), and Mining and quarrying (B) (Figure 4). In addition, firms

[10]The treatment takes three different specifications as defined in 3.2: (i) top GHG NACE – firms in the top polluting economic activities in terms of carbon dioxide and methane emissions, (ii) top GHG intensity – firms in the top quartile of the distribution of GHG emissions intensity, (iii) top GHG level – firms in the top quartile of the distribution of GHG emissions levels.

in the top quartile of GHG emissions intensity and firms in the top quartile of GHG emissions level had, on average, worse ratings after the Paris Agreement (Figure 5).

Figure 5: Average rating of European firms before and after the Paris Agreement in 2015 by firm-level GHG emission intensity (Panel A) and GHG emission level (Panel B).

Notes: Y-axis: Alphanumeric rating grade following the mapping of the rating scale to ordinal values ranging from 1 to 21, such that a higher ordinal value indicates a better rating. Panel A: X-axis: Quartile of GHG emission intensity. Panel B: X-axis: Quartile of GHG emission level. Sources: Eurostat, Orbis, ECB Ratings Database, and authors' calculations.



The results of the difference-in-differences regressions for the three types of treatment are shown in Table 13. The columns 1, 2, and 3 show the estimated coefficients for a basic difference-in-differences specification without controls and without fixed-effects. The columns 4, 5, 6 show the estimated coefficients as per Equation 6. The difference-in-differences estimates for the treatment top GHG NACE (*Top GHG NACE x post-Paris*) and for the treatment top GHG level (*Top GHG level x post-Paris*) are statistically significant with the treatment having a negative effect as indicated by the negative sign. These results hold both in the basic difference-in-differences specification as well as in the specification augmented with controls, firm and time fixed-effects. The difference-in-differences estimate for the treatment top GHG intensity (*Top GHG intensity x post-Paris*) is statistically significant in the basic difference-in-differences specification, but not once we add the controls and the fixed-effects, although the negative sign is still as expected. These results highlight that following the Paris agreement European firms active in the most polluting economic activities see their ratings fall by an additional half a notch relative to the control group. Similarly, following the Paris agreement, most GHG polluting European firms (based on Scope 1 GHG emissions in levels) see their ratings fall by an additional 0.38 notch relative to the control group.

These results are intuitive of a causal relationship between some transition risk metrics[11] and credit ratings.

The estimated coefficient for *Top GHG NACE* is positive and statistically significant at 5%, suggesting that, prior to the Paris Agreement, firms in the treatment group *Top GHG NACE* had higher ratings than the firms in the control group.

Table 13: Difference-in-differences results for changes in credit ratings for European firms following the Paris Agreement in 2015

Notes: The table shows the result of the OLS regressions, testing the relationship between GHG pollution and credit ratings for the subsample of European firms. Models 1 and 4 consider as "treated" firms in the *Top GHG NACE* sectors without and with controls and firm and time fixed-effects, respectively. Models 2 and 3 consider as "treated" firms in the *Top GHG intensity* quartile and in *Top GHG level* quartile, respectively. In models 5 and 6 the later specification is augmented with controls and firm and time fixed-effects.*post-Paris* is the indicator variable taking the value 1 for years following and including 2015, and 0 otherwise. The period of the subsample is from 2011 to 2019. Firm-level clustered standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Top GHG NACE x post-Paris	-0.55***			-0.53***		
	(0.17)			(0.16)		
Top GHG intensity x post-Paris		-0.16*			-0.28	
		(0.086)			(0.18)	
Top GHG level x post-Paris			-0.32*			-0.38**
			(0.17)			(0.16)
Top GHG NACE	0.84**					
	(0.34)					
Top GHG intensity		-0.58*				
		(0.35)				
Top GHG level			0.20			
			(0.39)			
Controls	N	N	N	Y	Y	Y
Time fixed-effects	N	N	N	Y	Y	Y
Firm fixed-effects	N	N	N	Y	Y	Y
Observations	1,530	1,530	1,530	1,474	1,474	1,474
Number of firms	170	170	170	170	170	170
R-squared	0.028	0.003	0.012	0.063	0.044	0.054

The parallel trend assumption underlying the difference-in-differences design presumes that in the absence of treatment, the difference in rating between the "treated" firms and the "control" firms is constant over time. Since we have observations over many time-points, we examine the dynamics over time for the treatment specifications *TopGHG-NACE*, *TopGHGintensity* and *TopGHGlevel* by estimating yearly coefficients for the treatment. To obtain an estimated coefficient of the treatment for each year, we run the regression for the treatment variable interacted with yearly dummies, instead of the

[11] In addition, we test an alternative specification where we define the treatment group as firms with an economic activity on the EU carbon leakage list and receiving free allowances (dummy variable *EU ETS NACE*). We do not find this treatment specification to be statistically significant in our difference-in-differences setup.

indicator variable *post-Paris*, including all controls, as in the Equation 6. The yearly estimated coefficients are shown in Figure 6. For the treatment specification *TopGHGlevel*, the estimated coefficient for point 0, i.e. the calendar year 2015, is well below the estimates for the period prior to the Paris Agreement event and below 0. The estimates for the four years preceding the Paris Agreement are all close to 0 and above the levels of the estimates post event. The estimates for all the four years following the Paris Agreement, i.e. 2016-2019, remain consistently below 0. This provides strong evidence of changes in ratings post-event for the treated firms and that the parallel trend assumption likely holds for the treatment specification *TopGHGlevel*.

For the treatment specification *TopGHGNACE* and to some extent for *TopGHGintensity* the dynamics of the estimated coefficients in the pre-event period suggest a pre-trend. Malani and Reif (2015) explain that such pre-trends should not discard the analysis as these could be seen as policy anticipation effects that arise naturally out of many theoretical models. And in practice, there may have been some anticipation of the Paris agreement goals in the preceding years.

Figure 6: Treatment effect for each period of the sample.

Notes: Panel A: Treatment corresponds to being a firm in a top polluting economic activity, *TopGHGNACE*. Panel B: Treatment corresponds to being a firm in the top quartile of GHG emissions intensity, *TopGHGintensity*. Panel C: Treatment corresponds to being a firm in the top quartile of GHG emissions level, *TopGHGlevel*. Y-axis: parameter estimate. X-axis: period of the sample where 0 indicates the year of the event, i.e. 2015. Sources: authors' calculations.

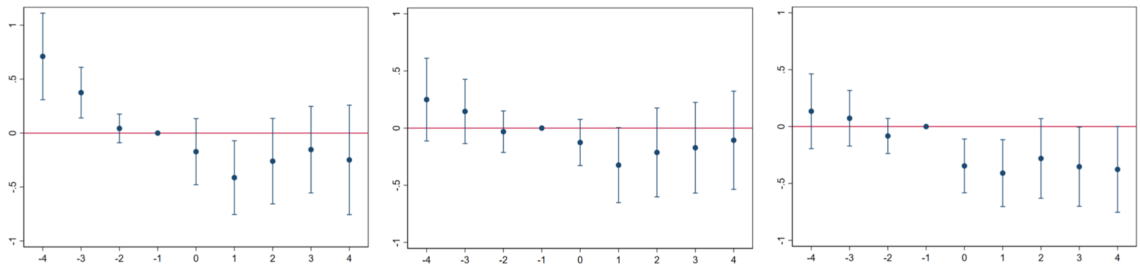
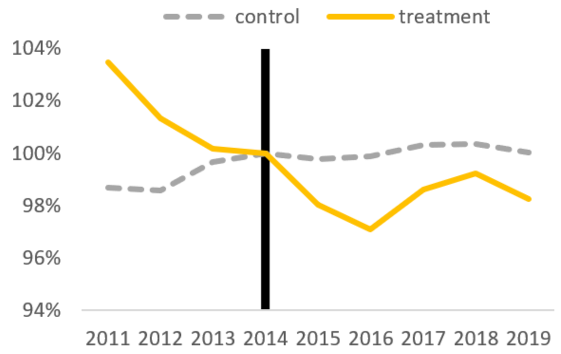
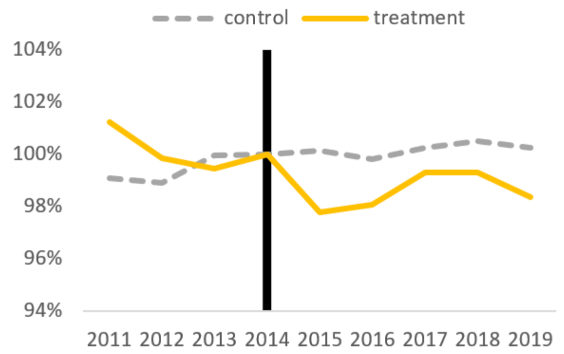


Figure 7 shows the rating dynamics of the treatment group relative to the control group over time for treatments *TopGHGNACE* and *TopGHGlevel*, for which the difference-in-difference estimated coefficients in 13 are consistently statistically significant across different specifications. In Figure 7, observations are scaled at 100 for the year 2014, preceding the event year, 2015. The average rating of "treated" firms (whether using a treatment defined based on *Top GHG NACE* or *Top GHG level*) in the years prior to the Paris Agreement was above the average rating of the "control" group. By contrast, following the Paris Agreement, the average rating of the "treated" firms decreases visibly and remains below the average rating of the "control" group throughout the post-event period. As for the "control" group, the average rating remains relatively stable post-event.

Figure 7: Dynamics of the treatment and control group over the time of the sample.

Notes: Panel A: Treatment corresponds to being a European firm in a top polluting economic activity, while the control group corresponds to European firms in non-top-polluting economic activities. Panel B: Treatment corresponds to being a European firm in the top quartile of polluting firms by GHG emissions level, while the control group corresponds to all other European firms. Y-axis: rating rescaled by the value observed for 2014. X-axis: period in years of the difference-in-differences sample. Sources: authors' calculations.





Next, we test whether credit rating agencies assess firms in countries with a low-carbon transition policy (European countries) differently from the one without (the US)[12]. For this purpose, we run a triple difference-in-differences analysis including an indicator variable differentiating on such countries. The results reported in Table 14 show a negative estimate for our main coefficients of interest *Treatment x Transition-policy x post-Paris*. Columns 1, 2, 3 show the estimated coefficients for a basic triple difference-in-differences specification while columns 4, 5, 6 – for a specification considering in addition firm-level controls and fixed-effects as per Equation 7. Treatment takes the values Top GHG NACE, Top GHG intensity, and Top GHG level. The sign of the estimate confirms that "treated" firms in European countries have experienced a worsening in credit ratings post-Paris relative to firms in the US. The magnitude of the worsening in credit ratings is of the order of 0.9 notch when considering firms in top GHG-polluting sectors, and of about half a notch when considering firms in the top quartile of GHG intensities and levels. The positive sign of the estimates of the coefficients *Top GHG NACE x post-Paris* and *Top GHG intensity x post-Paris* suggest that credit ratings actually improved for the

[12]The country of the firm is defined based on the country of registration retrieved from Orbis that is defined as the country where the firm is primarily conducting business. Where the country of registration is not available (limited number of cases), we use country of incorporation of the firm retrieved from Datastream.

most polluting firms in the US in the period following the Paris Agreement. Overall, the results from this triple difference-in-differences exercise indicate that the potential causal relationship between some transition risk metrics and credit ratings may be dependent on the extent of national climate change / carbon reduction commitments in the country where the firm primarily operates.

Table 14: Triple difference-in-differences results for changes in credit ratings considering the 2015 Paris Agreement and European countries versus the US

Notes: Model 1 considers as "treated" firms in the *Top GHG NACE* sectors in basic triple-difference-in-differences specification, while in model 4 the basic specification is augmented by firm-level controls and firm time fixed-effects as defined in Equation 7. Models 2 and 3 consider as "treated" firms in the *Top GHG intensity* quartile and in *Top GHG level* quartile, respectively. In models 5 and 6 the later specification is augmented with controls and firm and time fixed-effects. *post-Paris* is the indicator variable taking the value 1 for years following and including 2015, and 0 otherwise. The period of the sample is from 2011 to 2019. *Transition-policy* is an indicator variable taking the value 1 for firms conducting primarily business in European jurisdictions and 0 for those operating primarily in the US. Firm-level clustered standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Top GHG NACE x Transition-policy x post-Paris	-1.06***			-0.91***		
	(0.23)			(0.21)		
Top GHG intensity x Transition-policy x post-Paris		-0.55**			-0.53**	
		(0.25)			(0.22)	
Top GHG level x Transition-policy x post-Paris			-0.57**			-0.49**
			(0.24)			(0.20)
Top GHG NACE x post-Paris	0.51***			0.39***		
	(0.16)			(0.14)		
Top GHG intensity x post-Paris		0.38**			0.28**	
		(0.16)			(0.14)	
Top GHG level x post-Paris			0.25			0.11
			(0.17)			(0.14)
Top GHG NACE x Transition-policy	1.65***					
	(0.50)					
Top GHG intensity x Transition-policy		0.32				
		(0.54)				
Top GHG level x Transition-policy			0.60			
			(0.54)			
Transition-policy x post-Paris	0.22**	0.12	0.13	0.10	0.024	0.032
Firm-level controls	N	N	N	Y	Y	Y
Time fixed-effects	N	N	N	Y	Y	Y
Firm fixed-effects	N	N	N	Y	Y	Y
Observations	3,807	3,807	3,807	3,643	3,643	3,643
Number of firms	423	423	423	422	422	422
R-squared	0.026	0.010	0.008	0.094	0.081	0.081

5 Distance to default

In this section we analyse the relationship between climate-related transition risk metrics and our second measure of credit risk: Merton's measure of the firm's distance-to-default (DtD) as specified in Equation 13. The panel regressions outlined in Tables 3, 4 and 5 take DtD as the measure of credit risk, using the full sample of monthly data, spanning the period from 2010 to 2019. As a complement, the Appendix provides sub-sample estimates for the periods before and after the Paris Agreement. Given the continuous nature of the DtD as the dependent variable, we employ only standard ordinary least square estimators, controlling for traditional fixed-effects.

5.1 Results of the regression analysis

Our first hypothesis relates to the relationship between Scope 1, 2, and 3 emissions and DtD. Table 15 summarises the results. Strong statistical evidence is found in favour of the hypothesis. The negative coefficients found for Scope 1 and Scope 3 emission intensities suggest that firms with lower overall emissions are viewed by market participants as being less exposed to credit risk: lower emission intensities are associated with a higher DtD. Similar to the credit ratings, given their strong correlation, the variability of the Scope 2 emission intensities seems to be overshadowed by those of the Scope 1 intensities and therefore induce the statistical insignificance of the Scope 2 intensity coefficient.[13] Furthermore, similar to the empirical conclusions on H1 for credit ratings, it can be seen that the magnitude of the Scope 3 intensity coefficient is lower than that of the Scope 1 intensity coefficient, which indicates that also market participants are acknowledging the limitations on the proper accounting and disclosure of Scope 3 emission intensities. The emission levels Scope 1, 2 and 3 are, however, statistically insignificant for DtD, which can be explained by the fact that, due to a better longitudinal comparability between companies, both within and across sectors, it is the emission intensities that have emerged as the market's preferred key performance indicators for assessing the environmental footprint of a company, as further explained in TCFD (2017). To sum up, for H1, our findings for the H1 for the DtD are fully consistent with those of the credit ratings in Section 4.1 in that higher emission intensities are associated with higher credit risk and they also apply for the sub-samples before and after the Paris Agreement as shown in Appendix Table 26

[13] This becomes further clear when omitting Scope 1 intensities, in which case the Scope 2 coefficient becomes highly statistically highly. Nevertheless, given the remaining set of regression coefficients is shown to be robust regardless of whether or not the Scope 1 intensities are included, we maintain in the following the same set of explanatory variables as in Section 4 for the benefit of direct comparability of the results.

Table 15: Panel regression for Distance-to-Default (DtD) and emissions, Testing H1 from 2010-2019

Notes: The table shows the result of the panel regression relevant for H1, see Equation (3), where the relationship between emissions and distance-to-default (DtD) is tested for the full data sample covering the period from January 2010 to December 2019 using a monthly observation frequency. DtD falls when credit risk increases, so a negative estimate for the emission-coefficients implies the acceptance of H1. Model 1 shows the OLS results considering GHG emission intensity, while model 2 shows the OLS results considering GHG emission level. Firm-level clustered standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10 .

Variable	**(1 - int.)**	**(2 - levels)**
Scope 1 GHG intensity	-348***	
	(124)	
Scope 2 GHG intensity	26.8	
	(212)	
Scope 3 GHG intensity	-65.1***	
	(21.7)	
Scope 1 GHG level		-0.0069
		(0.0065)
Scope 2 GHG level		-0.0016
		(0.023)
Scope 3 GHG level		0.00086
		(0.00079)
Profitability	0.0055***	0.0056***
	(0.0020)	(0.0020)
Size	1.7e-09***	1.4e-09**
	(5.1e-10)	(5.7e-10)
Leverage	-0.056	-0.047
	(0.039)	(0.041)
Solvency	-0.22	-0.36
	(0.25)	(0.25)
Debt servicing capacity	0.00093*	0.00097*
	(0.00050)	(0.00051)
Governance	0.0032	0.0027
	(0.0019)	(0.0020)
Market	-0.027***	-0.027***
	(0.0024)	(0.0025)
Oil	-0.0045***	-0.0044***
	(0.00045)	(0.00045)
Inflation	0.061***	0.041*
	(0.024)	(0.023)
Industrial Production	0.034***	0.036***
	(0.0030)	(0.0030)
Gold	-0.022***	-0.022***
	(0.0011)	(0.0011)
Bills	0.60***	0.57***
	(0.067)	(0.066)
Volatility	-0.091***	-0.090***
	(0.0029)	(0.0029)
Constant	6.29***	6.23***
	(0.15)	(0.15)
Controls	Y	Y
Sectoral fixed-effects	Y	Y
Country fixed-effects	Y	Y
Observations	20,829	20,829
R-squared	0.348	0.342

Our second hypothesis tests both how decisions to disclose emissions affect a firm's DtD and whether information on emissions is treated differently depending on whether it is self-reported by firms or inferred by third party data providers. Table 16 summarises these results. Similar as for ratings in Section 4.1, we find that choosing to disclose GHG-emissions seems to increase a firm's DtD as shown with statistically significant parameter estimates equal to 0.15 for GHG-emission levels and 0.12 for GHG-emission intensities. Regarding the differentiation of the coefficients of published and inferred GHG emission intensities, the regression results lend support to two empirical observations. On the one hand, there is a highly statistically significant inverse relationship between disclosed Scope 1 GHG-emission intensities and DtD, whereas inferred Scope 1 GHG-emission intensities have a statistically insignificant coefficient of lower magnitude, which suggests the market pricing of credit risk is more attentive to disclosed Scope 1 intensities. On the other hand, the DtD for Scope 3 emission intensities seems to be rather influenced by inferred than by disclosed metrics as shown by the smaller magnitude and statistical significance of the latter ones, which can be related to the inherent uncertainty for capturing Scope 3 emissions, where apparently market data vendor inference methodologies seem to play a more important role for the market expectation of credit risk.

Table 16: Panel regression for Distance-to-Default (DtD) and emission disclosures, testing H2 from 2010-2019

Notes: The table shows the result of the panel regression relevant for H2, see (4), where the relationship between emission disclosures and distance-to-default (DtD) is tested for the data sample covering the full data sample from January 2010 to December 2019, using a monthly observation frequency. The relevance of disclosure, in itself, is tested via the dummy variable denoted by *Disclosure*. Similarly, the market assessment of the source of the GHG-emission data is investigated by including dummy interaction terms capturing whether a given firm's emission statistics are self-reported (*Disclosed*), or whether they are *inferred* by a third-party data provider. DtD falls when credit risk increases, so a negative estimate for the emission-coefficients implies the acceptance of H2. Model 1 shows the OLS results considering GHG emission intensity, while model 2 shows the OLS results considering GHG emission level. Firm-level clustered standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Variable	(1 - int.)	(2 - levels)
DiscloseGHG dummy	0.12	0.15**
	(0.081)	(0.069)
DiscloseGHG x Scope 1 GHG intensity	-357**	
	(150)	
DiscloseGHG x Scope 2 GHG intensity	-159	
	(597)	
DiscloseGHG x Scope 3 GHG intensity	-57.0**	
	(27.2)	
DiscloseGHG x Scope 1 GHG level		-0.018
		(0.011)
DiscloseGHG x Scope 2 GHG level		0.032
		(0.051)
DiscloseGHG x Scope 3 GHG level		0.00054
		(0.0011)
Inferred Scope 1 GHG intensity	-287	
	(200)	
Inferred Scope 2 GHG intensity	60.7	
	(151)	
Inferred Scope 3 GHG intensity	-73.4***	
	(24.9)	
Inferred Scope 1 level		-0.0021
		(0.0071)
Inferred Scope 2 level		-0.0081
		(0.018)
Inferred Scope 3 level		0.0011
		(0.00077)
Governance	0.0034***	0.0084**
	(0.0012)	(0.0036)
Constant	6.28***	6.21***
	(0.15)	(0.15)
Controls	Y	Y
Sectoral fixed-effects	Y	Y
Country fixed-effects	Y	Y
Observations	20,829	20,829
R-squared	0.350	0.345

Our third tested hypothesis focuses on firms' forward-looking commitments in relation to the reduction of the GHG-emissions alongside past performance in reducing emissions. These results are summarised in Table 18. We find a positive and statistically significant relationship between the communication of future emission targets for the full sample, both for GHG intensities and levels. This implies that financial markets assess it as credit-positive that firms communicate such forward-looking targets, since this is associated with an increase in the distance-to-default, and thus with lower market-based credit risk. As annex 7 shows in Table 27, this finding also holds in both sub-samples, though the magnitude of the effect is slightly stronger after the Paris agreement. Conversely, changes in past emissions are not found to be associated with market implied estimates of credit risk as indicated by the low magnitude and statistical significance of the corresponding parameter estimates relating to the change in disclosed Scope 1&2 GHG-emission intensities or levels. We attribute this finding to the fact that the financial markets are inherently forward-looking when assessing the creditworthiness of a company and therefore abstract from past achievements.

Table 17: Panel regression for Distance-to-Default (DtD) and emission targets, testing H3 from 2010-2019

Notes: The table shows the result of the panel regression relevant for H3, see (5), where the relationship between emission-disclosure targets and distance-to-default (DtD) is tested for the full data sample from January 2010 to December 2019, using a monthly observation frequency. DtD falls when credit risk increases, so if a firm communicates a future emission target, and this event is interpreted by financial markets as a credit-positive event, a positive parameter estimate would be obtained. Model 1 shows the OLS results considering GHG emission intensity, while model 2 shows the OLS results considering GHG emission level. Firm-level clustered standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Variable	**(1 - int.)**	**(2 - levels)**
DiscloseGHG dummy	0.25***	0.17**
	(0.078)	(0.072)
DiscloseGHG x Scope 1 GHG intensity	-317**	
	(135)	
DiscloseGHG x Scope 2 GHG intensity	-214	
	(616)	
DiscloseGHG x Scope 3 GHG intensity	-43.6	
	(26.6)	
Disclosed intensity change	75.7	
	(307)	
DiscloseCommit dummy	0.42***	0.43***
	(0.085)	(0.086)
DiscloseGHG x Scope 1 GHG level		-0.018*
		(0.011)
DiscloseGHG x Scope 2 GHG level		0.021
		(0.050)
DiscloseGHG x Scope 3 GHG level		0.00089
		(0.0010)
Disclosed level change		0.040
		(0.031)
Governance	0.0011	0.00095
	(0.0020)	(0.0020)
Constant	5.73***	5.74***
	(0.17)	(0.17)
Controls	Y	Y
Sectoral fixed-effects	Y	Y
Country fixed-effects	Y	Y
Observations	18,490	18,490
R-squared	0.357	0.354

As a final complement to the testing of hypothesis 3, Table 18 summarises the empirical testing of the relationship between DtD and the ambitiousness of targets as reflected in the

(*TargetPerc*) relative to current emissions, and the duration until the target is expected to be reached (*TargetYear*). While we cannot confirm a statistically significant relationship between credit risk and larger emissions reduction targets for the DtD analysis as is the case with credit ratings, we find some empirical evidence that suggests that financial markets penalise companies with less ambitious timing targets. Concretely, companies that communicate more distant emission reduction targets in the course of time seem to get penalised with a lower DtD as seen with the statistically significant coefficients for *TargetYear* based on Refinitiv data, which amounts to -0.021 for GHG-emission intensities and -0.02 for GHG-emission levels. However, due to the sparse data coverage of forward-looking commitments[14] and potentially different information content among data providers, this relationship can neither be confirmed nor rejected when looking at the CDP data with statistically and economically insignificant coefficients, so that the empirical relationship is still somewhat inconclusive. Nevertheless, our results from both metrics of credit risk highlight the potential importance of forward-looking targets and strategies in gauging firm' vulnerability to climate-related transition risk. This highlights an importance of understanding how credible such targets are, an issue to which we now turn.

[14]It is noted that forward-looking commitments only became available following the Paris agreement, so that no sub-sample analysis into pre- and post-Paris agreement can be made.

Table 18: Panel regression for Distance-to-Default (DtD) and emission targets, testing H3 from 2010-2019

Notes: The table shows the result of the panel regression relevant for H3, see (5). The impact on distance-to-default (DtD) of a communicated emission-reduction target (*Emission target percentage*) relative to current emissions and the duration until the target should be reached *Emission target arrival*, are investigated. Here the analysis is performed only for the full sample of data covering the period from 2010 to 2019, using a monthly observation frequency. It is assumed that the higher the communicated target is, as long as it is perceived to be credible, the better the market based credit risk assessment i.e. a higher DtD, so it is expected that a positive coefficient will be associated with the *Emission target arrival*. And, it is assumed that the sooner the communicated is expected to be achieved, the better it is for the market based credit risk assessment: as such we expect a negative coefficient for the *TargetYear* variables. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Variable	**(1 - int., OLS)**	**(2 - int., OLS)**	**(3 - levels, OLS)**	**(4 - levels, OLS)**
Scope 1 GHG intensity	-72.2	-634**		
	(129)	(293)		
Scope 2 GHG intensity	-147	289		
	(784)	(1,373)		
Scope 3 GHG intensity	-19.0	-63.9		
	(24.7)	(44.4)		
Disclosed intensity change	96.9	1,040		
	(261)	(639)		
Scope 1 GHG level			-0.0064	-0.029***
			(0.0041)	(0.010)
Scope 2 GHG level			0.031	0.027
			(0.049)	(0.071)
Scope 3 GHG level			-0.00067	-0.0034*
			(0.0012)	(0.0019)
Disclosed level change			-0.016	0.010
			(0.027)	(0.046)
TargetPerc Ref	0.0018		0.0020	
	(0.0021)		(0.0021)	
TargetYear Ref	-0.021*		-0.020*	
	(0.011)		(0.010)	
TargetPerc CDP		0.0027		0.0020
		(0.0025)		(0.0025)
TargetYear CDP		-0.00093		0.00011
		(0.0087)		(0.0081)
TargetBaseYear CDP		-0.012		-0.025**
		(0.014)		(0.011)
Constant	5.72***	29.3	5.72***	53.3*
	(0.34)	(33.8)	(0.34)	(27.2)
Firm-level controls	Y	Y	Y	Y
Macroeconomic controls	Y	Y	Y	Y
Sectoral fixed-effects	Y	Y	Y	Y
Country fixed-effects	Y	Y	Y	Y
Observations	3,793	3,917	3,793	3,917
R-squared	0.549	0.521	0.549	0.530

5.2 Robustness checks

We run the same two robustness exercises used for the credit ratings analysis. When we exclude the highest emitting companies, we find that the act of disclosure and making an emissions-reduction commitment are still both associated with lower market-implied credit risk (Table 23).

We also re-run our panel regressions again using firm fixed-effects as opposed to sector and country ones. The results shown in Table 24 for H3 confirm the continued significance of forward-looking commitments to reduce GHG emissions, though the disclosure dummy and Scope 1 emission levels and intensities lose their significance. But for the same reasons discussed in the robustness checks for credit ratings, we argue that the use of fixed-effects by sector and country in our baseline analysis is more appropriate for the empirical characteristics of our data set than the use of firm fixed-effects.

6 The credibility of climate targets and commitments

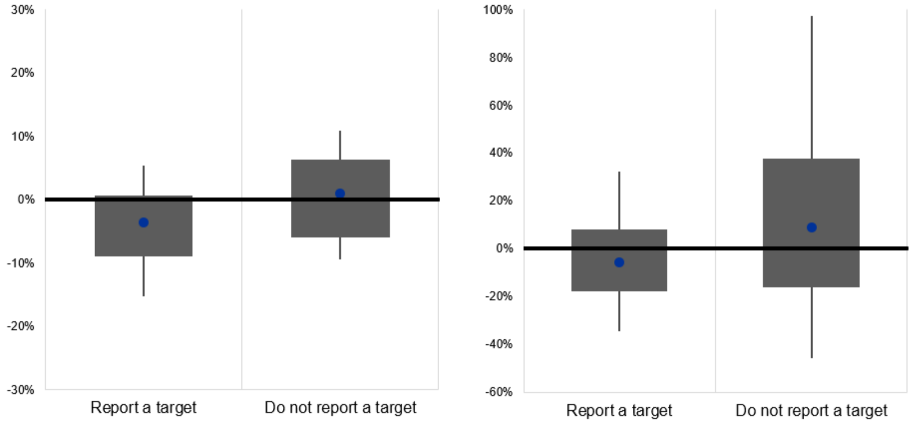
Disclosing an emission reduction target is an important first step in supporting the Paris goals and managing climate-related risks. The evidence we present also suggests that this is recognised by rating agencies and market participants. But ultimately such targets are only meaningful if they are credible and if steps are taken to meet them, which may require an independent assessment of the credibility of the target (NGFS, 2021). In particular, the credibility of a target depends on how realistic it is and how consistent the firm is over time in reducing emissions. In addition, targets may be not ambitious enough, in the sense that they may be not aligned with the overall global goal of achieving net-zero by 2050 or with country-level intermediate goals.

With these considerations in mind, this sections exploits our sample of 859 non-financial firms to analyse the credibility of targets descriptively. We first ask whether firms with a disclosed target reduce emissions. Figure 8 shows the relative change in Scope 1 and 2 GHG emission intensity over the last one year (left panel) and over the last three years (right panel) for firms disclosing a target versus those not disclosing a target. The left panel shows that the vast majority of firms that had a disclosed target in 2019 did reduce their GHG emission intensity over the last year whereas the firms that did not disclose a target showed little change in GHG emission intensity. When analysing the relative change of GHG emission intensity over the previous three years, firms with a target had a median emission intensity reduction of 6%, while firms without a target in 2019 actually showed a median emission intensity increase of 9%. This suggests that firms with a emission reduction target, have tended to reduce their emission intensity by more than firms that did not disclose a target. This is also in line with the findings of Bolton and

Kacperczyk (2021c) who find that firms that make commitments subsequently further reduce their emissions.

Figure 8: Change in Scope 1 and 2 GHG emission intensity for firms disclosing an emissions reduction target and those not disclosing a target

Notes: Left panel: Year-on-year change in 2019 relative to 2018. (Percentage of reduction in Scope 1 and 2 GHG emission intensity; Bucket of firms out of 859 NFCs). Right panel: 3-year change in 2019 relative to 2016 (Percentage of reduction in Scope 1 and 2 GHG emission intensity; Bucket of firms out of 859 NFCs). In both panels: the blue dot is the median, the shaded area is the interquartile range, bars are the 10th and 90th percentile. Sources: Refinitiv and authors' calculations.

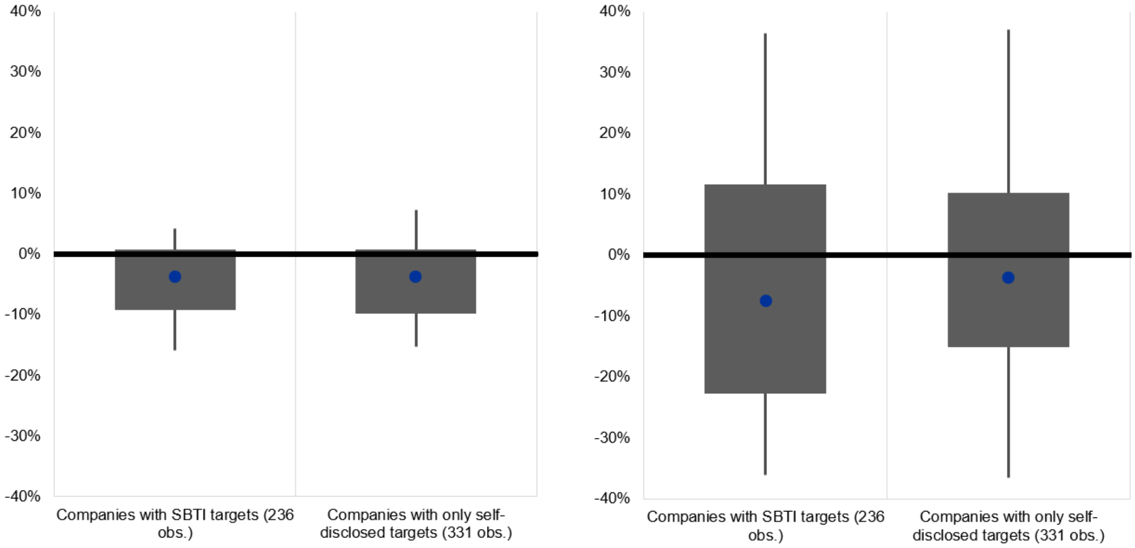


Next, we ask whether firms that have both a self-disclosed emission reduction target – in their financial or non-financial statements – and an SBTi target reduce emissions by more than firms that do not have an SBTi target. An SBTi-verified target is a target which is aligned with the Paris Agreement goals. Figure 9 shows the reduction in emission intensity over the last year (left panel) and over the last three years (right panel) for firms that disclosed a target in 2019. We construct two groups: firms with an SBTi verified target and firms with a self-disclosed emission reduction target only. We find that most firms that self-disclosed a target in 2019 reduced their emission intensity over the previous year, independent of whether the target was SBTi verified or not. We find broadly similar patterns between these two groups also in the distribution of observed changes in emission intensity over the three years preceding 2019. It is possible to observe however that the median firm with an SBTI target reported over this period slightly stronger reductions compared to the self disclosed group.

Finally, we ask whether firms that disclose an emission reduction target and have their non-financial statements audited reduce emissions by more than firms that disclose a target but have no audit. The audit of non-financial statements is a proxy of the assurance of the rigorousness of the emission reduction target (see section 2. Figure 10 shows the

Figure 9: Change in Scope 1 and 2 GHG emission intensity for firms disclosing a target, grouped by availability of an SBTi aligned target

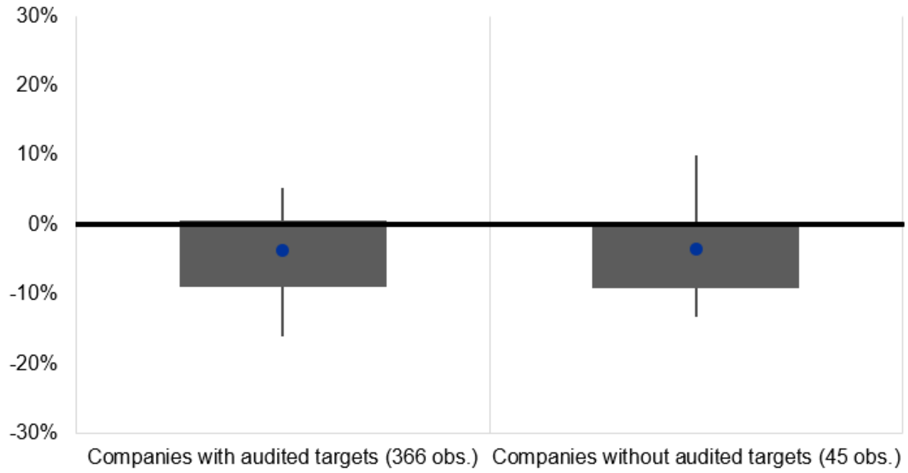
Notes: Left panel: Year-on-year change in GHG emission intensity in 2019 relative to 2018 (Percentage of reduction in Scope 1 and 2 GHG emission intensity in the range (+40%;-40%); Bucket of firms out of 859 NFCs). Right panel: 3-year change in GHG emission intensity in 2019 relative to 2016 (Percentage of reduction in Scope 1 and 2 GHG emission intensity in the range (+40%;-40%); Bucket of firms out of 859 NFCs). In both panels: the blue dot is the median, the shaded area is the interquartile range, bars are the 10th and 90th percentile. Sources: Refinitiv and authors' calculations.



boxplot of observed year-on-year changes in emission intensity of a subsample of listed non-financial firms that reported a target in 2019 and had or did not have their non-financial statements audited in 2019. There is no significant difference observed between the two groups in terms of emission intensity reduction, albeit the external validity of the result is limited by the fact that the vast majority of firms that reported a target in 2019 had their non-financial statements audited (331 firms) by comparison with a minority of firms without audited non-financial statements (41 firms).

Figure 10: Change in Scope 1 and 2 GHG emission intensity for firms disclosing a target, grouped by audit status of non-financial statements

Notes: Percentage of reduction in Scope 1 and 2 GHG emission intensity in the range (+30%;-30%); Bucket of firms out of 859 NFCs. In both panels: the blue dot is the median, the shaded area is the interquartile range, bars are the 10th and 90th percentile. Sources: Refinitiv and authors' calculations.



7 Conclusion and policy implications

This paper examines how climate-related transition risk is reflected in firm credit risk, as measured by market-implied distance-to-default and credit rating. Our results show that financial markets and credit rating agencies consider quantitative metrics of transition risk to some extent when assessing the ability of a company to repay and service its debt. First, higher GHG-emissions and emission intensities are associated with higher credit risk under both of our metrics. Second, governments' climate policies and expectations around such policies affect the transition risk of firms, and therefore their credit risk. We find that after the Paris agreement, firms most exposed to climate transition risk saw their ratings deteriorate by more than other firms with similar characteristics, with the effect larger for European firms than their US peers, probably reflecting differential (expectations around) climate policies both after the Paris agreement and across countries. Third, the practice of disclosing emissions is associated with better credit ratings and, to some extent, with a lower market-implied distance-to-default. Finally, committing to an emission reduction target is associated with lower credit risk estimates, with the effects tending to be stronger for more ambitious targets. Overall, our results suggest that firms that are better prepared for the low-carbon transition have lower credit risk. At the same time, it is important to emphasise that the true extent of climate-related credit risks could still be materially under-estimated by rating agencies and market participants, and to acknowledge that there are naturally some limitations related to the reliability and comparability of climate-related transition risk metrics.

Our results have several important policy implications. First, the fact that credit risk estimates reflect disclosed transition risk metrics to some extent highlights how an improvement in the coverage, quality and comparability of disclosure of GHG emissions and emission reduction strategies would facilitate better assessment and pricing of firm-level climate risk. The disclosure and monitoring of forward-looking metrics seem particularly important in this regard, since these reflect a firm's strategy to reduce transition risk. Better and more harmonised information would allow financial institutions and investors to improve their assessment of the transition-related credit risk of their portfolios and reduce the likelihood that financial markets misprice carbon transition risk (see for example Schnabel (2020a,b, 2021); Panetta (2021); Hauser (2021); Thomä and Chenet (2017)). It would also make it easier for authorities to gauge overall risks in the financial sector (De Guindos, 2021). The climate change-related disclosure standards under the European Union's Corporate Sustainability Reporting Directive will be used by companies for the first time in 2024 for the financial year 2023. Our results call for ambition in such standards, especially around forward-looking targets and strategies. They also provide support for wider efforts to introduce mandatory and standardized reporting and disclosure standards with an audit requirement across further jurisdictions, and where possible at the global level.

Second, our results have potential implications for the way that central banks approach climate-related transition risk in their monetary and non-monetary policy operations. In particular, they highlight how climate change and the carbon transition will affect the value and the risk profile of the assets held on central bank balance sheets. Partly with these considerations in mind, several central banks have started to take action. For example, the ECB has recently decided to introduce disclosure requirements for private sector assets as a new eligibility criterion or as a basis for a differentiated treatment for collateral and asset purchases [15]. This type of measure can both promote more consistent disclosure practices in the market and allow the valuation and risk control frameworks

[15] See the ECB action plan to include climate change considerations in its monetary policy strategy (ECB, 2021a)

used by central banks to better reflect firm-level transition risk. The ECB also plans to adjust the framework guiding the allocation of corporate bond purchases to incorporate climate change criteria, in line with its mandate, including a focus on the alignment of issuers with the goals of the Paris agreement. And the Bank of England has set out details of how it will green its corporate bond purchase scheme, placing particular emphasis on realised reductions in emissions, disclosure practices and emissions reduction targets when assessing the climate performance of firms [16]. Our findings are supportive of such approaches. In particular, they highlight the importance of central banks focussing on firms' disclosures and forward-looking targets and strategies, alongside how well they are doing in actually cutting their emissions, when considering their monetary and non-monetary policy portfolios.

Third, our findings are relevant for the regulatory framework for banks and insurance companies. In particular, they highlight the importance of assessing whether the climate-related transition risk faced by firms is adequately and consistently reflected in prudential and supervisory standards. Under capital adequacy regulations, the risk-weighted level of capital related to credit risk is determined based on risk weights. Institutions may determine these weights either based on external ratings provided by credit rating agencies in the Standardised Approach or internal ratings in the Internal Ratings-Based Approach. Our results suggest that credit rating agencies do reflect – to some extent – transition risk considerations in their ratings. At the same time, it remains important for regulators to consider whether risk weights based on credit ratings sufficiently reflect transition risk, and this needs to be supported by the adoption of systematic, consistent and transparent disclosure practices and enhanced methodologies by credit rating agencies. The extent to which risk weights based on internal models reflect climate-related transition risk is less clear (see for example ECB (2021b)). Overall, our results highlight the importance of regulators and supervisors assessing whether climate-related transition risk is appropriately reflected in risk weights, irrespective of how they are calculated, and in the wider regulatory framework.

Future work could consider how credit ratings and market-based gauges of credit risk reflect the mobilization efforts of the firm to transition to a low carbon economy. For

[16] See https://www.bankofengland.co.uk/markets/greening-the-corporate-bond-purchase-scheme

example, metrics related to green investment and innovation efforts, such as R&D investment and green patents could be considered, though these present significant data challenges. In addition, further research assessing the credibility of different emission targets and their alignment with country-level Nationally Determined Contributions (NDC) targets would deepen understanding of how well firms' plans are aligned with the Paris climate change goals. Finally, future research on financing constraints of firms would enhance understanding of how to help close the investment gap related to the low-carbon transition (see for instance Maurin, Barci, Davradakis, Gereben, Tueske, and Wolski (2021) and Kacperczyk and Peydró (2021)).

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Appendix A

Table 19: Data description

Variable name	Description	Source
	Firm credit risk related variables	
Credit rating	Long-term ratings issued by S&P and Moody's	ECB Ratings DB
DtD	Market-implied distance-to-default	Constructed
	Firm-level controls (yearly)	
Profitability	Return on equity	Refinitiv
Size	Total assets	Refinitiv
Leverage	Ratio of total debt (short-term and long-term debt) and EBITDA	Refinitiv
Debt service	Ratio of EBIT and interest expenses	Refinitiv
Solvency	Ratio of property, plant, and equipment (PPE) and Total assets	Refinitiv
Governance	Score of the quality of governance of the firm	Refinitiv
Sector	Sector of economic activity (NACE1) of the firm. NACE1-sector Manufacturing (C) is devided into two subclasses: firms in manufacturing of coke and refined petroleum products (C19) and other manufacturing firms.	Orbis
Country	Country of the firm constructed based on country of registration and, where not available, country of incorporation	Constructed
Country of registration	Country where the firm is registered and is primarily conducting business. May be different from the country of incorporation.	Orbis
Country of incorporation	Country of incorporation of the firm. A firm may be incorporated only in one country and registered in other country(s) where conducting business.	Datastream
Year	Fiscal year of the firm's financial and non-financial statements	Refinitiv
	Macroeconomic controls (monthly)	
Market return	MoM local currency market return of S&P 500 for US firms and of STOXX600 for EA firms	Refinitiv
Oil	MoM local currency return of oil spot, WTI for US firms, Brent for EA firms	Refinitiv
Inflation	YoY change, PCE deflator for the US firms, core HCPI for EA firms	Refinitiv

Continuation of Table 19		
Variable name	**Description**	**Source**
Industrial production	YoY change, US industrial production for US firms, EA industrial production for EA firms	Refinitiv
Gold	MoM return of gold in terms of USD	Refinitiv
Bills	End of month Bill rates, T-Bills for US firms, Bubills for EA firms	Refinitiv
Volatility	End of month implied market volatility, VIX for US firms, VSTOXX for EA firms	Refinitiv

Table 20: Pooled correlations

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Rating S&P	1.000															
2. Rating Moody's	0.868	1.000														
3. Size	0.335	0.373	1.000													
4. Governance	0.168	0.189	0.128	1.000												
5. Solvency	-0.017	-0.030	0.056	0.099	1.000											
6. Leverage	-0.255	-0.263	0.143	-0.004	0.108	1.000										
7. Profitability	0.140	0.157	-0.053	0.038	-0.079	-0.229	1.000									
8. Debt service	0.200	0.199	-0.006	-0.019	-0.066	-0.229	0.124	1.000								
9. Scope 1 GHG intensity	-0.024	-0.053	0.037	0.102	0.433	0.188	-0.121	-0.077	1.000							
10. Scope 2 GHG intensity	-0.040	-0.047	-0.038	0.077	0.259	0.066	-0.068	-0.047	0.241	1.000						
11. Scope 3 GHG intensity	-0.114	-0.109	-0.051	-0.043	0.056	0.026	-0.037	-0.040	0.020	0.063	1.000					
12. Scope 1 GHG level	0.063	0.091	0.303	0.102	0.282	0.100	-0.107	-0.046	0.474	0.168	0.010	1.000				
13. Scope 2 GHG level	0.107	0.130	0.279	0.070	0.130	0.008	-0.043	-0.014	0.098	0.241	0.030	0.338	1.000			
14. Scope 3 GHG level	0.156	0.207	0.403	0.108	0.137	-0.005	-0.067	-0.007	0.046	0.043	0.043	0.467	0.392	1.000		
15. DiscloseGHG dummy	0.189	0.221	0.163	0.232	0.038	0.027	0.029	0.005	0.062	0.031	-0.066	0.113	-0.022	0.068	1.000	
16. DiscloseCommit dummy	0.228	0.240	0.185	0.265	0.055	0.007	0.041	-0.007	0.074	0.049	-0.039	0.109	0.092	0.067	0.475	1.000

Appendix B (intended for Internet Appendix only)

Following Merton we solve the following system of equations (9) and (10) to obtain distance-to-default measures, with firm equity (E), assets (A), time to expiry (T) of the debt (e.g. next debt repayment date), the nominal amount of the debt (D), the risk-free rate (r), with N denoting the cumulative normal distribution:

$$E = A \cdot N(d_1) D \cdot e^{rT} \cdot N(d_2) \tag{9}$$

$$\sigma_E = \frac{A}{E} \cdot N(d_1) \cdot \sigma_A. \tag{10}$$

where d1 and d2 are given by:

$$d_1 = \frac{log\left(\frac{A}{D}\right) + \left(r + \frac{1}{2}\sigma_A^2\right) \cdot T}{\sigma_A \cdot \sqrt{T}} \tag{11}$$

$$d_2 = d_1 - \sigma_A \cdot \sqrt{T} \tag{12}$$

The solution to equations (9) and (10) provides estimates for the unknown variables $\{A, \sigma_A\}$, which are then used to compute the distance-to-default (DtD) as:

$$DtD = \frac{1}{\sigma_A \cdot \sqrt{T}} \cdot \left(log(A) + \left(r - \frac{1}{2}\sigma_A^2\right) - log(D)\right) \tag{13}$$

giving rise to the expression that computes the probability of default (PD):

$$PD = 1 - N(DtD). \tag{14}$$

Finally, it is worth recalling that the market based credit risk measures, by virtue of relying on market prices, will be influenced by the general risk perception of the agents that trade in the markets. In other words, risk premia will influence the market-implied default probabilities. Conversely, ratings issued by rating agencies are presumably expressed as through-the-cycle gauges for credit risk, and should as such not be as affected by the current state of financial markets. To the extent that risk premia vary considerably over time, differences in conclusions may materialise as a consequence of this difference.

Appendix C (intended for Internet Appendix only)

Table 21: Panel regression for credit ratings and emissions, Testing H3 for the sub-sample excluding high emitters

Notes: The table shows the result of the panel regression relevant for H3, see Equation 5, where the relationship between quantitative backward and qualitative forward-looking metrics (commitment to reduce emissions) and credit ratings is tested for the data sample excluding high emitters, covering the period from 2010 to 2019. High emitters are defined as the firms belonging to the top tercile of the distribution of Scope 1 and 2 emissions. Model 1 shows the OLS results considering GHG emissions intensity, while model 2 shows the corresponding ordered logit results. Model 3 shows the OLS results considering GHG emissions level, while model 4 shows the ordered logit results. Firm-level clustered standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Variable	**(1 - int., OLS)**	**(2 - int., logit)**	**(3 - levels, OLS)**	**(4 - levels, logit)**
DiscloseGHG dummy	0.27***	0.87***	0.21***	0.66***
	(0.095)	(0.30)	(0.066)	(0.21)
DiscloseGHG x Scope 1 GHG intensity	-443**	-1,298**		
	(203)	(642)		
DiscloseGHG x Scope 2 GHG intensity	25.0	-108		
	(998)	(3,138)		
DiscloseGHG x Scope 3 GHG intensity	-108	-318		
	(66.8)	(208)		
Disclosed intensity change	-0.014	-0.048		
	(0.012)	(0.034)		
DiscloseCommit dummy	0.19***	0.63***	0.19***	0.62***
	(0.061)	(0.19)	(0.062)	(0.19)
DiscloseGHG x Scope 1 GHG level			-0.0099	-0.031
			(0.0089)	(0.027)
DiscloseGHG x Scope 2 GHG level			-0.0037	0.021
			(0.030)	(0.10)
DiscloseGHG x Scope 3 GHG level			-0.0034***	-0.0098***
			(0.00098)	(0.0031)
Disclosed level change			-0.031***	-0.096***
			(0.011)	(0.032)
Constant	3.82***		3.86***	
	(0.13)		(0.11)	
Firm-level controls	Y	Y	Y	Y
Time fixed-effects	Y	Y	Y	Y
Sectoral fixed-effects	Y	Y	Y	Y
Country fixed-effects	Y	Y	Y	Y
Observations	2,885	2,885	2,872	2,872
R-squared	0.384	0.1781	0.381	0.1774

Table 22: Panel regression for credit ratings and emissions, Testing H3 for the full-sample employing firm-level fixed-effects

Notes: The table shows the result of the panel regression relevant for H3, see Equation 5, where the relationship between quantitative backward and qualitative forward-looking metrics (commitment to reduce emissions) and credit ratings is tested for the data sample covering the period from 2010 to 2019. Firm-level fixed-effects are employed in place of sector, country and year. Model 1 shows the OLS results considering GHG emissions intensity, while model 2 shows the corresponding result for GHG emissions level. Firm-level clustered standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Variable	**(1 - int., OLS)**	**(2 - levels., OLS)**
DiscloseGHG dummy	0.027	0.022
	(0.025)	(0.023)
DiscloseGHG x Scope 1 GHG intensity	-11.2	
	(24.3)	
DiscloseGHG x Scope 2 GHG intensity	-136	
	(231)	
DiscloseGHG x Scope 3 GHG intensity	-0.56	
	(0.90)	
Disclosed intensity change	-0.019*	
	(0.011)	
DiscloseCommit dummy	0.014	0.0022
	(0.026)	(0.027)
DiscloseGHG x Scope 1 GHG level		0.0038
		(0.0027)
DiscloseGHG x Scope 2 GHG level		0.00022
		(0.0088)
DiscloseGHG x Scope 3 GHG level		-0.00043***
		(0.00017)
Disclosed level change		-0.00051
		(0.00055)
Constant	4.07***	4.07***
	(0.092)	(0.088)
Firm-level controls	Y	Y
Firm fixed-effects	Y	Y
Observations	3,970	3,945
R-squared	0.882	0.882

Table 23: Panel regression for Distance-to-Default (DtD) and emissions, Testing H3 for the sub-sample excluding high emitters

Notes: The table shows the result of the panel regression relevant for H3, see Equation 5, where the relationship between quantitative backward and qualitative forward-looking metrics (commitment to reduce emissions) and distance-to-default (DtD) is tested for the data sample excluding high emitters, covering the period from 2010 to 2019. High emitters are defined as the firms belonging to the top tercile of the distribution of Scope 1 and 2 emissions. Model 1 shows the OLS results considering GHG emissions intensity, while model 3 shows the OLS results considering GHG emissions level. Firm-level clustered standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Variable	**(1 - int., OLS)**	**(2 - levels)**
DiscloseGHG dummy	0.28**	0.16
	(0.12)	(0.12)
DiscloseGHG x Scope 1 GHG intensity	-555***	
	(162)	
DiscloseGHG x Scope 2 GHG intensity	159	
	(1,160)	
DiscloseGHG x Scope 3 GHG intensity	-196	
	(189)	
Disclosed intensity change	696***	
	(264)	
DiscloseCommit dummy	0.50***	0.46***
	(0.10)	(0.099)
DiscloseGHG x Scope 1 GHG level		-0.040*
		(0.021)
DiscloseGHG x Scope 2 GHG level		-0.015
		(0.17)
DiscloseGHG x Scope 3 GHG level		0.020
		(0.033)
Disclosed level change		0.094
		(0.076)
Constant	5.69***	5.79***
	(0.18)	(0.19)
Controls	Y	Y
Sectoral fixed-effects	Y	Y
Country fixed-effects	Y	Y
Observations	13,001	12,602
R-squared	0.326	0.322

Table 24: Panel regression for Distance-to-Default (DtD) and emissions, Testing H3 for the full-sample employing firm-level fixed-effects

Notes: The table shows the result of the panel regression relevant for H3, see Equation 5, where the relationship between quantitative backward and qualitative forward-looking metrics (commitment to reduce emissions) and distance-to-default (DtD) is tested for the data sample covering the period from 2010 to 2019. Firm-level fixed-effects are employed in place of sector and country. Model 1 shows the OLS results considering GHG emissions intensity, while model 2 shows the corresponding result for GHG emissions level. Firm-level clustered standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Variable	**(1 - int.)**	**(2 - levels)**
DiscloseGHG dummy	0.019	-0.0031
	(0.055)	(0.050)
DiscloseGHG x Scope 1 GHG intensity	-43.5	
	(96.0)	
DiscloseGHG x Scope 2 GHG intensity	93.5	
	(485)	
DiscloseGHG x Scope 3 GHG intensity	-3.78	
	(16.5)	
Disclosed intensity change	-58.6	
	(310)	
DiscloseCommit dummy	0.16**	0.16**
	(0.075)	(0.076)
DiscloseGHG x Scope 1 GHG level		-0.0023
		(0.0063)
DiscloseGHG x Scope 2 GHG level		0.037
		(0.028)
DiscloseGHG x Scope 3 GHG level		-7.7e-06
		(0.00045)
Disclosed level change		0.025
		(0.022)
Constant	6.29***	6.29***
	(0.21)	(0.21)
Controls	Y	Y
Firm fixed-effects	Y	Y
Observations	18,573	18,573
R-squared	0.565	0.565

Table 25: Panel regression for credit ratings and emissions for European firms and for US firms

Notes: The table shows the result of the panel regression relevant for H1, see (3), where the relationship between GHG emissions and credit ratings is tested for the subsample of European firms and the subsample of US firms. Model 1 tests the relationship between GHG emissions intensity and credit rating for European firms; Model 2 tests the relationship between GHG emissions level and credit rating for European firms. Model 3 and model 4 test for US firms the relationship between GHG emissions intensity and credit rating and between GHG emissions level and credit rating, respectively. The period of the subsamples is from 2010 to 2019. We report ordered logit estimators. Firm-level clustered standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Variable	**(1)**	**(2)**	**(3)**	**(4)**
Scope 1 GHG intensity	-396***		-7.35	
	(140)		(118)	
Scope 2 GHG intensity	-1,956		380	
	(1,643)		(1,009)	
Scope 3 GHG intensity	-14.7***		0.91	
	(3.72)		(3.50)	
Scope 1 GHG level		-0.015***		-0.00079
		(0.0049)		(0.0088)
Scope 2 GHG level		-0.018*		0.018
		(0.010)		(0.018)
Scope 3 GHG level		0.00035		0.00090
		(0.0012)		(0.00079)
EU ETS Carbon Price	-0.075***	-0.053***		
	(0.020)	(0.020)		
Controls	Y	Y	Y	Y
Time fixed-effects	Y	Y	Y	Y
Sectoral fixed-effects	Y	Y	Y	Y
Country fixed-effects	Y	Y	Y	Y
Observations	1,818	1,817	2,563	2,556
R-squared	0.2334	0.2314	0.1739	0.1737

Table 26: Panel regression for Distance-to-Default (DtD) and emissions, Testing H1 for the sub-samples 2010-2015 and 2016-2019

Notes: The table shows the result of the panel regression relevant for H1, see Equation (3), where the relationship between emissions and distance-to-default (DtD) is tested for the sub-sample before the Paris agreement (i.e. 2010-2015) and thereafter (i.e. 2016-2019) using a monthly observation frequency. DtD falls when credit risk increases, so a negative estimate for the emission-coefficients implies the acceptance of H1. Models 1 and 3 show the OLS results considering GHG emission intensity, while models 3 and 4 shows the OLS results considering GHG emission level. Firm-level clustered standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Variable	**(1 - int.)** (2010-2015)	**(2 - levels)** (2010-2015)	**(3 - int.)** (2016-2019)	**(4 - levels)** (2016-2019)
Scope 1 GHG intensity	-573**		-310**	
	(226)		(123)	
Scope 2 GHG intensity	65.2		-121	
	(151)		(677)	
Scope 3 GHG intensity	-102***		-59.9**	
	(24.4)		(28.2)	
Scope 1 GHG level		-0.00094		-0.0097
		(0.0081)		(0.0070)
Scope 2 GHG level		-0.013		-0.00072
		(0.018)		(0.047)
Scope 3 GHG level		0.0011		0.00036
		(0.00076)		(0.0010)
Profitability	0.0040**	0.0041**	0.0076***	0.0077***
	(0.0019)	(0.0020)	(0.0025)	(0.0026)
Size	2.3e-09***	1.9e-09***	1.3e-09**	1.2e-09**
	(6.1e-10)	(6.8e-10)	(5.2e-10)	(6.0e-10)
Leverage	-0.025	-0.011	-0.066	-0.058
	(0.065)	(0.068)	(0.042)	(0.043)
Solvency	-0.14	-0.32	-0.30	-0.45
	(0.28)	(0.30)	(0.29)	(0.28)
Debt servicing capacity	0.0018***	0.0018***	0.00043	0.00048
	(0.00054)	(0.00058)	(0.00056)	(0.00057)
Governance	0.0031	0.0025	0.0052**	0.0049**
	(0.0022)	(0.0023)	(0.0023)	(0.0024)
Market	-0.039***	-0.040***	-0.036***	-0.035***
	(0.0023)	(0.0023)	(0.0039)	(0.0040)
Oil	-0.0011	-0.0014	0.0033***	0.0033***
	(0.00100)	(0.00100)	(0.00051)	(0.00052)
Inflation	-0.18***	-0.21***	0.12***	0.11***
	(0.038)	(0.037)	(0.026)	(0.025)
Industrial Production	-0.12***	-0.11***	0.044***	0.045***
	(0.011)	(0.011)	(0.0027)	(0.0027)
Gold	-0.0100***	-0.0094***	-0.018***	-0.018***
	(0.0012)	(0.0012)	(0.0018)	(0.0018)
Bills	0.65***	0.59***	-1.57***	-1.59***
	(0.079)	(0.079)	(0.15)	(0.16)
Constant	6.61***	6.48***	4.18***	4.13***
	(0.17)	(0.17)	(0.22)	(0.23)
Controls	Y	Y	Y	Y
Sectoral fixed-effects	Y	Y	Y	Y
Country fixed-effects	Y	Y	Y	Y
Observations	9,624	9,624	11,205	11,205
R-squared	0.354	0.344	0.414	0.407

Table 27: Panel regression for Distance-to-Default (DtD) and emission targets, testing H3 for the sub-samples 2010-2015 and 2016-2019

Notes: The table shows the result of the panel regression relevant for H3, see (5), where the relationship between emission-disclosure targets and distance-to-default (DtD) is tested for the sub-sample before the Paris agreement (i.e. 2010-2015) and thereafter (i.e. 2016-2019) using a monthly observation frequency. DtD falls when credit risk increases, so if a firm communicates a future emission target, and this event is interpreted by financial markets as a credit-positive event, a positive parameter estimate would be obtained. Model 1 shows the OLS results considering GHG emission intensity, while model 2 shows the OLS results considering GHG emission level. Firm-level clustered standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Variable	**(1 - int.)** (2010-2015)	**(2 - levels)** (2010-2015)	**(3 - int.)** (2016-2019)	**(4 - levels)** (2016-2019)
DiscloseGHG dummy	0.48***	0.31***	0.16*	0.10
	(0.13)	(0.099)	(0.097)	(0.091)
DiscloseGHG x Scope 1 GHG intensity	-524		-313**	
	(435)		(124)	
DiscloseGHG x Scope 2 GHG intensity	-823		-241	
	(1,413)		(697)	
DiscloseGHG x Scope 3 GHG intensity	-74.0		-40.5	
	(53.2)		(28.6)	
Disclosed intensity change	864		96.4	
	(7,890)		(276)	
DiscloseCommit dummy	0.49***	0.50***	0.34***	0.34***
	(0.11)	(0.11)	(0.099)	(0.099)
DiscloseGHG x Scope 1 GHG level		-0.040**		-0.014
		(0.015)		(0.012)
DiscloseGHG x Scope 2 GHG level		0.098		0.0019
		(0.080)		(0.058)
DiscloseGHG x Scope 3 GHG level		0.0012		0.00084
		(0.00085)		(0.0012)
Disclosed level change		0.55		0.031
		(1.82)		(0.027)
Governance	0.00048	0.00019	0.0030	0.0029
	(0.0024)	(0.0024)	(0.0024)	(0.0024)
Constant	5.95***	5.97***	4.02***	4.02***
	(0.21)	(0.21)	(0.22)	(0.23)
Controls	Y	Y	Y	Y
Sectoral fixed-effects	Y	Y	Y	Y
Country fixed-effects	Y	Y	Y	Y
Observations	7,499	7,499	10,991	10,991
R-squared	0.290	0.291	0.422	0.417

EUROPEAN CENTRAL BANK

EUROSYSTEM

The low-carbon transition, climate disclosure and firm credit risk

International Conference on "Statistics for Sustainable Finance"
September 14-15, 2021

Carbone, Giuzio, Kapadia, Krämer, Nyholm, Vozian

The transition to the low-carbon economy requires firms to significantly reduce their emissions

Issue:

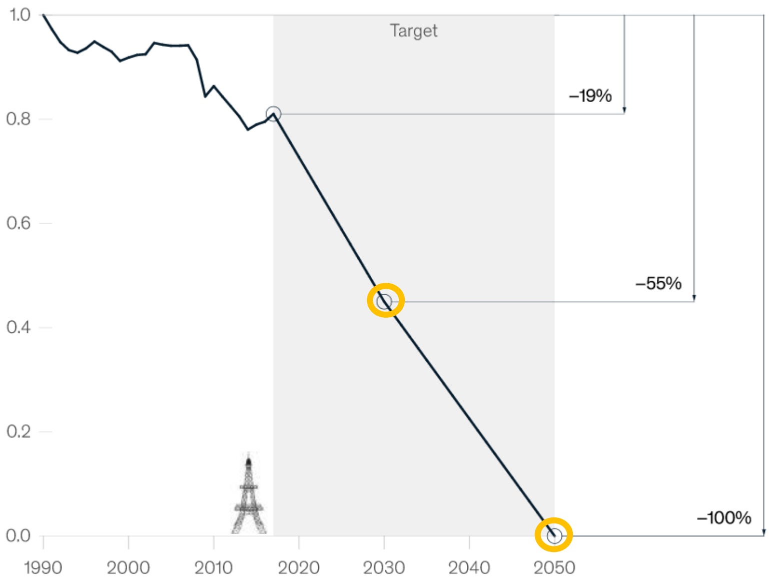
- **Climate-related transition risk** arises from uncertainties surrounding the timing and speed of transition to a low-carbon economy. This risk can affect firm's **credit risk.**

Motivation:

- Understanding **whether and how** transition risk is reflected in measures of credit risk is important for firms, banks, investors, and regulators**.**

EU GHG emissions reduction path

Percentage of CO2/e tonnes observed in 1990



Source: EEA, Eurostat, McKinsey analysis

Research question and Hypotheses

How is climate-related transition risk reflected in firm credit risk estimates?

H1: There is a positive relationship between a **firm's exposure to transition risk**, as proxied by GHG emissions, and its credit risk, as proxied by Credit Ratings and Distance-to Default.

H2: The interaction between firms' GHG emissions and its decision to **disclose** GHG emissions has a significant impact on credit risk estimates.

H3: There is a negative relationship between **firm's management of transition risk**, as proxied by disclosed GHG emission reduction targets and actual GHG emission reduction, and credit risk estimates.

A novel dataset

- Firms: non-financial firms of S&P 500 and of STOXX Europe 600
- Period: 2010 - 2019
- Geography: USA and Europe
- Sources: Refinitiv, Urgentem, Bloomberg, SBTi, ECB Ratings Database, ICE, Eurostat

Credit Risk Estimate	=	Exposure to Transition Risk	+	Management of Transition Risk	+	Controls	
Credit Rating $Rating_{i,t+3m}$ Distance-to-Default $DtD_{i,t}$		Firm-level GHG emissions variables (yearly)		Firm-level GHG emission reduction variables (yearly)		Firm reference and financial variables (yearly)	Macro variables (monthly)

*The higher the *Rating* (or *DtD*), the lower the Credit Risk associated with the firm

H1: Regression Credit Rating and Emissions

$$Rating_{i,t+3m} = \alpha + \beta_1 Scope\ 1_{\ i,t} + \beta_2 Scope\ 2_{i,t} + \beta_3 Scope\ 3_{i,t} + \sum_{j=1}^{6} \gamma_j FinancialControls_{j,i,t} + \rho\ SectorFE_i + \tau TimeFE_t + \sigma Country\ FE_i + \epsilon_{i,t}$$

Variable	**(1 - int., OLS)**	**(2 - int., logit)**	**(3 - levels, OLS)**	**(4 - levels, logit)**
Scope 1 GHG intensity	-66.6**	-194**		
	(29.4)	(93.0)		
Scope 2 GHG intensity	259	900		
	(283)	(918)		
Scope 3 GHG intensity	-2.01**	-6.26**		
	(0.86)	(2.71)		
Scope 1 GHG level			-0.0037***	-0.012***
			(0.0012)	(0.0038)
Scope 2 GHG level			0.0017	0.0058
			(0.0023)	(0.0073)
Scope 3 GHG level			-0.000093	-0.00024
			(0.00016)	(0.00050)
Controls	Y	Y	Y	Y
Time fixed-effects	Y	Y	Y	Y
Sectoral fixed-effects	Y	Y	Y	Y
Country fixed-effects	Y	Y	Y	Y
Observations	4,201	4,201	4,194	4,194
R-squared	0.343	0.1697	0.343	0.1698

H1: Regression DtD and Emissions

$$logDtD_{i,t} = \alpha + \beta_1 Scope\ 1\ and\ 2_{i,t} + \beta_2 Scope\ 3_{i,t} + \sum_{j=1}^{N} \gamma_j Controls_{j,i,t} + \rho\ SectorFE_i + \tau TimeFE_t + \sigma Country\ FE_i + \delta RatingFE_i + \epsilon_{i,t}$$

- Lower **Scope 1 and 2 intensities** are generally associated to lower credit risk estimate

- Also **Scope 3 intensities** lead to lower credit risk estimate

	2010-2019	
Scope 1 and 2 GHG intensities	-0.0233	***
	(0.0020)	
Scope 3 GHG intensity	-0.0250	***
	(0.0019)	
Time fixed-effects	Y	
Sectoral fixed-effects	Y	
Country fixed-effects	Y	
Observations	40037	
R-squared	0.4629	

H1: TripleDiD Ratings & High-polluters Europe vs US

$$
\begin{aligned}
CreditRating_{i,t} = & \alpha + \beta_0 Treatment_i \times TransitionPolicy_i \times postParis_t + \\
& \beta_1 Treatment_i \times postParis_t + \\
& \beta_2 TransitionPolicy_i \times postParis_t + \\
& \Sigma_{j=1}^{N} \gamma_j Controls_{j,i,t} + \rho FirmFE_i + \tau TimeFE_t + \epsilon_{i,t}
\end{aligned}
$$

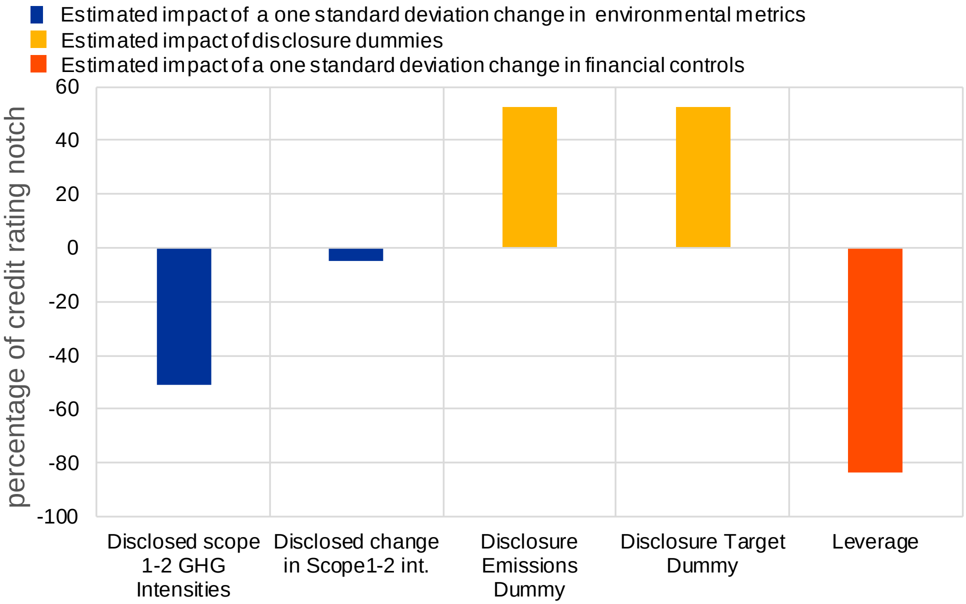
Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Top GHG NACE x Transition-policy x post-Paris	-1.06***			-0.91***		
	(0.23)			(0.21)		
Top GHG intensity x Transition-policy x post-Paris		-0.55**			-0.53**	
		(0.25)			(0.22)	
Top GHG level x Transition-policy x post-Paris			-0.57**			-0.49**
			(0.24)			(0.20)
Top GHG NACE x post-Paris	0.51***			0.39***		
	(0.16)			(0.14)		
Top GHG intensity x post-Paris		0.38**			0.28**	
		(0.16)			(0.14)	
Top GHG level x post-Paris			0.25			0.11
			(0.17)			(0.14)
Firm-level controls	N	N	N	Y	Y	Y
Time fixed-effects	N	N	N	Y	Y	Y
Firm fixed-effects	N	N	N	Y	Y	Y
Observations	3,807	3,807	3,807	3,643	3,643	3,643
Number of firms	423	423	423	422	422	422
R-squared	0.026	0.010	0.008	0.094	0.081	0.081

European firms

US firms

H2 & H3: Credit Rating and Climate Disclosure

$$Rating_{i,t+3m} = \alpha + \beta_1 DiscloseGHG\_d_{i,t} + \beta_2 DiscloseGHG\_d_{i,t} * Scope\ 1\ and\ 2_{i,t} + \beta_3 DiscloseGHG\_d_{i,t} * Scope\ 3_{i,t} + \beta_4 YoY\ Scope\ 1\ and\ 2_{i,t} + \beta_5 Target_{i,t} + \sum_{j=1}^{6} \gamma_j Controls_{j,i,t} + \rho\ SectorFE_i + \tau TimeFE_t + \sigma Country\ FE_i + \epsilon_{i,t}$$



- Firms with **lower disclosed GHG intensity** and **actual GHG reduction** tend to have better ratings.
- Firms **disclosing emissions** and a **forward-looking target** to reduce emissions tend to have better ratings.
- The **magnitude** of the effect of disclosed GHG intensity is comparable to that of traditional determinants of rating
- **Endogeneity**: results remain robust under alternative specifications.

H2 & H3: DtD and Climate Disclosure

$$logDtD_{i,t} = \alpha + \beta_1 DiscloseGHG\_d_{i,t} + \beta_2 DiscloseGHG\_d_{i,t} * Scope\ 1\ and\ 2_{i,t} + \beta_3 DiscloseGHG\_d_{i,t} * Scope\ 3_{i,t} + \beta_4 YoY\ Scope\ 1\ and\ 2_{i,t} + \beta_5 Target_{i,t} + \sum_{j=1}^{6} \gamma_j Controls_{j,i,t} + \rho\ SectorFE_i + \tau TimeFE_t + \sigma Country\ FE_i + \epsilon_{i,t}$$

	2010-2019	
Fwd-looking commitment	0.0176	***
	(0.0051)	
Disclosure	-0.0100	
	(0.0265)	
Disclosed Scope 1 and 2 GHG intensities	0.0065	***
	(0.0026)	
Disclosed Scope 3 GHG intensity	0.0039	
	(0.0033)	
Change in disclosed Scope 1 and 2 GHG intensities	0.0026	
	(0.0035)	
Time fixed-effects	Y	
Sectoral fixed-effects	Y	
Country fixed-effects	Y	
Observations	40795	
R-squared	0.4648	

H3: Rating, DtD and Quantitative Targets

Credit Rating
$Rating_{i,t+3m}$

Variable	(1 - int., OLS)	(2 - int., OLS)	(3 - levels, OLS)	(4 - levels, OLS)
Scope 1 GHG intensity	-66.0 (42.0)	-49.6 (88.4)		
Scope 2 GHG intensity	66.7 (271)	-21.5 (516)		
Scope 3 GHG intensity	5.58 (12.2)	27.6* (16.1)		
Disclosed intensity change	0.023 (0.036)	-0.014*** (0.0049)		
Scope 1 GHG level			-0.0033** (0.0017)	-0.0044 (0.0039)
Scope 2 GHG level			0.0076 (0.0086)	0.018 (0.023)
Scope 3 GHG level			0.00045 (0.00039)	0.00045 (0.00031)
Disclosed level change			0.0013** (0.00049)	0.0014*** (0.00053)
TargetPerc Ref	0.0036** (0.0015)		0.0036** (0.0015)	
TargetYear Ref	-0.0024 (0.0066)		-0.0025 (0.0064)	
TargetPerc CDP		0.0032** (0.0014)		0.0031** (0.0015)
TargetYear CDP		0.0027 (0.0042)		0.0031 (0.0041)
TargetBaseYear CDP		-0.014* (0.0083)		-0.013 (0.0084)
Constant	4.80*** (0.21)	11.2 (19.7)	4.80*** (0.21)	6.72 (21.2)
Firm-level controls	Y	Y	Y	Y
Time fixed-effects	Y	Y	Y	Y
Sectoral fixed-effects	Y	Y	Y	Y
Country fixed-effects	Y	Y	Y	Y
Observations	815	1,116	808	1,111
R-squared	0.335	0.395	0.333	0.394

Distance-to-Default
$DtD_{i,t}$

	2010-2019	
Emission target percentage	0.1397 (0.0205)	***
Emission target arrival, in years	-0.0033 (0.0008)	***
Time fixed-effects	Y	
Sectoral fixed-effects	Y	
Country fixed-effects	Y	
Observations	8900	
R-squared	0.3884	

Conclusion

How is climate-related transition risk reflected in firm credit risk?

Caveats: Availability, reliability, and comparability of disclosed and inferred metrics of transition risk.

- ✓ High emissions are already associated to some extent with higher credit risk, both ratings and DtD.
- ✓ Governments' low-carbon transition policies affect transition risk, and affect the ratings.
- ✓ Disclosing emissions moderates the relation between emissions and ratings.
- ✓ Disclosing commitment to reduce emissions is associated with lower credit risk, both ratings and DtD.

Policy relevance of this work

Corporates	• Climate disclosure
Credit rating agencies	• Transparency on incorporating climate factors
Banking and insurance	• Risk weights
Central bank	• Monetary operations • Non-monetary operations

The low-carbon transition, climate disclosure and firm credit risk

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Joint work with Carbone, Giuzio, Kapadia, Krämer, Nyholm

Appendix

Why it matters?

Transmission channel

Drivers of transition risk:

Government policy, technological change, market sentiment urge firms to adapt to a low-carbon economy and to reduce their GHG emissions

Firms' credit risk:

Reduced ability of the borrower to repay and service debt

Banks and investors' risk of losses:

Reduced ability to fully recover the value of an investment in the event of default*

Policy relevance: Climate disclosure, Risk weights, Central bank operations

* BCBS (2021). Climate-related risk drivers and their transmission channels

Contribution

Literature on Credit Risk and Climate-related Transition Risk	
Assessment by **Credit Rating Agencies**:	Assessment by **Financial Markets**:
External Credit Rating	Market-implied DtD, Bond yield spread, CDS spread

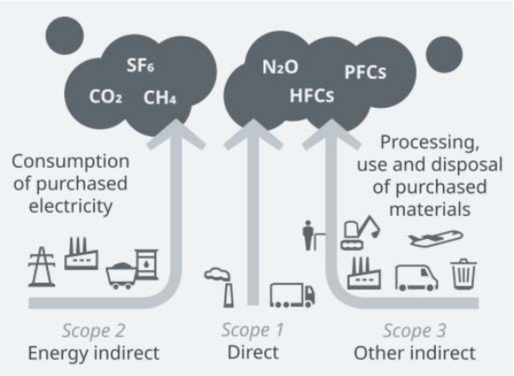
Safiullah et al. (2021) // Emissions (US)
Kiesel and Lucke (2019) // Text
Devalle et al. (2017) // E-Score
Attig et al. (2013) // E-Score
Seltzer et al. (2020) // E-Score, Emissions (US)
Stellner et al. (2015) // E-Score
	Kabir et al. (2021) // Emissions
	Kölbel et al. (2020) // Text
	Barth et al. (2020) // E-Score
	Capasso et al. (2020) // Emissions
	Höck et al. (2020) // Emissions
	Seltzer et al. (2020) // E-score, Emissions (US)
	Stellner et al. (2015) // E-Score

This paper: Novel dataset, Common framework Rating and DtD, Europe vs US Transition

Data: Backward-looking environmental variables

$Scope\ 1_{i,t}$	Scope 1 GHG emissions of a firm per unit of revenue. May be self-disclosed or 3rd-party-estimated.	Urgentem
$Scope\ 2_{i,t}$	Scope 2 GHG emissions of a firm per unit of revenue. May be self-disclosed or 3rd-party-estimated.	Urgentem
$Scope\ 3_{i,t}$	Scope 3 GHG emissions of a firm per unit of revenue. May be self-disclosed or 3rd-party-estimated.	Urgentem
$DiscloseGHG\_d_{i,t}$	Dummy indicating whether a firm's Scope 1, 2, &/or 3 GHG emissions are self-disclosed	Urgentem
$InferGHG\_d_{i,t}$	Dummy indicating whether a firm's 1, 2, &/or 3 GHG emissions are inferred (not self-disclosed), i.e. $(1 - DiscloseGHG\_d_{i,t})$	Constructed
$YoY\ Scope\ 1\ and\ 2_{i,t}$	Year-on-year change in self-disclosed Scope 1 and 2 GHG emissions of a firm per unit of revenue.	Urgentem

Scope 1, 2, 3 Green House Gas (GHG) emissions



Source: GHG protocol

Legend:

Backward-looking metrics

Forward-looking metrics

Data: Forward-looking environmental variables

$DiscloseTarget\_d_{i,t}$	Dummy indicating whether a firm discloses a GHG emissions reduction target	Refinitiv
$TargetPerc_{i,t}$	Percentage by which the firm commits to reduce GHG emissions	Refinitiv
$TargetYear_{i,t}$	Number of years until reaching the target year by which firm commits to reduce GHG emissions	Refinitiv
$SBTi\_d_{i,t}$	Dummy indicating whether the firm has a 2050-temperature-goal	SBTi
$Audited\_d_{i,t}$	Dummy indicating whether the non-financial statement of the firm has been audited.	Refinitiv

Legend:

Backward-looking metrics

Forward-looking metrics

H1: DiD Ratings and High-polluters in Europe

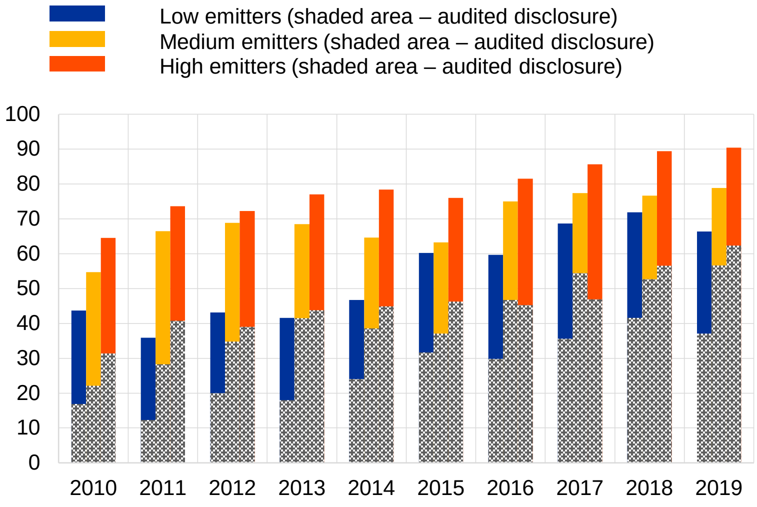
$$CreditRating_{i,t} = \alpha + \beta_0 Treatment_i \times postParis_t + \Sigma_{j=1}^{N} \gamma_j Controls_{j,i,t} + \rho FirmFE_i + \tau TimeFE_t + \epsilon_{i,t}$$

Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Top GHG NACE x post-Paris	-0.55***			-0.53***		
	(0.17)			(0.16)		
Top GHG intensity x post-Paris		-0.16*			-0.28	
		(0.086)			(0.18)	
Top GHG level x post-Paris			-0.32*			-0.38**
			(0.17)			(0.16)
Top GHG NACE	0.84**					
	(0.34)					
Top GHG intensity		-0.58*				
		(0.35)				
Top GHG level			0.20			
			(0.39)			
Controls	N	N	N	Y	Y	Y
Time fixed-effects	N	N	N	Y	Y	Y
Firm fixed-effects	N	N	N	Y	Y	Y
Observations	1,530	1,530	1,530	1,474	1,474	1,474
Number of firms	170	170	170	170	170	170
R-squared	0.028	0.003	0.012	0.063	0.044	0.054

H2 & H3: Stylised facts

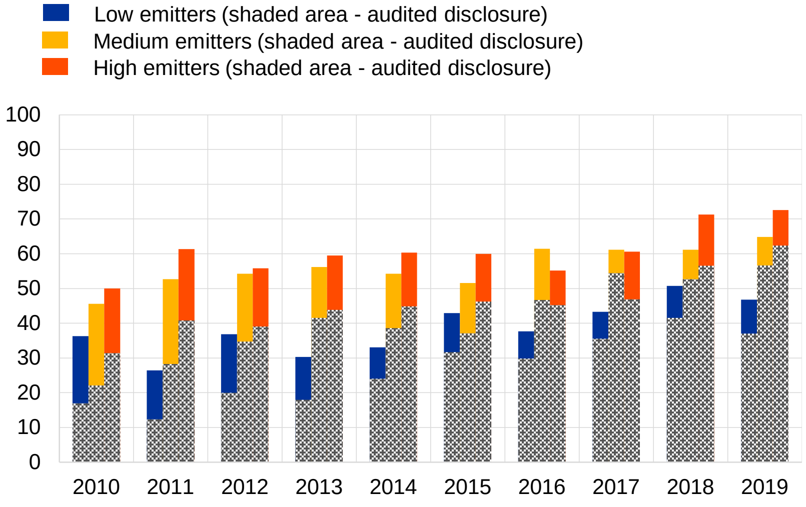
Firms disclosing GHG emissions

Lhs: Percentage of firms in the respective emitters tercile out of 859 listed NFCs



Firms disclosing emissions reduction targets

Lhs: Percentage of firms disclosing emission reduction targets in the respective emitters tercile out of 859 listed NFCs



Sources: Urgentem, Refinitiv, and ECB calculations

H2 & H3: Endogeneity: what may drive firm's adoption of climate disclosure?

Country	Regulation in a certain country …	➢ Country FE
Sector	Public environmental scrutiny of a certain sector …	➢ Sector FE
Year	Public scrutiny in years before the Paris Agreement…	➢ Year FE
Governance	Value(s)-driven management of the firm…	➢ Governance as control
High emitters	Public scrutiny of high-emitters…	➢ High-emitters robustness
Other firm-specifics	Firms preferences for green…	➢ Firm FE robustness

International Conference on "Statistics for Sustainable Finance", co-organised with the Banque de France and the Deutsche Bundesbank

14-15 September 2021, Paris, France, hybrid format

Greening Monetary Policy: Evidence from the People's Bank of China[1]

Camille Macaire and Alain Naef,
Banque de France

[1] This presentation was prepared for the conference. The views expressed are those of the authors and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

Greening Monetary Policy: Evidence from the People's Bank of China

Camille Macaire and Alain Naef[1]

Abstract

In June 2018, the People's Bank of China (PBoC) decided to include green financial bonds into the pool of assets eligible as collateral for its Medium Term Lending Facility. The PBoC also gave green financial bonds a "first-among-equals" status. We measure the impact of the policy on the yield spread between green and non-green bonds. Using a difference-in-differences approach, we show that the policy increased the spread by 46 basis points. Our approach differs from the literature in that we match bonds under review with non-green bonds with similar characteristics and issued by the same firm, which allows for highly relevant firm fixed-effects. We also specifically investigate the impact on green bonds. The granularity of the data (daily) also allows us to conduct a dynamic analysis by dividing the sample into weekly, monthly and quarterly observations. We show that pre-trends are minor. Our results also show that the impact of the reform starts to materialize after three weeks, has a maximum effect after three months, and has a persistent effect over six months.

Keywords: People's Bank of China, central bank collateral framework, green bonds, bond yields, greenium.

JEL classification: Q58, Q51, G12, E52

[1] The views expressed in this paper do not represent the opinion of the Banque de France or the Eurosystem. We thank Damien Bonnot for excellent research assistance. For comments and discussions, we thank Zeynep Alraqeb, Pauline Bacos, Rafael Cezar, Chiara Colesanti Senni, Ugo Dubois, Hanming Fang, Sam Foxall, Simon Hinrichsen, Walter Jansson, Jens van 't Klooster, Rémy Lecat, Lukas Leucht, Jean-Stéphane Mésonnier, Pierre Monnin, Dongyang Pan, Naelle Verniest, Adrian von Jagow, Pierre-François Weber, participants at the SERMI-BdF workshop, E-axes seminar, and members of the Berkeley research Fika.

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Introduction

Central banks have begun to investigate the impact of climate change on the stability of the financial system (Campiglio et al. 2018). They have also started to find possible ways to reduce the carbon intensity of their portfolio and support low-carbon initiatives.

One way monetary policy can support a transition towards a greener economy is through lending facilities. With these facilities, central banks supply loans to financial institutions in exchange for securities as collateral. Adding a security in the list of eligible collateral can affect its price, and in turn affect the real economy. On June 1, 2018, the People's Bank of China (PBoC) broadened the asset classes accepted as collateral for its Medium Term Lending Facility (MLF) to include financial bonds, in particular, green bonds, bonds issued by small and micro enterprises (Xiaowei bonds) and bonds issued by agricultural corporations (Sannong bonds).[2] The PBoC also gave green bonds priority over other financial bonds (a first-among-equals status). We study the impact of this policy on the yield differential between green and non-green bonds.

While many papers study the effect of accepting a bond as collateral, or "eligibility premium" (Mésonnier, O'Donnell, and Toutain 2017; Van Bekkum, Gabarro, and Irani 2018), here green bonds were not only accepted but also given a preferential status. This policy has, to the best of our knowledge, not been used in other countries. And the effects we find here are large in magnitude (46bp), suggesting that the policy had an important impact.

We use a difference-in-differences approach with higher frequency data than for most other studies.[3] We compare green financial bonds with other financial bonds issued by the same firm, hence with identical firm specifications. This means that our identification process focuses on analyzing green and non-green bonds with similar characteristics, except for their green status. We measure the spread between green and non-green bonds' yields before and after the reform. The premium of green assets over non-green assets has been labelled "greenium" and is subject to a large literature. 4 We show that the greenium, i.e. the average yield differential between green and non-green bonds, amounted to 32 basis points at the time 2018 reform in China. We find that the policy further increased the spread between green and non-green bonds by 46 basis points.

Green bonds are fixed-income assets, which finance projects meant to have a positive impact on the environment or reduce harm caused by current activities. The money raised needs to be used by banks to lend to green projects. A company financed by the bank can have both green projects and other projects, financed with different instruments. Here we will refrain from assessing whether these green bonds have an impact on the environment. We also refrain from assessing whether the Chinese green bond taxonomy is in line with international standards. For example, Chinese standards allow for clean coal projects to be financed by green bonds (Gilchrist, Yu, and Zhong 2021). Such projects reduce the carbon footprint of coal

[2] Note that these companies are either small or "micro", which usually involves one employee working on a freelance basis.

[3] Traditionally, the method is used with two time periods. Here we test the impact over a one-year time period with different length of time sub-periods, up to a week.

[4] See for example Harrison, Partridge, and Tripathy 2020; Larcker and Watts 2020; Larsson 2019; Alessi, Ossola, and Panzica 2019; Partridge and Medda 2020; Partridge and Romana 2020; Zerbib 2019.

mines but still represent investment in non-green technologies. The goal is to see whether a central bank can affect green bond pricing through its monetary policy, both through the direct impact of collateral eligibility, as well as via the signal effect that promotes the market for green financial bonds, which was still in its infancy in China at the time of the reform. This is useful as most central banks are currently trying to support low-carbon initiatives (Campiglio et al. 2018).

Literature review – green monetary policy in China and elsewhere

Central banks have started formal reviews of the impact of their monetary policy on the environment, and in this context the Chinese experience can prove useful. The Bank of England pioneer the idea that central banks should have an impact on climate (Carney 2015). Proposals for greener central banking by van 't Klooster and Tilburg (2020) and Dafermos et al. (2020), have suggested a broader understanding of central bank market neutrality, within the context of a green transition.[5] Market neutrality implies that monetary policy operations should not favor one industry over another. But the literature highlights the fact that the current market might be biased towards sectors more at risk of a climate transition shock and climate risks might not be priced in correctly (Campiglio 2016; Schnabel 2020). Findings suggest that a low carbon allocation could be done with no interference with the price stability mandate in the Eurozone (Schoenmaker 2021). Christine Lagarde has also questioned whether market neutrality is warranted, if there is a market failure linked to the pricing of assets exposed to climate risk.[6]

Several proposals have emerged to understand how central banks can better mitigate their impact on the climate. McConnell, Yanovski, and Lessmann (2020) suggest that central bank have a role to play because of their independence. They suggest using collateral haircuts based on assets' carbon intensity. Ferrari and Nispi Landi (2021) suggest using a temporary green QE and to temporarily tilt central bank's balance sheet toward green bonds.

In the European context for example, van 't Klooster and Tilburg (2020) suggest the ECB uses green Targeted Longer-Term Refinancing Operations (TLTRO) to finance transition to green housing. Dafermos et al. (2020) argued that because of the structure of the market, the ECB unwillingly had a bias towards brown assets and hence might not be market neutral. Oustry et al. (2020) suggest a "climate-hedging portfolio approach" where the central bank would align the aggregate of its portfolio rather than an asset-by-asset approach. Other central banks have questioned the concept of market neutrality in the light of catastrophic climate risks. The Swiss National Bank (SNB) has recently announced plans to divest from coal in the context of its monetary policy (van 't Klooster and Naef 2021).[7]

Researchers have tried to model how a monetary policy aligned with the Paris Accord might look like; Böser and Colesanti Senni (2020) offer a dynamic general equilibrium model and show how a climate-oriented monetary policy could help with

[5] On the market neutrality of the SNB and ECB, see also Klooster and Fontan (2019).

[6] "In the face of what I call the market failures" we have to ask "whether market neutrality should be the actual principle that drives our monetary-policy portfolio management" https://www.bloomberg.com/news/articles/2020-10-14/lagarde-says-ecb-needs-to-question-market-neutrality-on-climate.

[7] See the announcement by the SNB chairman here: https://www.snb.ch/en/mmr/speeches/id/ref_20201217_tjn

transition. While there is no clear consensus on how central banks can mitigate climate change, there is a consensus that central banks are thinking about ways to mitigate climate risks (Campiglio et al. 2018). In the European context, it is also clear that the financial system is exposed to climate-policy-relevant sectors (Battiston et al. 2017) and that an abrupt transition could pose systemic risks.

In terms of changes to securities accepted as collateral, our study relates to a broader literature. Mésonnier, O'Donnell, and Toutain (2017) found that when an asset becomes eligible in the Eurosystem's collateral framework, it translates into a reduction of 7bp yield for new loans issued by a firm, even when controlling for loan and firm specific effects. Giovanardi et al. (2021) run an analysis closely related to our in Europe. They find that after each ECB announcement favourable to green bonds, green bond yields drop by 9.3bp on average over a twenty trading day window.

In the Chinese context, Fang, Wang, and Wu (2020) also study the 2018 policy change analyzed here, but their focus is not specifically on the green bond market. They focus on the impact on asset prices of the inclusion of lower-graded bonds in the pool of eligible collateral for the PBoC's Medium Term Lending Facility. They present empirical evidence for the causal impact of the reform on the secondary bond market. By exploiting the fragmented nature of China's bond markets, with a dual-listing of similar bonds in two segmented markets, they use a triple-difference empirical design to assess the impact of the policy shift on the prices of the newly collateralizable bonds, using a series of indicators to construct bond issuer controls. They find that the policy reduced the spreads of these bonds to China Bond Government Bond (CGB) of the same term to maturity by 42-62 basis points on the secondary market (in line with our findings of 46bps spread increase between green bonds and similar non-green bonds). They also find that there is a pass-through effect to the primary market with a reduction in spreads at issuance by 53.8 basis points (ca. 100% pass through), thus a positive impact on the real economy.

They single out the different types of bonds from the overall pool: they find that *Xiaowei* (small and micro-firms) bonds seem to have experienced a particularly large spread reduction after the policy shock (additional 47.6 bps), while their estimates for the Green and *Sannong* (agricultural) bonds are quite noisy. On the primary market, they find that the Green and *Sannong* bonds see a significant decrease in spreads. Our approach differs from theirs in that we match bonds under review with non-green bonds with similar characteristics and issued by the same firm. Our approach largely refines the bond issuer controls and allows for more precise estimates when it comes to the analysis of green bonds.

Also looking at the Chinese market, Chen et al. (2019) analyse a policy change in 2014 when AA+ and AA bonds were excluded from the list of securities eligible as repo collateral. They find that the change in policy led to an increase in yields of excluded bonds between 40 to 83 basis points. Their study is essentially looking at the inverse situation of what we analyse here, namely an exclusion when we study an inclusion.

Wang and Xu (2019) study the impact on the primary bond market issuance price of a change in collateral accepted by the China Central Depository & Clearing Co (CCDC), a public central depository for Chinese government bonds. Before April 2017, the CCDC accepted AA rated bonds, which were no longer accepted after the reform. The change penalized AA rated bonds by 60-70 basis points.

Dikau and Volz (2021) argue that Chinese monetary authorities were pioneer in green finance. They show that the PBoC and the China Banking Regulatory

Commission (CBRC) used window guidance to encourage financial institutions to expand credit to sustainable activities. Cui et al. (2018) study a dataset of 24 Chinese banks that adding more green loans to bank's portfolio reduces the non-performing loan ration. Wang et al. (2020) document the existence of a greenium on Chinese debt and stock markets.

The contribution of this paper is to focus specifically on the impact of the policy change on green bonds, which can inform current policy choices in countries looking at ways to make their monetary policy more compatible with the Paris agreement.

We retrieve daily yields data for green and non-green bonds, pairing them by issuer. Using a difference-in-differences approach, we analyze whether the reform had a significant impact on the spread between the bond yields of each pair.

Institutional background – the PBoC reform of 2018

China is the world's biggest producer of greenhouse gases, with 28% of *worldwide* carbon dioxide emissions in 2018 according to the Energy Information Administration (EIA).[8] In September 2020, China's president Xi Jinping announced the country would be carbon neutral, meaning that it would cut its net carbon dioxide emissions to nearly zero, by 2060. This pledge would imply a dramatic reshaping of the Chinese energy consumption model, considering the fact that coal is still by large the main energy source (57.7% of total energy consumption in 2019). China's extremely rapid development over the last few decades has been at the expense of environmental issues. The current high level of pollution has major implications for public health. The Chinese authorities say they have become aware of the urgency of the situation. They have made the energy transition a key objective of the development strategy and have enshrined the concept of "ecological civilization" in the constitution in 2018. Achieving market neutrality in 2060 means that China will need to transition from peak in 2030 in only 30 years. This is much faster than other countries like Japan or the EU, and remains a huge challenge.

Concrete action in supporting the development of green finance through official guidelines dates back a decade (Aizawa and Yang 2010). China's government, banking regulator, and central bank have issued guidelines in 2012 to accelerate green lending and green bond issuance. In 2015, the PBoC released a taxonomy for projects eligible for green financing in the *Green Bond Endorsed Project Catalogue*. The introduction of taxonomies improved market integrity and led to a surge in green bond emissions in the country. In 2016, several ministerial agencies including the PBoC and the Ministry of Finance jointly released the *Guidelines for Establishing the Green Financial System*. This marked the start of structural reforms aiming to promote green finance in the country.

This new framework led to rapid development of green finance in the country. The first Chinese green bond was issued in 2015 (Volz 2018). The green bond market then expanded rapidly. With a USD 31.3bn emission of green bonds aligned with international standards in 2019, China accounted for 12% of the global market, ranking second after the US (20% of the total market), and closely followed by France. In addition, China's domestic green bond market includes securities that are not aligned with international standards but compliant with the local regulation (e.g. "clean coal" projects). In 2019, total issuance of such bonds amounted to

[8] https://www.iea.org/data-and-statistics

approximately USD25bn. This trend takes place in the context of a broader reform aiming at reinforcing domestic markets' attractiveness for international investors through broader openness and increased sophistication (Aglietta and Macaire 2019).

To support the green bond market, the PBoC expanded the pool of collateral eligible to borrow from its Medium Term Loan Facility (MLF) on 1 June 2018. Understanding the impact of this reform is the focus of this paper. This decision was the first time that monetary policy was directly used to promote green finance in the country. We build on the findings of the BIS's Committee on the Global Financial System Markets Committee (BIS 2015). The report shows that central bank operations on collateral markets can influence those markets through scarcity effects and structural effects. These choices have been in some cases used deliberately to support the functioning of those collateral markets.

The 2018 institutional change

On 1 June 2018, the PBoC expanded the pool of eligible collateral to borrow from its Medium-Term Lending Facility (MLF). The PBoC had launched the MLF in 2014. The scheme offers 3-, 6- and 12-month lending to financial institutions. Outstanding lending lines through the MLF accounted as of September 2020 for 52% of the PBoC's lending facilities to Chinese banks.

The 2018 reform was a broad reform of monetary policy (see Fang, Wang, and Wu 2020 for the broader context). Here we focus on two main aspects of this reform, the inclusion of green financial bonds into the pool of eligible collateral and their preferential status. Table 1 offers a summary of all the changes, which occurred to financial bonds during that time.[9]

As detailed in the introduction, the PBoC enlarged the pool of assets accepted as collateral to include financial green bonds, financial bonds issued to finance small and micro enterprises (*Xiaowei* bonds) and financial bonds issued to finance agricultural corporations (*Sannong* bonds). Moreover, the PBoC granted a first-among-equals status to green and SME financial bonds.[10]

Table 1 – 2018 institutional changes by asset classes

	Before June 2018	After June 2018
Green financial bonds (AAA, AA+ and AA)	Not accepted	Accepted and first-among equals status
Small and micro enterprises financial bonds (AAA, AA+ and AA)	Not accepted	Accepted
Agricultural bonds (AAA, AA+ and AA)	Not accepted	Accepted
All other financial bonds (AAA, AA+ and AA)	Not accepted	Not accepted

[9] Note that corporate bonds also underwent a reform, and AA and AA+ corporate bonds were also included in the list of eligible collaterals for the MLF facility. Prior to the reform, the MLF operations accepted government securities, central bank bills, China Development Bank bonds, policy financial bonds, local government debts, AAA-rated corporate bonds as collaterals.

[10] http://www.pbc.gov.cn/en/3688110/3688172/4048314/3711516/index.html

Chinese green and non-green financial bonds data

We use market data on Chinese bonds yields gathered from Bloomberg to study the impact of the policy change. We first select bonds that present the following characteristics: green-labelled, with above AA credit rating, issued by financial institutions, and for which the issue date was before 1/6/2017, and the maturity date after 31/5/2019 (hence, 6 months before the beginning and after the end of our timeframe, respectively) to avoid disturbances linked to the beginning and the end of a bond lifespan. Due to the narrowness and lack of liquidity of the market for green bond at the time of the reform, data limitation is strong and we are much constrained in the choice of securities. On the exhaustive list of 26 bonds featured in the Bloomberg database and matching those criteria, 11 only present exploitable data series.[11] Many bonds do not have available data since they were acquired at the time of their issuance, and never or very rarely traded on the market. This is linked to the fact that the major investors in the bond market in China are banks, which mostly have a buy-and-hold attitude. We chose to construct pairs of green and non-green bonds issued by the same firm. This methodology allows us to accurately incorporate company-specific characteristics (size, sector of activity) without having to add additional control variables.

As our identification relies on using firm fixed effects, we chose to exclude one green bond time series for which no non-green bond issued by the same institution can be found (but adding or removing this bond does not change our results). For the remaining 10 green bonds, we select non-green bonds issued by the same financial institutions, and with the closest matching characteristics (rating, coupon type, maturity etc.) to serve as a control group.

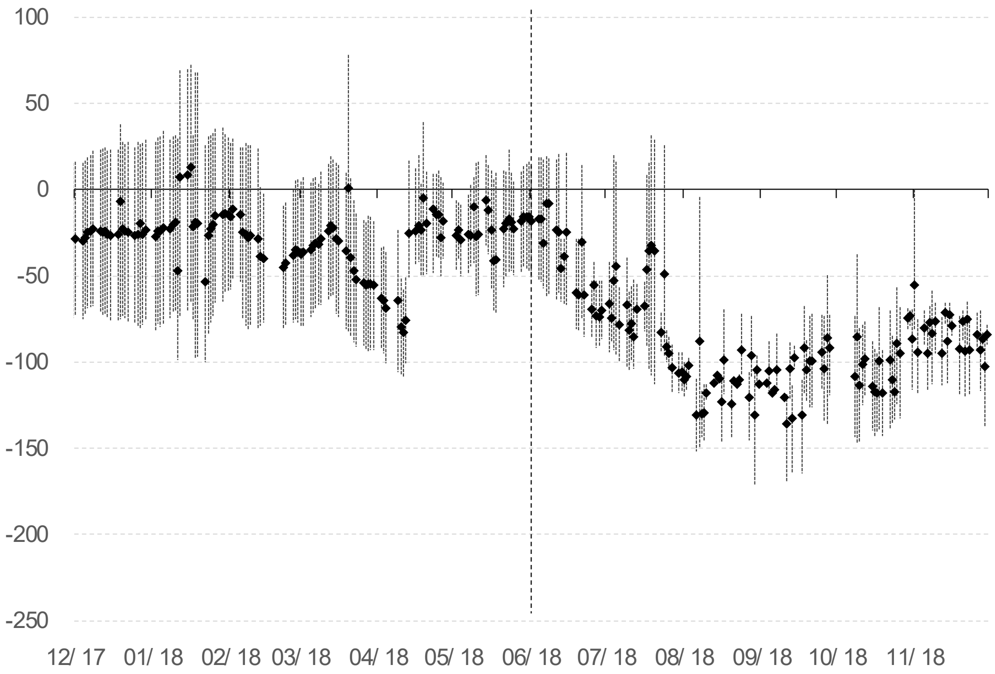
Our dataset is composed of yield series for 10 green and 8 non-green bonds, issued by 7 different financial institutions (Table 3 in the appendix shows the main characteristics of all the selected bonds). Data limitation and narrowness of the whole universe of securities presenting our search criteria do not allow for perfect matching. For example, the average residual maturity of all green bonds is 3.2 years, while the average residual maturity of matching non-green bonds is 7.6 years. This might cause a bias.

Our dataset is composed of 2609 observations over a total period of one year, or 261 workdays (01/12/2017 to 30/11/2018), six months before the reform and six after. We chose this timeframe as green bonds were virtually non-existent before 2016 and the market only really develops in 2017.

Figure 1 shows the difference in yield by green and non-green bonds issued by the same companies; we observe an increase in the differential after 1 June 2018.

[11] Series that we removed either presented insufficient number of data points, were extremely nonlinear or flat, suggesting that they did not reflect real market prices.

Figure 1 – Spread of non-green vs green bond yield, in basis points



Note: The perpendicular dotted line shows the policy change on 1 June 2018. The graph covers the period 01/12/2017 to 30/11/2018. Each point represents the average spread between green and non-green bonds from the same issuer. The vertical whisk around the point represents the min-max interval for each green and non-green pair of bonds.

What was the impact of the policy?

Our main identification uses a difference-in-differences approach. We have a large pre- and post-period (6 months, respectively), which shows the effect of the policy within a broader context. This yields results that are more robust and unlikely to misrepresent a temporary feature of the data, as a simple two periods difference-in-differences might.

To allow for perfect comparison between the treated and control groups, we compare bonds from the same financial institutions. This means that both groups would react similarly to any company specific news, such as for example an increase default risk after the announcement of a large loss. News regarding the company will affect both green and non-green bonds similarly. This means that the intrinsic default risk is the same for the green and non-green bonds compared. Doing so we control for firm-level factors. More specifically, the main difference between these bonds is their green status; the difference-in-differences setting therefore captures the change in the spread between green and non-green after the policy.

Scholars have traditionally used difference-in-differences methods with only two set of observations, one before the treatment and one after. Egami and Yamauchi (2019) discuss how longer time series also fit difference-in-differences designs. Callaway and Sant'Anna (2019) also offer identifications for difference-in-differences with multiple time periods. Here we offer not only multiple pre-treatment periods but also multiple post-treatment periods to have a broader overview of the impact of the policy and its lasting effect. First we run the difference-in-differences dividing the data in a pre- and post- group, before fine tuning our approach in different time periods.

We focus on pairs of green and non-green financial bonds. Our model is as follows:

$$Y_{it} = \alpha + \beta_1 T_i + \beta_2 P_t + \beta_3 (T_i \times P_t) + \gamma FE + \varepsilon_{it}$$

where Y_{it} is the yield of bond i, at time t. T_i is a treatment dummy taking the value 1 for all *green* bonds (affected by the policy) and 0 for all *non-green* bonds. P_t is a treatment dummy taking the value 1 after the policy change, 0 before, γFE are company fixed effects. β_3 is the coefficient of interest measuring the impact of the policy of the PBoC on the treated group. Table 2 presents the results of the difference-in-differences estimation.

Our results show that the policy had a significant impact on the path of green vs. non-green bond yields, and that it reduced the yield of green bonds by 46 basis points over non-green bonds on average. The next section takes a more detailed approach dividing the sample into weekly, monthly and quarterly observations and showing the difference is not due to pre-trends. We also show the lasting effects of the reform.

Table 2

Dependent variable: Bond yields	
Intercept	4.45*** (0.024)
Treated dummy	-0.32** (0.11)
Post dummy	-0.41** (0.19)
Treated x Post	-0.46** (0.19)
Company fixed effects	YES
Adjusted R^2	0.69
Observations	2609

Standard errors rare clustered at the bond level.[12] *** signifies statistically significant at the 1% level of significance; ** at the 5% level of significance; * at the 10% level of significance.

Adding pre- and post-trends and counterfactual policy changes

The part above showed that there is evidence that the reform implemented on June 1 2018 had a significant impact on the treated green bonds, compared to non-treated non-green bonds. Now, we use multiple time periods to generate a counterfactual policy change. We sequence our dataset by quarters, months and weeks. We then conduct a difference-in-differences between the time period preceding the policy change and each of the other time periods separately, as if they had each experienced the change in policy. In a sense, for periods prior to the policy change, the check act as a placebo test and allows us to examine the parallel trend assumption. For each periods after the policy change, it gives a view of the timeliness and persistency of the shock.

[12] Note that clustering at the green/non-green level yield similar results. Using a non-clustered Newey-West standard errors yield results significant at 1%.

We estimate the following specification:

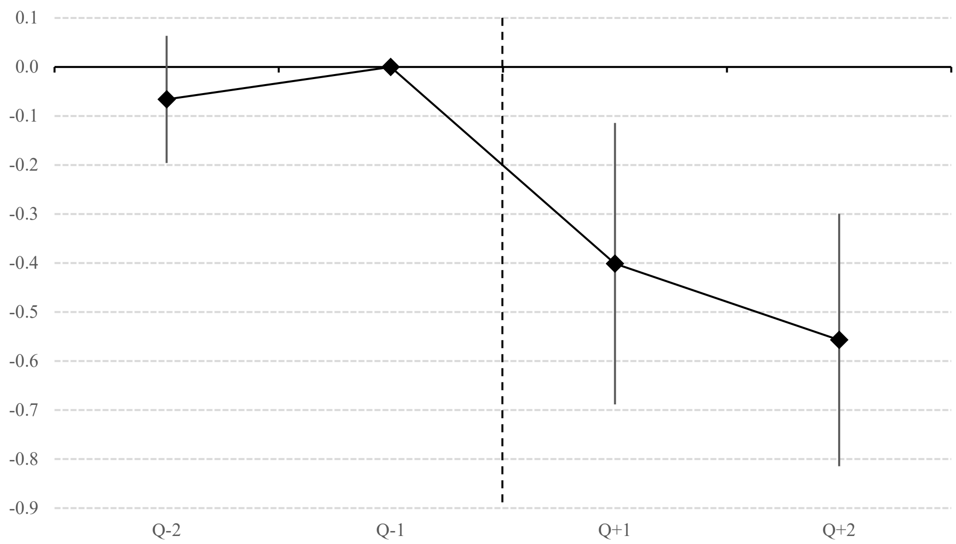
$$Y_{it} = \alpha + \beta'_1 T_i + \beta'_2 Test_{t'} + \beta'_3 (T_i \times Test_{t'}) + \gamma' FE + \varepsilon_{it'}$$

where Y_{it} are the yields of bond i, at time t, i.e. either during the period prior to the change (the reference period), or the tested time period. T_i is a Treatment dummy taking the value 1 for all green bonds (affected by the policy) and 0 for all non-green bonds. $Test_t$ is a treatment dummy taking the value 0 during the reference time period, and 1 during the tested time period, $\gamma' FE$ are company fixed effects. β'_3 is the coefficient of interest here measuring the impact of the policy of the PBoC on the treated group.

Figures 2 to 4 shows the estimated values of the treatment factors β'_3 for each period, on a quarterly, monthly and weekly frequency. They show that, prior to the policy shock, β'_3 are smaller and tend to be statistically insignificant (see the left side of Figure 3 and 4), especially for the time periods more closely preceding the reference period. During these periods, the difference between green and non-green bonds are not statistically different from what they are just before the reform. This means that the trends in green and non-green bonds' yields before the reform tend to be similar. This is less marked (see the very left of Figure 2 and 3) when testing earlier time periods, yet the factors tend to be lower than the value just before the reform, meaning that from the start of the timeframe up until 5 months before the reform, the spread between green and non-green bonds (the greemium) tend to decrease.

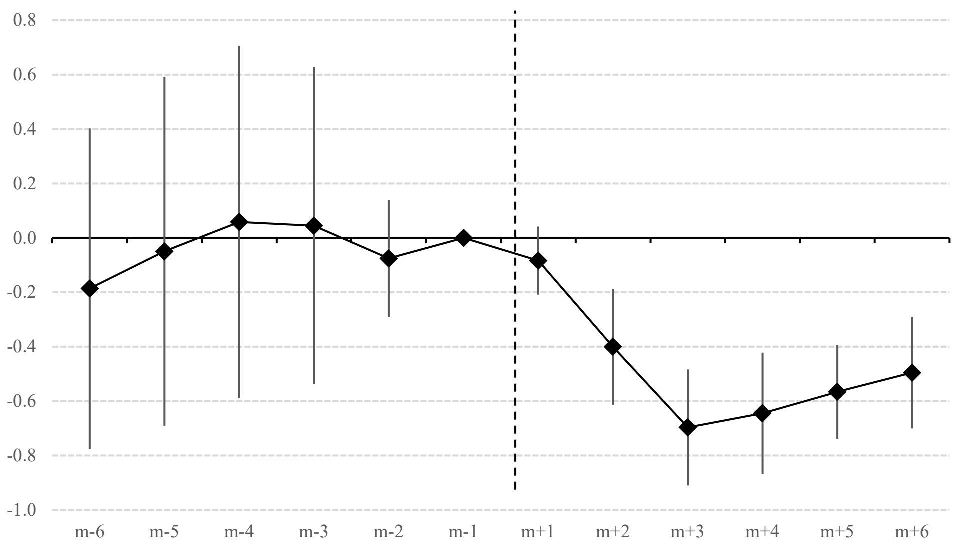
After the policy shock, yields of the green bonds are significantly reduced compared to non-green bonds. The policy reform therefore reversed a potential ongoing trend of homogenization of green and non-green bonds, clearly reducing yield of green bonds, all other things equal. The graphs show that the impact is almost immediate. The weekly analysis in Figure 4 shows that there might be around three weeks delay in the materialization of the impact. The effect is persistent throughout the timeframe analysed. Looking at Figure 1, it also looks there were no anticipation effects. The chart shows no movement before the reform.

Figure 2 – Dynamic effect, quarterly basis



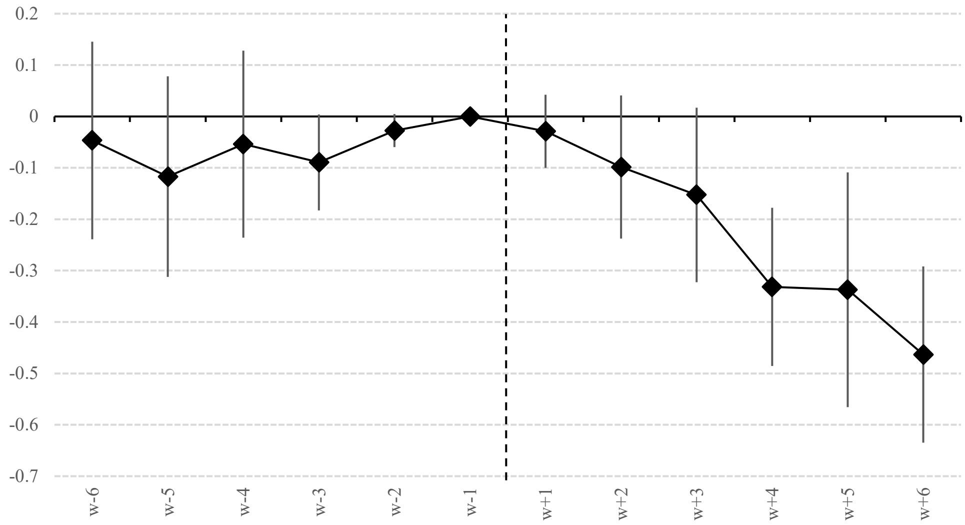
Note: The perpendicular dotted line shows the policy change on 1 June 2018. The graph covers the period 01/12/2017 to 30/11/2018, hence 4 quarters. The 01/06/2018 shocks occurs in the beginning of Q+1. Each point represents the coefficient of DID conducted between Q-1 and the specific quarter. The vertical whisk around the point is the 95% confidence interval.

Figure 3 – Dynamic effect, monthly basis



Note: The perpendicular dotted line shows the policy change on 1 June 2018. The graph covers the period 01/12/2017 to 30/11/2018, hence 12 months. The 01/06/2018 shocks occurs in the beginning of m+1. Each point represents the coefficient of DID conducted between m-1 and the specific month. The vertical whisk around the point is the 95% confidence interval.

Figure 4 – Dynamic effect, weekly basis



Note: The perpendicular dotted line shows the policy change on 1 June 2018. The graph covers the period 23/04/2018 to 13/07/2018, hence 12 weeks. The 01/06/2018 shocks occurs in in the beginning of w+1. Each point represents the coefficient of DID conducted between w-1 and the specific week. The vertical whisk around the point is the 95% confidence interval.

Our findings provide an insight into how central bank collateral policy can significantly influence specific financial assets and thus pursue targeted objectives. In particular, China has had a pioneering attitude towards green finance and our results show encouraging ways in which central banks can support this market segment. Yet, some caveats apply. First, green finance is only as good as the green taxonomy underlying it and in this paper we refrain from evaluating the green taxonomy in China and take it as a given. Since there is no standardized framework for identifying green assets globally, distinct definitions arose globally, which brings limitation to the study of one national market (Gilchrist, Yu, and Zhong 2021). Issues of greenwashing could make these policies less effective (Jones et al. 2020). Then, the reform forms part of a more comprehensive strategy to support green financing in the country, and its impact might have been amplified by a supportive environment.

Another shortcoming of our study is that it happened in the midst of a trade war between China and the US. It is unlikely that the trade war would have affected green over non green bonds at the exact time of the reform by this order of magnitude. Yet, it is not impossible that the trade war could have had heterogeneous effects affecting our results.

Lastly, improved financing of green bonds cannot mitigate the drastic effects of climate change, as green bonds only represent an extremely small proportion of outstanding bonds. Sure, measures as the one presented here can potentially favor green bonds emissions but, alone, they might not be sufficient to mitigate the devastating effects of climate change. Other measures by governments such as an international carbon tax are needed. Central banks can also undertake additional measures related to non-green assets, such as asset reallocation out of the most polluting assets (Naef 2020) or when possible more activism in asset ownership based on the example of the Norges Bank (van 't Klooster and Naef 2021).

Conclusion

In this paper, we show how the PBoC lowered yields of green-labelled financial bonds compared to similar non-green bonds by including them as favoured tools for collateral policy. Using a difference-in-differences approach, we find that the policy had significant and persistent effects over several months. Specifically, the reform lowered the yield differential between green and non-green financial bonds by 46 basis points after the policy when compared to before.

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Appendix

Data description: Main characteristics of observed bonds

Table 3 – bonds analysed

Issuer name	Green status	Local Credit Rating	Issue Date	Maturity	Coupon type	Curr.	Amount Issued kCNY	Exchange Market	Security Name
Bank of Qingdao	G	AAA	14/03/2016	14/03/2021	fixed	CNY	500	Interbank	QDBANK 3.4 03/14/21
Bank of Qingdao	NG	AA+	14/07/2017	14/07/2027	fixed	CNY	2 000	Interbank	QDBANK 5 07/14/27
Bank of Qingdao	G	AAA	24/11/2016	24/11/2021	fixed	CNY	1 000	Interbank	QDBANK 3.4 11/24/21
Jiangxi Bank	G	AAA	08/08/2016	08/08/2021	fixed	CNY	1 500	Interbank	NANCHB 3.48 08/08/21
Jiangxi Bank	NG	AA+	28/09/2017	28/09/2027	fixed	CNY	3 000	Interbank	NANCHB 5 09/28/27
Jiangxi Bank	G	AAA	17/07/2016	14/07/2021	fixed	CNY	1 500	Interbank	NANCHB 3.7 07/14/21
Jiangxi Bank	NG	AA+	07/06/2017	07/06/2027	fixed	CNY	3 000	Interbank	NANCHB 5 06/07/27
Sh. Pudong Dev. Bank	G	AAA	18/07/2016	18/07/2021	fixed	CNY	15 000	Interbank	SHANPU 3.4 07/18/21
Sh. Pudong Dev. Bank	NG	AAA	28/12/2012	28/12/2027	fixed	CNY	12 000	Interbank	SHANPU 5.2 12/28/27
Bank of Beijing	G	AAA	17/04/2017	17/04/2022	fixed	CNY	3 000	Interbank	BOBJ 4.5 04/19/22
Bank of Beijing	NG	AA+	18/01/2011	18/01/2026	fixed	CNY	3 500	Interbank	BOBJ 4.9 01/18/26
Bank of Nanjing	G	AAA	27/04/2017	27/04/2022	fixed	CNY	1 000	Interbank	NANJBK 4.6 04/27/22
Bank of Nanjing	NG	AAA	17/11/2016	17/11/2021	fixed	CNY	10 000	Interbank	NANJBK 3.45 11/17/21
Bank of Comm.	G	AAA	22/11/2016	22/11/2021	fixed	CNY	20 000	Interbank	BOCOM 3.25 11/22/21
Bank of Comm.	NG	AAA	22/12/2015	22/12/2022	fixed	CNY	30 000	Interbank	BOCOM 3.45 12/22/20
Industrial Bank	G	AAA	17/11/2006	17/11/2021	fixed	CNY	20 000	Interbank	INDUBK 3.4 11/17/2021
Industrial Bank	NG	AAA	13/04/2016	13/04/2026	fixed	CNY	30 000	Interbank	INDUBK 3.74 04/13/2026
Industrial Bank	G	AAA	18/07/2016	18/07/2019	fixed	CNY	20 000	Interbank	INDUBK 3.2 07/18/2019

Source: Bloomberg

Data limitations: bond selection process

Table 4

Restriction	**Number of bonds**
Chinese bonds issued in RMB	282’960
And with an issue date priori to June 2017	86’306
And a maturity date later than November 2019	17’538
And with a rating higher than AA	10’922
And which are financial bonds	368
And which are green bonds	26

The list of bonds presented here are an exhaustive list of bonds available within our selection criteria. The reform we study only concerns financial green bonds with at least a rating of AA. We selected only bonds issued before our period of interest and with enough remaining maturity. This is to avoid abnormal fluctuation. Loosening these last criteria by several months does not increase the number of bonds. Our sample is as exhaustive as can be, within the specifications of the paper. Out of the 26 green bonds available, only 10 offered exploitable market data. Some were not traded at all. Others offer only very infrequent market prices. Finally some were completely flat and offered no variation at all. They were all not exploitable.

Data description: Main characteristics of observed issuing institution

Table 5

Name	Bank type (main activity)	Ownership	Equity listing	Largest shareholder
Bank of Qingdao	Retail bank	Private and public	Listed in Mainland China and Hong Kong	Qingdao Conson Development group (9% of Mainland China shares)
Jiangxi Bank	Commercial bank	Private and public	Listed in Mainland China and Hong Kong	Huan Fund management and co LTD (17.06% of Hong Kong shares)
Shanghai Pudong Development Bank	Commercial bank	Private and public	Listed in Mainland China, Singapore and London	Shanghai International group (21.57% of Mainland China shares)
Bank of Beijing	Commercial bank	Private and public	Listed in Mainland China only	ING Groep NV (13.03% of Mainland China shares)
Bank of Nanjing	Commercial bank	Private and public	Listed in Mainland China only	BNP Paribas (13.92% of Mainland China shares)
Industrial Bank	Retail bank	Private and public	Listed in Mainland China and Hong Kong	Fujian Province Finance Bureau (18.78% of Mainland China shares)

Source: Bloomberg

Robustness check – regression on AAA bonds only

To verify whether the integration into the dataframe of AA+ bonds might include a significant biais, we conduct the same regression with groups of firms for which we have both green and non-green AAA bond yields series. Results are broadly similar.

Table 6

Dependent variable: Bond yields	
Intercept	4.86*** (0.025)
Treated dummy	-0.15*** (0.047)
Post dummy	-0.43*** (0.029)
Treated x Post	-0.48*** (0.047)
Company fixed effects	YES
Adjusted R^2	0.71
Observations	881

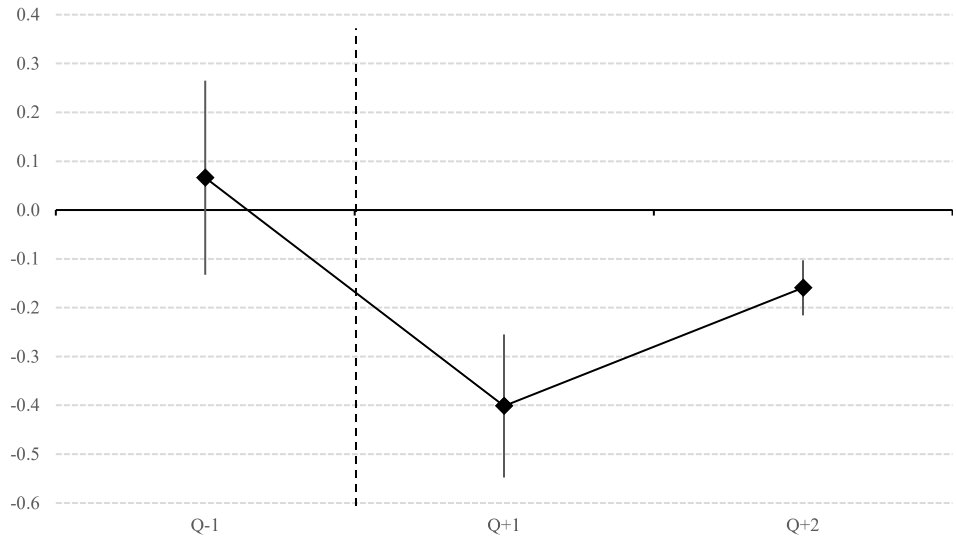
*** signifies statistically significant at the 1% level of significance; ** at the 5% level of significance; * at the 10% level of significance.

Robustness check – counterfactual reforms

We presented a difference-in-differences approach where we compared each period with the periods before the reform (or t-1). Here we compare each period with the previous one. This acts as a counterfactual, as if the reform occurred between each period. The ideal result would be to show that there is only a significant break before and after the reform, and in no other time period.

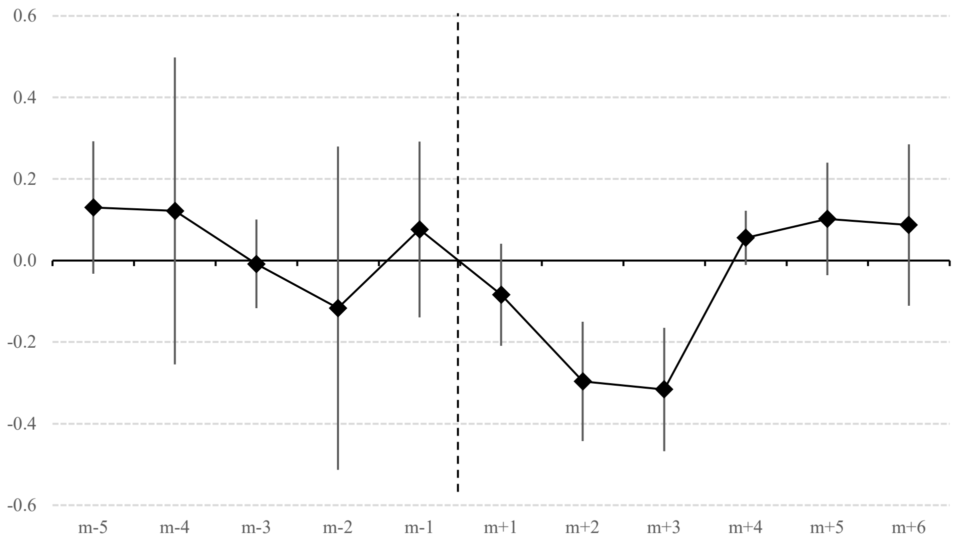
Figures 5 to 7 show the different coefficients over time. At the quarterly level in Figure 5, the largest drop is the period right after the reform, reinforcing our findings. At a monthly frequency (Figure 6), we can see the largest drops of the sample 2 and 3 month after the reform. At a weekly frequency (Figure 7), the data becomes noisier and shows less of a trend (when compared with Figure 4). What all three figures show is the clear absence of downward pre-trend, reinforcing that what happened in June 2018 at the time of the reform is not linked to previous trends in the data.

Figure 5 – Iterative effect, quarterly basis



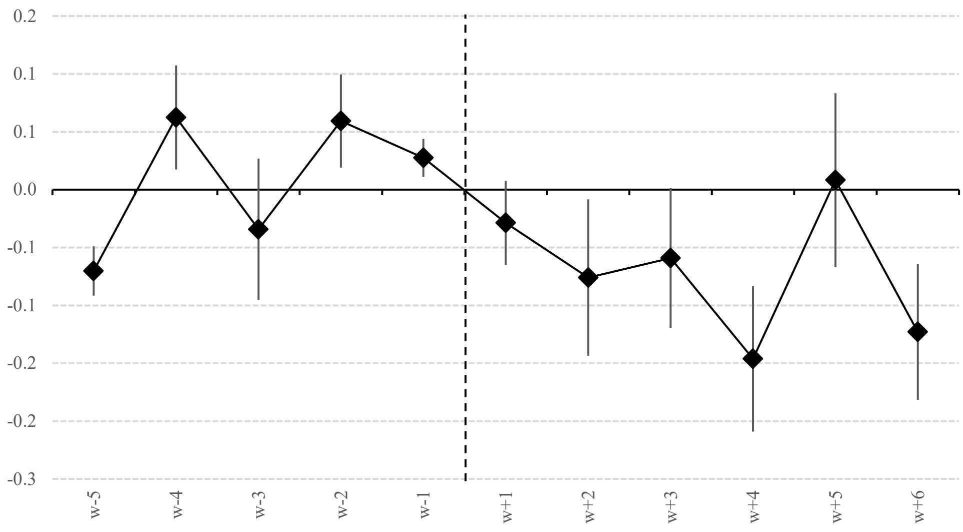
Note: The perpendicular dotted line shows the policy change on 1 June 2018. The graph covers the period 01/12/2017 to 30/11/2018, hence 4 quarters. The 01/06/2018 shocks occurs in the beginning of Q+1. Each point represents the coefficient of DID conducted between Q(t-1) and Q(t). The vertical whisk around the point is the 95% confidence interval.

Figure 6 – Iterative effect, monthly basis



Note: The perpendicular dotted line shows the policy change on 1 June 2018. The graph covers the period 01/12/2017 to 30/11/2018, hence 12 months. The 01/06/2018 shocks occurs in the beginning of m+1. Each point represents the coefficient of DID conducted between m(t-1) and m(t). The vertical whisk around the point is the 95% confidence interval.

Figure 7 – Iterative effect, weekly basis



Note: The perpendicular dotted line shows the policy change on 1 June 2018. The graph covers the period 23/04/2018 to 13/07/2018, hence 12 weeks. The 01/06/2018 shocks occurs in in the beginning of w0. Each point represents the coefficient of DID conducted between w(t-1) and w(t). The vertical whisk around the point is the 95% confidence interval.

Robustness check – Similar maturities and differential with government bonds

Because of the limited bonds to compare available, maturities and issues dates in Table 3 are not perfectly matched. This might introduce a bias in our results. To better match both the remaining maturity and issuance date, we run our exercise again. This time we match each bond with a government of equivalent maturity and with a similar issue date. Table 7 shows our matching as well as the difference of remaining maturity. We re-run the same regression than in Table 2. Table 8below shows the results. Using the difference with government bonds yields similar results. The point estimate is slightly lower.

Table 7

Matching bond identifier	Government bond issue date	Government bond maturity	Remaining maturity difference in days	Issue Date	Maturity	Bond analysed
JK712524	04/07/2016	04/07/2021	112	14/03/2016	14/03/2021	QDBANK 3.4 03/14/21
AO5171597	03/08/2017	03/08/2027	20	14/07/2017	14/07/2027	QDBANK 5 07/14/27
AL5500353	12/12/2016	12/12/2021	18	24/11/2016	24/11/2021	QDBANK 3.4 11/24/21
LW7656413	14/07/2016	14/07/2021	-25	08/08/2016	08/08/2021	NANCHB 3.48 08/08/21
AO5171597	03/08/2017	03/08/2027	-56	28/09/2017	28/09/2027	NANCHB 5 09/28/27
LW7656413	14/07/2016	14/07/2021	0	17/07/2016	14/07/2021	NANCHB 3.7 07/14/21
AN3476131	04/05/2017	04/05/2027	-34	07/06/2017	07/06/2027	NANCHB 5 06/07/27
LW7656413	14/07/2016	14/07/2021	-4	18/07/2016	18/07/2021	SHANPU 3.4 07/18/21
EJ713183	27/06/2013	27/06/2028	182	28/12/2012	28/12/2027	SHANPU 5.2 12/28/27
AN153582	13/04/2017	13/04/2022	-4	17/04/2017	17/04/2022	BOBJ 4.5 04/19/22
QJ892208	30/11/2015	30/11/2025	-49	18/01/2011	18/01/2026	BOBJ 4.9 01/18/26
AN153582	13/04/2017	13/04/2022	-14	27/04/2017	27/04/2022	NANJBK 4.6 04/27/22
AL5500353	12/12/2016	12/12/2021	25	17/11/2016	17/11/2021	NANJBK 3.45 11/17/21
AL5500353	12/12/2016	12/12/2021	20	22/11/2016	22/11/2021	BOCOM 3.25 11/22/21
QJ189862	22/10/2015	22/10/2022	-61	22/12/2015	22/12/2022	BOCOM 3.45 12/22/20
EF828393	15/11/2006	15/11/2021	-2	17/11/2006	17/11/2021	INDUBK 3.4 11/17/2021
JK9343183	05/05/2016	05/05/2026	22	13/04/2016	13/04/2026	INDUBK 3.74 04/13/2026
LW5458572	04/07/2016	04/07/2019	-14	18/07/2016	18/07/2019	INDUBK 3.2 07/18/2019

Table 8

Dependent variable: Bond yields (difference with matching government bonds)	
Intercept	0.51*** (0.023)
Treated dummy	-0.17*** (0.021)
Post dummy	-0.12*** (0.020)
Treated x Post	-0.31*** (0.026)
Company fixed effects	YES
Adjusted R^2	0.52
Observations	2615

*** signifies statistically significant at the 1% level of significance; ** at the 5% level of significance; * at the 10% level of significance.

Greening Monetary Policy: Evidence from the People's Bank of China

14-15 September 2021

International Conference on Statistics for Sustainable Finance

Camille Macaire
Alain Naef

Questions of "Green" Monetary Policy

- There are debates on the relevance of market neutrality when it comes to address "market failures" such as climate change (Schnabel, 2020)

- Christine Lagarde (2020):

  "In the face of what I call the market failures, it is a question that we have to ask ourselves as to whether market neutrality should be the actual principle that drives our monetary policy portfolio management."

- Literature shows that the ECB verbal interventions have an impact on green bond yields (Giovanardi, Kaldorf, Radke and Wicking 2021) and that the current portfolio of the ECB is probably not aligned with the European Union's targets (Oustry, Erkan, Svartzman and Weber 2020).

Why should we care about China?

China has a pioneering attitude when it comes to green finance

- China is the world's biggest producer of greenhouse gases (28% of world total in 2020); **carbon neutrality in 2060** will require a dramatic reshaping of the energy consumption model

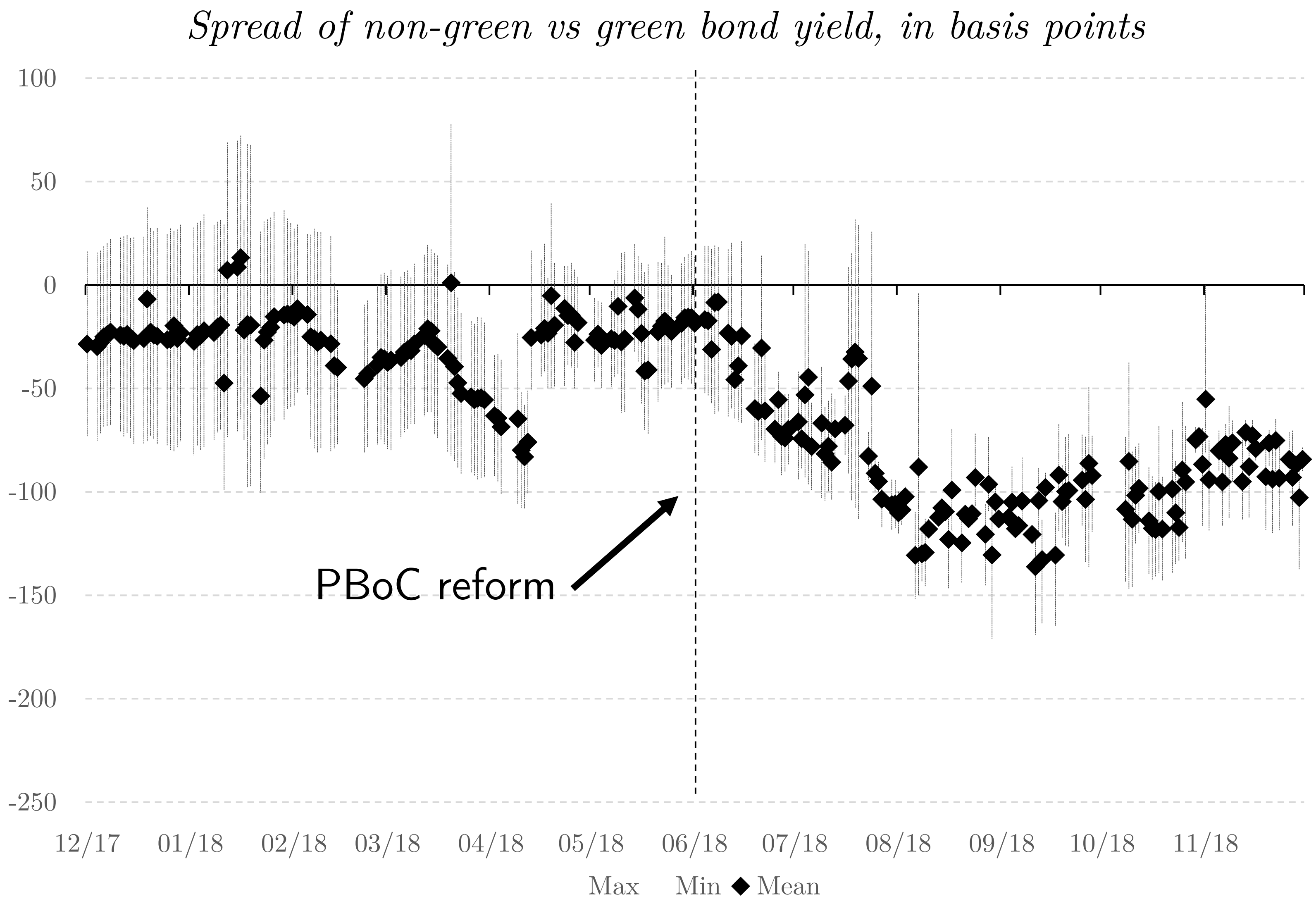
- Concrete action in supporting the development of green finance through official guidelines dates back a decade
  - Main breakthrough : **publication of Taxonomies in 2015** → led to more green bond emissions (China accounted for **12% of the global green bond emissions in 2019**, ranking second).

- **On 1st June 2018, the PBoC** changed its collateral policy and **started to accept green financial bonds** (bonds issued by banks)

Data overview

- Data for 10 green and 10 non-green bonds, for the 01/12/2017 to 30/11/2018 timeframe (retrieved from Bloomberg)
- 7 issuing firms, with both green and non green bonds for each firm, allowing to control for fixed firm effects
- The main difference is the green status (and to some extent maturities)

Raw data – green vs non-green yield differential 2017-18 (daily data)



Results over the whole sample

Dependent variable: Bond yields

Intercept	4.45*** (0.024)
Treated dummy	-0.32** (0.11)
Post dummy	-0.41** (0.19)
Treated x Post	-0.46** (0.19)
Company fixed effects	YES
Adjusted R^2	0.69
Observations	2609

Standard errors rare clustered at the bond level. *** signifies statistically significant at the 1% level of significance; ** at the 5% level of significance; * at the 10% level of significance.

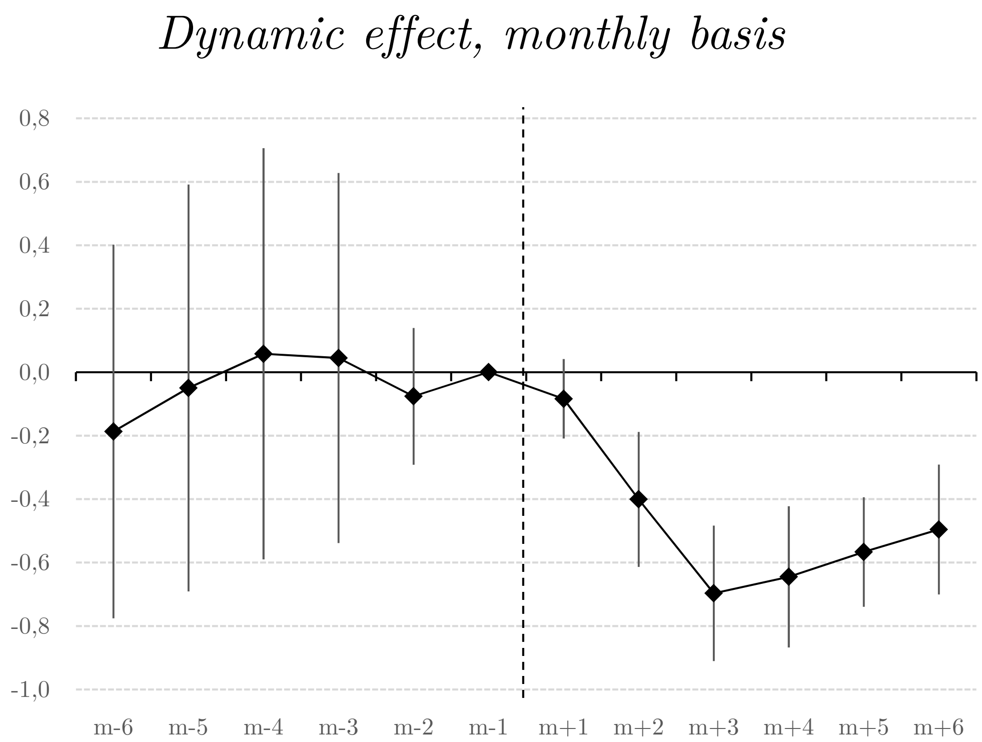
Using longer pre-trends in time series

- The part above showed that there is evidence that the reform implemented on June 1 2018 had a significant impact on the treated green bonds, compared to non-treated non-green bonds.
- Now, we use multiple time periods to generate a counterfactual policy change
- For periods prior to the policy change, the check act as a placebo test and allows us to examine the parallel trend assumption. For each periods after the policy change, it gives a view of the timeliness and persistency of the shock.

Previous DID $$Y_{it} = \alpha + \beta_1 T_i + \beta_2 P_t + \beta_3 (T_i \times P_t) + \gamma FE + \varepsilon_{it}$$

Counterfactual $$Y_{it} = \alpha + \beta'_1 T_i + \beta'_2 Test_{t'} + \beta'_3 (T_i \times Test_{t'}) + \gamma' FE + \varepsilon_{it'}$$

Monthly effect



Note: The perpendicular dotted line shows the policy change on 1 June 2018. The graph covers the period 01/12/2017 to 30/11/2018, hence 12 months. The 01/06/2018 shocks occurs in the beginning of m+1. Each point represents the coefficient of DID conducted between m-1 and the specific month. The vertical whisk around the point is the 95% confidence interval.

Policy implications and limitations

Policy Implications

- The PBoC was one of the first central banks to have a policy specifically targeting green bonds in 2018. Investigating the impact of the reform is an interesting case study for other central banks considering similar policies
- The reform happened in China as the green bond market was still nascent
    - Implications in terms of *Developmental Central Banking*
    - Also relevant for emerging countries

Limitations

- ECB already accepts green bonds so not applicable
- No measure of the effect on the real economy but see Giovanardi, Kaldorf, Radke and Wicking (2021) for a model on how this could impact the real economy

Conclusion

- We show that the policy by the PBoC reduced the spread between green bond and non green bond yields by **46 basis points on average**
- These findings can be interesting for other central banks considering similar policies, especially in emerging markets
- More research is needed to see if this impact on the secondary market also has an impact on the primary market, and on new green projects financed

International Conference on "Statistics for Sustainable Finance", co-organised with the Banque de France and the Deutsche Bundesbank

14-15 September 2021, Paris, France, hybrid format

BCCR's experience in environmental accounting and advancements of the Climate Change Strategic Analysis Group[1]

Irene Alvarado-Quesada,
Central Bank of Costa Rica

[1] This presentation was prepared for the conference. The views expressed are those of the author and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

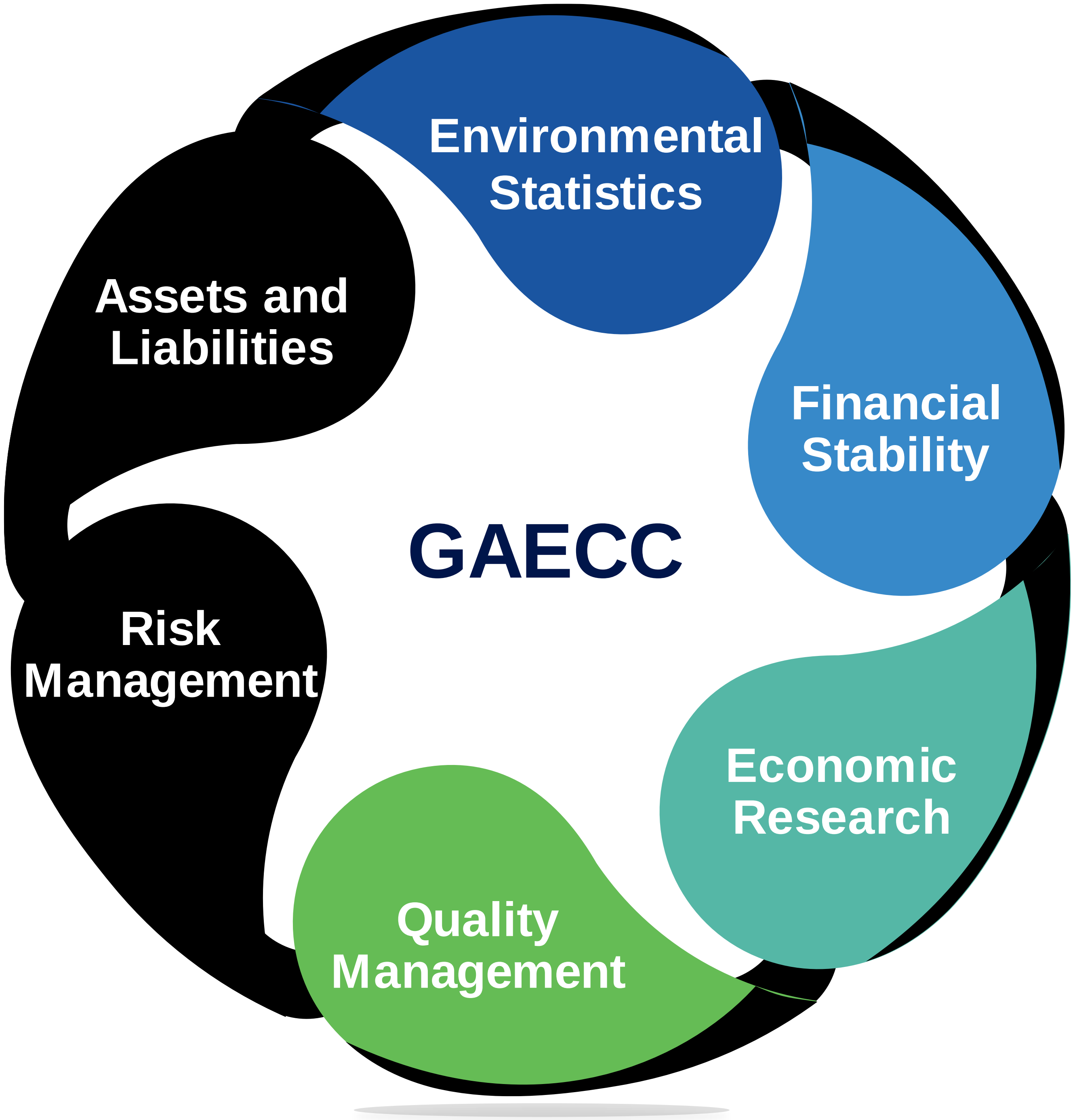
BANCO CENTRAL DE COSTA RICA

BCCR's experience in environmental accounting and advancements of the Climate Change Strategic Analysis Group

International Conference on Statistics for Sustainable Finance

Tuesday, September 14th, 2021.

Climate Change Strategic Analysis Group (GAECC)



Strategic Plan 2020-2023

Axis 1. Low and stable inflation with external stability

Climate change variables
- Analytical capacity
- Macroeconomic modelling

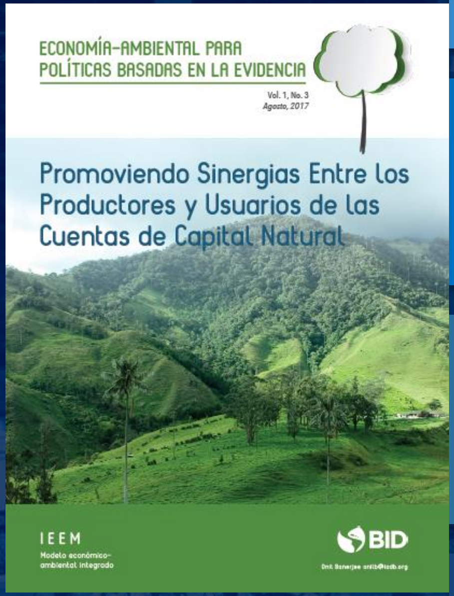
Axis 2. Stability of the financial system

- Stress tests
- Joint research (national and international entities)
- Coordination with supervisors
- Risk assessment update

BCCR BANCO CENTRAL DE COSTA RICA

Click here to access BCCR's Strategic Plan 2020-2023.

Integrated Environmental Equilibrium Model for Costa Rica (IEEM-CR)



Dynamic recursive GEM that incorporates the environmental accounts.

Forward-looking analysis of public policies and understanding of the impact of decisions prior to their implementation.

Risk scenarios that consider environmental factors for macroeconomic projections.

Use of the platform to link national and environmental accounts to analyze feasibility of achieving environmental commitments.

Some examples of the uses of IEEM-CR

Estimates for the National Development and Public Investment Plan 2019-2022

Projection of CO_2 emissions associated with the use of energy for the period 2015-2030.

[Link]

Energy substitution in transportation in Costa Rica: macroeconomic and environmental impacts

Alvarado-Quesada & Rodríguez-Zúñiga, 2019.

[Link]

Macroeconomic effects of a reduction of the single fuel tax

Agüero-Morera, 2019.

[Link]

Financial stability survey (February 2019)

Aim

To identify the vision of financial entities about the soundness of the financial system, in the face of main macro-financial events and vulnerabilities they perceive.

Assessment of the climate risk perception and management:

i. Degree of relevance in which risks from climate change and extreme climate are perceived,

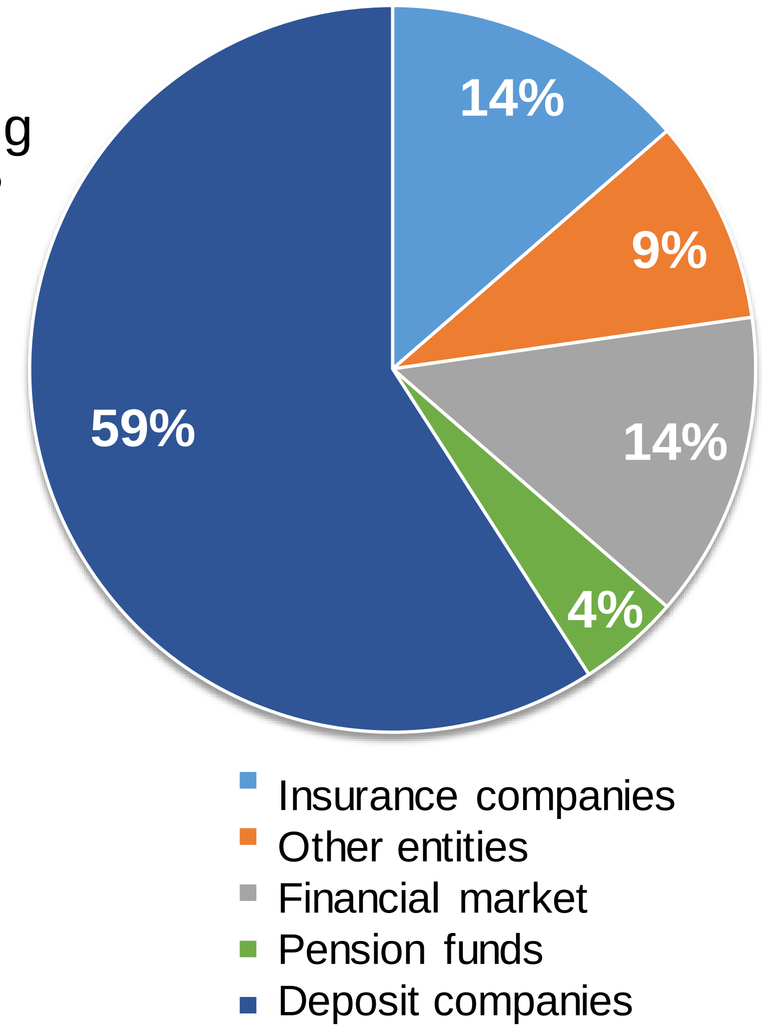
ii. Exposure according to business lines and climatic zones,

iii. Progress in risk management, and

iv. Identification of opportunities for proper management.

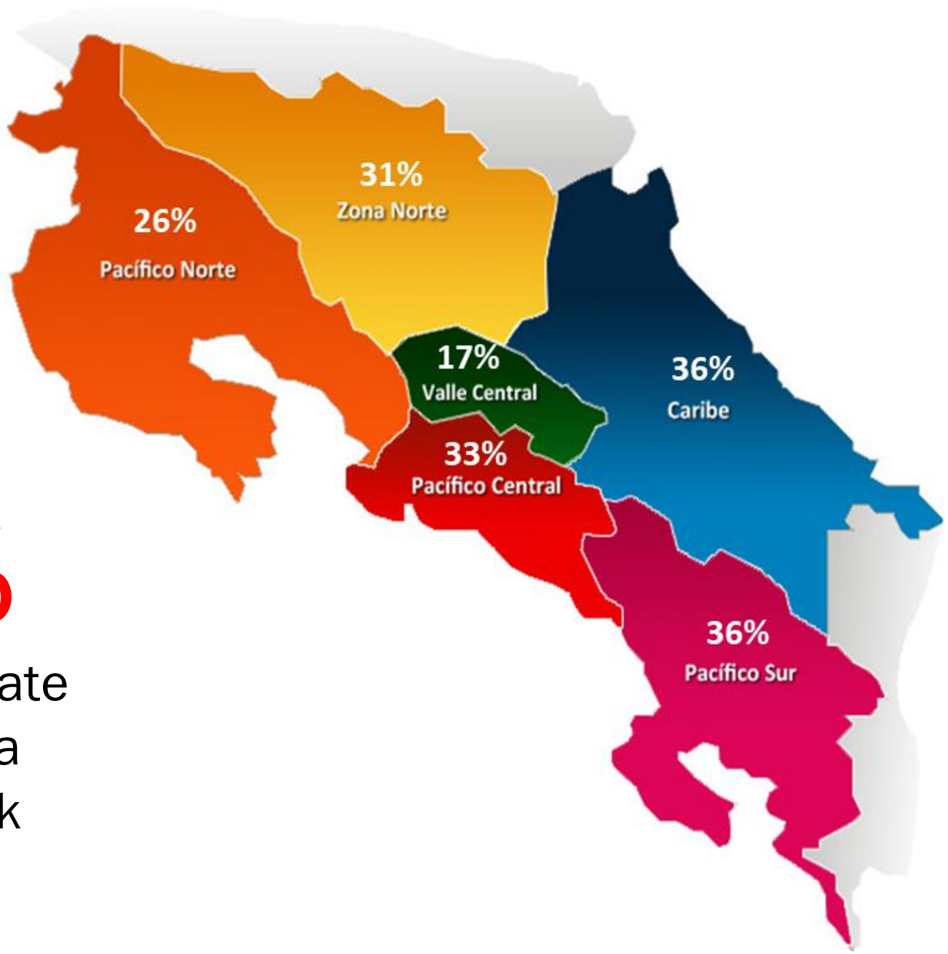
Perception of climate change as a relevant risk

Who is perceiving this risk?



52%

perceive climate change as a relevant risk



Design of a strategy to green the international monetary reserves

The governor of BCCR requested to work on a proposal to green the reserves.

While preparing the proposal, BCCR has contacted different entities for assistance and advice: NGFS, BIS, WB, several central banks and portfolio managers.

Preliminary proposal presented to the board of directors: Impact strategy to green reserve management

Aim

To generate a green and sustainable investment portfolio, without causing any prejudice to the current objectives of the Bank.

Investments in green bonds through the Green Bond Fund of BIS

Environmental “best-in-class” in BCCR’s portfolio

Agreement with the IMF: Three-year extended fund facility

MEFP Action	Agreed date
BCCR: Development of a roadmap to integrate climate change considerations into the design of monetary and fiscal policy.	December 2021

Climate change roadmap of BCCR – work areas

- Data and information availability
- Strengthening analytical capacity
- Climate change risk management in the financial system
- Greening of international reserves

BANCO CENTRAL DE COSTA RICA

Experience in environmental accounting and advancements of the Climate Change Strategic Analysis Group

International Conference on Statistics for Sustainable Finance

Irene Alvarado-Quesada

Climate Change Strategic Analysis Group (GAECC)

Tuesday, September 14th, 2021.

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How integrated reporting by banks may foster sustainable finance?[1]

Antonio Colangelo, European Central Bank (ECB),
and Jean-Marc Israël, formerly ECB

[1] This presentation was prepared for the conference. The views expressed are those of the authors and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

How integrated reporting by banks may foster sustainable finance?[1]

Antonio Colangelo, Senior Team Lead, Analytical Credit and Master Data Division, ECB
Jean-Marc Israël, former Head of the Analytical Credit and Master Data Division, ECB

Abstract

Central bank statistics have steadily developed over the past decades, especially in the wake of the 2008 financial crisis. Their use has steeply intensified in response to the crisis and the need for an in-depth understanding of economic and financial developments and a close monitoring of the impact of (monetary, economic and macroprudential) policy measures. A major breakthrough in the statistical data collection of the European System of Central Banks (ESCB) has been the move towards granular reporting of securities in the context of Securities Holdings Statistics since 2012, (further enhanced in recent years) and of loans through the AnaCredit project completed in 2018. Through the multiple dimensions available in the datasets and their combination with other data sources (eg registries on entities and commercial data sources), granular data have proven very valuable for a wide range of analyses, including on assessing risks arising from climate change. Going forward, the ESCB is working on reengineering and integrating its statistical reporting with the establishment of the Integrated Reporting Framework and the Banks' Integrated Reporting Dictionary. These projects will further enhance the availability and usability of granular data to policy makers and markets at large, and could align to other ongoing initiatives like the development of taxonomies to classify sustainable economic activities. They will accompany and contribute to the digitalisation and standardisation of financial market activities while also supporting and monitoring in how far they develop into sustainable finance.

Keywords: sustainable finance, climate change, central bank statistics, banks reporting, granular data, AnaCredit, integrated reporting framework (IReF), banks' integrated reporting dictionary (BIRD)

JEL classification: G21, E50, Q56, C81

[1] The views expressed are solely those of the authors and do not necessarily reflect the opinion of the European Central Bank. The authors would also like to thank Catherine Ahsbahs, Davide Continanza, Violetta Damia, Corinne Devillers, Francis Gross, Paul Hiebert, Angelo Saponara, Florian Schuster and Frauke Skudelny for useful discussions.

Contents

1. Introduction

The 2008 financial crisis showed limits of traditional central bank statistics to monitor and analyse economic and financial developments in interaction with a highly concentrated and interlinked global financial system. In a world of rapid and deep interconnectedness across markets and actors, policy makers need to unveil the heterogeneity across different economic areas (countries or groups of countries), industry sectors, market segments. The G20 Data Gaps Initiative[2] also gave an impetus for central bank statistics to further steadily develop towards timelier and disaggregated statistical information that allows drilling down from aggregates to micro developments.

The need for more granular data became prominent, at individual institution or even an individual instrument level on, eg, single securities and loans exposures. Granular data on loans through credit registers – and recently through AnaCredit in the ESCB – and holdings of securities, duly enriched with information on the characteristics of the borrowers and the lenders, can be directly used for panel data analyses. Granular data also allow for dynamically building aggregates that can provide researchers with methodologically sound time series, also when developing new analyses or new macroeconomic or macroprudential models. They also allow assessing with accuracy tail factors and distribution measures in a given population under review. Micro-prudential supervision has only given further impetus to the need for more detailed information. More recently, granular data have become key to analyse the impact of climate change and, more specifically, to assess physical risks that might impact the value of financial assets (also in their role as collateral) as well as transition risks that would arise from mitigation policies and changes in public sentiment. The increasing relevance of granular data, together with the interconnectedness of financial markets, also highlights the benefits of data harmonisation and standardisation, for regulators and for the financial industry.

The paper explores how the availability of granular data determined a shift in the analytical toolbox of central banks, and how this can help going forward in the context of assessing the risks of climate change and the pace of implementing sustainable finance. Section 2 looks into the main features of granular data, with particular reference to Securities Holdings Statistics and the Analytical Credit dataset (AnaCredit). Their use for policy analysis is possible also thanks to an extended use of identifiers and through linkages to the ESCB Register of Institutions and Affiliates Data (RIAD). Section 3 puts the paper into perspective, describing the wide range of policy analyses run by central banks and other policy makers and by researches. The section also looks into more detail in the analytical needs arising from climate change, discussing current uses and existing challenges. Section 4 introduces the Integrated Reporting Framework (IReF) and the Banks' Integrated Reporting Dictionary (BIRD), two on-going ESCB initiatives aimed at increasing the efficiency of data collection from banks. While these initiatives aim at alleviating the burden on the banking system, they will improve the information set of policymakers in terms of content and usability of the data in particular to assess sustainable finance. The section also offers a longer-term perspective, providing some perspectives to the future of reporting in

[2] See the IMF website for detailed information on these initiatives.

the digital age, notably to classify sustainable economic activities. Section 5 concludes.

2 Recent developments in processing granular data

Traditionally, economic and financial statistics have focused on describing the economy through aggregated indicators, implicitly considering economic areas as homogeneous entities. Describing the complex behaviour of economic agents by means of simple or weighted averages led to a substantial loss of information and to ignore complex relationships between agents. Furthermore, defining and developing macroeconomic statistical indicators require long lead-time, and the resulting aggregates provide little flexibility to support a wide range of policies.

The financial crisis showed the limits of such paradigm and catalysed the development of granular datasets, which allow measuring economic phenomena at the level at which they occur. These better supports policy makers in analysing the heterogeneity of the economy and financial markets. The new paradigm enabled central bank statistics to 'move beyond the aggregates' towards the collection of granular data to serve diverse policy needs in a timely, flexible and cost-effective manner. Indeed, granular data allow high flexibility and timeliness in adjusting to new user demands. Also thanks to new performing technologies, it is now possible to extract, classify and aggregate data at any point in time — also building consistent time series over several years — to respond to new user requests, without collecting new information either via an ad-hoc survey or via a new (aggregate) statistical requirement. An additional value for analysis of the data is the possibility for analysts to drill down from aggregated to institution-level or contract-level data so as to better understand new developments.

The section provides a high-level overview of Securities Holdings Statistics, AnaCredit and RIAD, which currently represent the core granular statistical datasets of the ESCB.

2.1 Securities Holdings Statistics

Securities Holdings Statistics provides since 2013 security-by-security quarterly information on securities held in the euro area, broken down by instrument type, sector and residency area of the debtor and further additional classifications.

Two modules are currently covered in the dataset. The sector module provides information on the holdings of listed ISIN securities by investors resident in the euro area (eg households in Germany or banks in France) and holdings of euro area securities by investors resident outside the euro area and deposited with a euro area custodian. The group module covers individual holdings by the largest banking groups with head offices in the euro area.

The data refer to four instrument types: short- and long-term debt securities, listed shares and investment funds shares/units. The collected information focusses on the holder side (eg amount held of a particular ISIN), while the data are enriched during the compilation process with reference data from the ESCB reference database on securities (ie the Centralised Securities Database[3]), which contains rich information on individual securities such as the type of security, the name and sector of the issuer, the maturity and issue dates, price, outstanding amount/market capitalisation. Using ISIN codes, securities issues statistics can also be derived.

Additional attributes and/or dimensions can be obtained by linking Securities Holdings Statistics with other databases using a common identifier (the ISIN code and the name of the issuer are the most common options).[4]

2.2 Credit registers and AnaCredit

As regards loans, data on credit and credit risk were traditionally collected in several countries to support a variety of needs, often as a means to help banks in assessing the creditworthiness of their clients or potential new borrowers. In other cases, micro-prudential supervisors intended to better assess credit exposures of the supervised banks. In most cases, the wealth of information collected on credit and credit risk were scarcely shared across national authorities, and even less so with other competent authorities.

In line with initiatives by the World Bank (2011) to encourage credit registers, AnaCredit marks a paradigm shift for central bank statistics. The initiative was launched in 2013 to construct a pan-European granular database on loans provided by euro area credit institutions to legal entities that would model credit intermediation on an instrument-by instrument, counterparty-by-counterparty and protection-by-protection basis (as well as the relationship among these three building blocks). Since 2019 it provides a large set of harmonised and comparable information to Eurosystem users, with an unprecedented level of detail (ie 88 attributes that were defined based on the needs of a variety of business areas). The standardised attributes allow defining a wide range of indicators across multiple dimensions, with the possibility to back-cast them, also supporting an assessment of modelling and their results, eg in the context of stress testing.

As discussed by Collazo and Watfe (2017), the variables and measures included in AnaCredit can be combined in multiple ways to measure economic phenomena at different levels in a flexible way and construct networks between agents when enriched with reference data on entities (see below Section 2.3 on RIAD). This helps, among others, to analyse concentration of risk at different levels, eg within banking and corporate groups, or according to sectors of economic activity. Distribution of individual measures can be derived across the whole population, as well as across strata or segments. For instance, the tail(s) of the distribution reveal important insights, eg about risky counterparties. These analyses were hardly possible beforehand at euro area level. Even where national credit registers were in place, significant methodological differences existed in terms of scope, underlying definitions, collection basis (eg loan by loan or borrower by borrower) and reporting thresholds. The successful implementation of AnaCredit also relies on the establishment of the BIRD dictionary (see also Sections 4.2 and 4.3), which paved the way for further harmonising its implementation across euro area countries.

3 See ECB (2010).

4 See also Fache Rousová and Rodriguez Caloca (2014) for a more detailed description of the dataset.

2.3 The role of a repository of legal entities

The value of granular data on exposures and risks relies on the possibility to analyse the heterogeneity of the economy. Whether the granular data are collected from reporting agents or are purchased from commercial data providers, the first crucial step is the effective identification of the entities and, in the case of legal entities, the entity's ownership structure, eg to identify the actual risk bearer (usually the headquarters).

Traditionally, the identification of counterparties in the euro area has relied on national heterogenous systems. At the international level, with the support of G20, the Financial Stability Board and many regulators around the world, an initiative has been launched in recent years to develop a global Legal Entity Identifier (LEI). The current coverage of the LEI is still suboptimal and relationships across entities are still scarce.[5] In general, the LEI aims at providing a snapshot of factual information. For instance, the relationships are based on the accounting group perimeter of the legal entities, and no information is available on other variables of interest for policy purposes like the sector of economic activity (i.e. the NACE code), the statistical sector of classification or other relationship data.

This role is normally fulfilled by repositories of legal entities, which require an institution complementing facts with additional informational that require judgement. In the euro area, RIAD has been established as a common repository of master data on entities. Whereas it initially helped identifying reporting agents under ECB statistical regulations, its coverage has extended to ca. 10 million entities throughout the EU that are counterparties to loans covered in AnaCredit. RIAD can provides for the unique identification of legal entities, linking the existing available national sources, the LEI where available and information collected from reporting agents. Further to information on characteristics of the entities such as the statistical institutional sector and the NACE code, RIAD also supports information on links with other institutions to facilitate a broad range of policy analysis, both at the aggregated level (e.g. foreign direct investment relationships for the balance of payments) and at the exposure level.

3. Strengthening the analytical frameworks of policy makers with granular data

This section describes how granular data provided, in particular but not only, by Securities Holdings Statistics, AnaCredit and RIAD have strengthened the analytical framework of traditional central banking policy areas.[6] The use of granular data to assess climate-related risks is then discussed, reviewing the opportunities that granular datasets opened to support these analytical needs and the existing challenges that would need to be tackled going forward.

5 See also GLEIF (2021)

6 See also Israel and Tissot (2021)

3.1 Monetary policy conduct and operation

The monetary analysis toolset has much enriched in recent years thanks to the use of granular data along two main dimensions: zooming-in from aggregated data for the banking sector to bank-specific information (eg risk exposures and individual balance sheet information) and including data on individual loans and securities held duly enriched with information on the characteristics of the borrower (eg probability of default and rating). The resulting large datasets are then used for panel data analyses with a wide range of applications, like studying demand and supply effects in credit markets[7], or identifying shocks to credit demand and credit crunches. Granular credit data are also key to assess the heterogeneity in segments of lenders and borrowers that policy makers should consider when defining policies[8] and identify potential vulnerabilities as bottlenecks in some sectors may spread over other sectors, also depending on specific features of different economies.

A key aspect is the analysis of credit market conditions for small and medium-sized enterprises (SMEs), also in response to monetary policy measures. It has long been uneasy to stratify the population of enterprises. Statisticians and economists have developed international standards to accurately define industry activities – eg the International Standard of Industry Classification or the General Industrial Classification of Economic Activities within the European Communities (NACE)[9]. Crossing activity and size fosters a meaningful assessment of aggregate developments and trends in credit to the economy. This is all the more relevant that SMEs have the strongest impact on employment. Indeed, an accurate stratification of businesses requires also other criteria, in particular the size of firms (in turnover, number of employees, or total balance sheet).

These various elements are important both for defining monetary policy, especially unconventional monetary policy measures (eg ECB Targeted Long Term Refinancing Operations), and for monitoring the transmission channels of standard, as well as non-standard monetary policy measures. This fosters the possibility to analyse the "credit channel" and "risk-taking channel" of monetary policy. This also allows fine-tuning the measures more accurately and in a timelier manner.

3.2 Macroprudential policies

Whereas micro prudential supervision focuses on the soundness of individual institutions, macroprudential policies address systemic risk, which is the risk that the entire financial system may collapse as a consequence of idiosyncratic events affecting individual institutions. The assessment of the interconnectedness among financial intermediaries and market concentration are thus at the very core of macroprudential policies. As discussed in Collazo and Watfe (2017), granular datasets prove essential in this context. Besides the high level of detail, which provides flexibility to define new indicators, granular datasets (duly complemented by reference information on counterparties – eg their ultimate parent) allow users to identify linkages between agents, which are key to assess risk concentrations and

[7] For instance, see Altavilla et al (2020).

[8] For instance, see Altavilla et al (2018).

[9] See the dedicated pages on the websites of the United Nations and of Eurostat.

propagations. In addition, granular data would enable to focus on specific parts of the distributions – eg the tails.

Granular data is also instrumental for defining structural and cyclical macroprudential policies, as well for monitoring their effects and fine-tune them when needed. For example, instrument-level data on loans and holdings of securities can be used to set-up structural or countercyclical capital buffers[10] or to define limits on loan-to-value ratios (LTVs).

More recently, macroprudential (and financial stability) analyses have increasingly looked at risks arising from climate change and the greening of the economy. The use of granular data in this context is discussed in detail in the next section.

3.3 Micro prudential supervision

Micro prudential supervision aims at assessing the stability of individual supervised institutions. These activities are performed based on data on individual banks but can benefit significantly from granular risk data on loans and holdings of securities. For instance, supervisors can assess the effectiveness and accuracy of internal ratings models of banks and analyse credit exposures vis-à-vis groups of connected clients (non-financial groups, supply-demand chains, country-risk, indirect financing of firms). At the juncture of on-site inspections in supervised banks, accurate credit and credit risk data facilitate the identification of strata in the credit portfolio of institutions for a more effective and efficient review. This is particularly the case for the identification of non-performing and forborne loans, or for assessing the fairness in the way institutions classify their loans in different classes.

Granular data may also reduce the burden on banks when running stress tests, as data are already available to supervisors and may facilitate the dialogue with the banks on salient features in the results of the tests.

3.4 Using granular data to assess climate-related risks

In recent years central banks around the world have intensified their analytical work aimed at assessing climate-related risks to financial stability and monitoring of brown vs green financing. For instance, the Network of central banks and supervisors for Greening the Financial System (NGFS) was launched in 2017 to prepare approaches that could operationalise an active development in financing towards sustainability.[11]

Climate change poses unique challenges to financial stability through two main channels: i) physical risks, relating to natural disasters such as flooding and wildfires as well as heat and water stress, that might impact the value of financial assets (eg corporate and household exposures of financial intermediaries in stressed areas); and ii) transition risks, arising from mitigation policies and changes in public sentiment.

Analyses aimed at assessing and monitoring these risks intrinsically need to capture the heterogeneity of the economy and therefore call for an intensive use of

[10] For instance, see Budnik et al (2019).

[11] See also Network for Greening the Financial System (2020).

granular data to assess the impact across groups of counterparties rather than modelling aggregated developments. As described in ECB (2021a), a "*fine resolution measurement is required to trace out heterogeneous and novel physical and transition risk impacts across geographies, sectors and firms.*" For instance, to capture the localised effects of physical risks, granular data is key to correctly identify the location of counterparties and/or collateral. Similarly, for analysing the impact of transition risks, granular data can be used to assess the nature of counterparties and even individual exposures on loans and securities, to the extent they relate to activities with different climate impact.

In general, assessing climate-related financial risks requires a three-layer approach: derive economic risk factors from climate risk drivers; linking climate-adjusted economic risk factors to exposures of banks and other financial intermediaries; and translating this input into an assessment of the related financial risks based on sound analytical models. As regards the first layer. geolocational datasets from public or commercial data providers are available to capture risks of physical damage associated with physical risks. Sectoral and institution-level data on carbon footprint can also be used to define scenarios on risks arising to the green-transition.

These new user needs were certainly not the strongest drivers when the ESCB granular reporting was first set-up. Through the multiple dimensions available in the granular datasets and their combination, it becomes possible to assess in great depth the status-quo and closely monitor the extent to which the funding evolves – eg from brown to green firms. However, as explained in ECB (2021b), data are currently far from being complete and their usability is often questionable not least due to limited comparability. New and more granular data collections will thus be needed for both physical and transition risk assessments. The EU regulatory framework for sustainable finance (including the EU Taxonomy[12] for sustainable activities), should contribute to filling in some of the existing data gaps.

4. On-going ESCB initiatives and a vision for the future

Mapping climate risk drivers to financial exposures is also quite challenging at current stage. Firstly, gaps exist in the current granular data collections. For instance, AnaCredit covers loans of credit institutions above € 25,000, leaving out many banks' counterparties and particularly smaller firms. In addition, AnaCredit does not cover other non-banks financial intermediaries, which do offer loans to the economy (e.g. factoring and leasing companies). Similarly, Securities Holdings Statistics focus on listed ISIN securities and do not foresee the direct collection of data on holdings of securities from securities and derivatives dealers and captives, resulting in potential information gaps.

The existing granular statistical datasets are also based on independent legal acts and in many countries are collected in silos. This is challenging for users, who often have to reconcile the available statistical information to effectively support their analyses. In fact, the dictionaries that are supporting the national statistical collections

[12] Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088 (OJ L 198, 22.6.2020, p. 13).

are harmonised, but not fully standardised, meaning that concrete financial market instruments that are mapped to the statistical definitions of 'loans' and 'securities' may not be completely overlapping across countries (and across reporting agents). The reconciliation of statistical and supervisory granular datasets may be even more challenging due to the use of different dictionaries.

In line with the approach that was followed for collecting data on insurance corporations in 2016 and for pension funds in 2019 thanks to a very close cooperation between the ECB and EIOPA and across national authorities in the EU, the ESCB has embarked into visionary data integration activities for banks. These initiatives are mainly aimed at reducing the burden of reporting agents while providing users with data of better quality, and are strictly connected to the feasibility study requested under Article 430c of the updated Capital Requirements Regulation[13].

The section provides a brief overview of the on-going activities and stresses the key role of a data dictionary going forward. Some considerations are also provided for the longer-term, in the light of the opportunities that digitalisation may create.

4.1 The Integrated Reporting Framework (IReF)

The IReF integrates banks' statistical reporting requirements into a unique framework that would be directly applicable to euro area banks, without any translation into national collection frameworks. In particular, the IReF targets primarily the datasets collected under the ECB regulations on MFI balance sheet item (BSI) and interest rate (MIR) statistics, Securities Holdings Statistics and AnaCredit. As explained in Bier et al. (2018), in order to effectively integrate the existing requirements, the IReF will encompass a set of requirements with different levels of granularity that will consolidate the existing reporting lines across countries. To achieve an effective multiuse of the data, it is envisaged to collect most of the information at a monthly frequency and according to earlier transmission timelines compared to the current timeliness in the national statistical collection frameworks. For instance, if loan by loan and security by security data would be directly used to compile aggregated statistics, the reporting of this information shall take place at monthly frequency and early enough to be able to release data on monetary aggregates. Processes will overall be speeded up, with more possibilities to develop early indicators.

Collecting data as part of the same framework ensures that they are integrated, consistent and standardised at the source. Several data gaps are also being looked at. For instance, while the shared AnaCredit dataset only covers loans to legal entities above the € 25,000 threshold, the current IReF baseline scenario foresees the granular collection of data on all loans to legal entities. Similarly, banks' exposures to extra-euro area counterparties include significant positions relating to non-ISIN securities, which are currently excluded from Securities Holdings Statistics. The proposed

[13] Regulation (EU) 2019/876 of the European Parliament and of the Council of 20 May 2019 amending Regulation (EU) No 575/2013 as regards the leverage ratio, the net stable funding ratio, requirements for own funds and eligible liabilities, counterparty credit risk, market risk, exposures to central counterparties, exposures to collective investment undertakings, large exposures, reporting and disclosure requirements (OJ L 150, 7.06.2019, p. 1).

scenario for the IReF is to collect this information at the granular level.[14] These possible extensions may prove useful in the area of sustainable finance.

While the IReF is currently focusing on the integration of the existing statistical reporting of banks (ie deposit-taking corporations, in the statistical terminology), going forward it could be further strengthened. In fact, the IReF is being developed as a scalable product that could easily be extended to cover the existing reporting of other financial intermediaries or set out new reporting requirements in an integrated and standardised way.[15] For instance, should the user needs justify it (assessed via the 'merits and costs' ESCB procedure), (money market and non-money market) investment funds or non-bank financial corporations engaged in factoring and leasing could report according to the draft IReF reporting scheme. Such reporting in a standard format would be facilitated by the possible re-use of pieces of software within banking groups or via software vendors. Moreover, based on the EU Taxonomy, the IReF scheme could be enriched to cover the classification of individual loans or securities recorded on-balance sheet to help assess whether the economic activities they finance can be considered sustainable. The labelling and scoring provided by institutional and/or market sources could possibly be extended to counterparty data.

The IReF implementation will provide new impetus on closing data gaps on master data on entities. The coverage of RIAD will further extend to 'all' legal entities that are borrowing from euro area credit institutions. The sharing of master data on legal entities with reporting agents (or at least the main attributes that are not confidential) will also be instrumental to the process, making the identification process of counterparties easier and thus enhancing the quality of reference information available in the system overall.

4.2 The Banks' Integrated Reporting Dictionary (BIRD)

The ESCB's medium-term approach to data collection from banks also foresees supporting reporting agents in optimising the organisation of the information stored in their internal systems (e.g. for accounting, risk management, securities or deposits) in a single redundancy-free 'input layer', which could then provide the basis for fulfilling the statistical requirements covered in the IReF, as well as prudential and resolution reporting obligations. The BIRD also defines transformation rules to be applied to banks' input data in order to transmit data to the authorities. Those transformation rules would be specified in a single formal language facilitating their implementation by banks, leading to reduced efforts and costs. Figure 1 shows how BIRD and IReF will affect the reporting of banks.

The BIRD is being developed in close collaboration by a group composed of members from the ECB, some euro area NCBs and the banking industry. Banks occupy a central role in the process, as they have specific knowledge of their operational systems and reporting systems, while the ECB and NCBs mainly work as catalysts of the initiative and ensure the management and the maintenance of the BIRD over time.

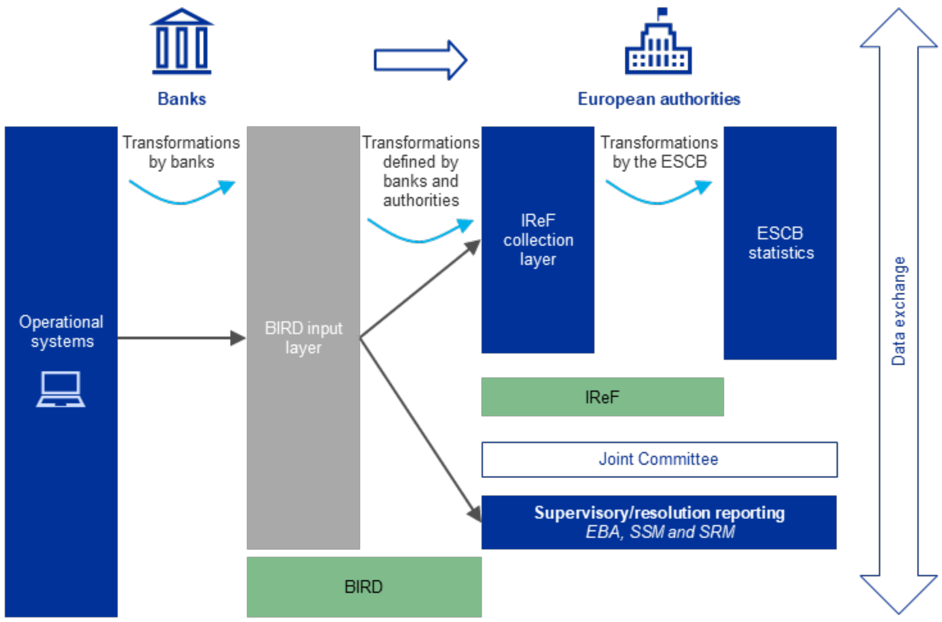
[14] These possible features of the IReF reporting were tested with the stakeholders in the cost-benefit assessment that took place from November 2020 to April 2021; see also ECB (2020c). The results of the questionnaire are currently being analyses.

[15] See also Sections 4.2 and 4.3 for some perspectives on the wider integration of statistical, prudential and resolution data.

Also due to its governance structure, the BIRD can be easily extended to incorporate other data needs of banks. Due to the granularity of input layer, for instance, it could be relatively straightforward to model additional variables of relevance for sustainable finance – eg for internal purposes, to fulfil disclosure requirements or submit them to authorities, as needed.

The BIRD and IReF are strictly related to each other. Without the IReF, the BIRD would need to undergo national adaptations to tune the input layer to the national collection systems of each country. In turn, the BIRD moves one step closer to the operational systems of banks, enabling banks to fulfil all reporting requirements in a consistent way. To the extent this approach will bear fruit, in the future authorities might be more inclined and willing to abandon aggregated (eg template) reporting in favour of a more structured and (close to) redundancy-free granular reporting. Aggregated reporting might stepwise diminish through an extension of the IReF. Only limited aggregated requirements may continue to apply as reporting agents should remain liable for certain values, eg on the side of prudential requirements, leading to an integration of statistical, prudential and resolution data.

Figure 1. Eurosystem strategy for collecting data from banks



Notes: The figure is from ECB (2020b). EBA stands for European Banking Authority, SSM for Single Supervisory Mechanism and SRM for Single Resolution Mechanism.

4.3 The role of a single data dictionary

The IReF and the BIRD will rely on a common data dictionary[16] that will ideally be developed as a joint endeavour by the ESCB, the European Banking Authority (EBA), the Single Resolution Board and the Directorate General for Financial Stability,

[16] See ECB (2020b).

Financial Services and Capital Markets Union (DG FISMA) of the European Commission as a follow-up to the on-going EBA feasibility study.[17]

This common dictionary can be thought of as a repository of the definitions (and the corresponding codifications) of all the minimum distinct data items which are required to derive the existing statistical, prudential and resolution requirements. It will thus ensure the standardisation of the definitions, reducing the effort banks would otherwise make interpreting and reconciling instructions formulated in different frameworks. Even in the absence of the physical integration of statistical, prudential and resolution requirements depicted in the previous section for the longer-term, such a data dictionary would thus support the 'semantic' integration of the requirements. Most crucially, for users this will introduce much higher quality thanks to a precise and unambiguous definition of the information. For instance, with a common data dictionary the linkage between the definitions of the Large Exposure requirements with AnaCredit and Securities Holdings Statistics would be performed at the source.

While the BIRD is expected to remain voluntary for the banking industry (at least for the time being), the use of a common dictionary will represent an important incentive for adopting it.

4.4 The future of reporting in the digital age

The on-going acceleration in digitalisation activities, also in finance, creates unique challenges for statistical measurement. Machine-to-machine interactions are fast and automatic and lead to high data volumes on a global scale which cannot be controlled and measured by humans with a traditional approach – i.e. by reconciling source information to ensure harmonised output based on standards and manuals.

As elaborated in Colangelo et al (2021), while the initiatives mentioned above are moving in the right direction, only a complete change of paradigm can effectively support measurement activities of statisticians in the longer run. Statistics have to adapt to the world they measure, effectively using the traces that digital interactions leave. The economy could be seen as a network of contracts that connect a global population of parties. A data infrastructure that would hold globally standardised identification of all parties and contracts in real-time represents a key strategic objective going forward. As regards the identification of legal entities, the LEI system could represent a good basis but would need to obviously aim at a universal coverage. All contracts should then be represented in a standardised, mathematically rigorous algorithmic language. The development of standards for financial contracts is thus instrumental towards the setting-up of such infrastructure. While many initiatives are on-going in this direction, more global efforts, coordinated among the relevant authorities, need to be made.

As an example, a repository of master data on legal entities as indicated in Section 2.3 would be a derived product of such an infrastructure. All relationship data step from contracts, and those can be used to trace in (close to) real time linkages of all types among legal entities. The dictionary of BIRD and IReF would also have to

[17] The development work would be carried out by a Joint Committee to be established by the mentioned authorities; see also ECB (2020a). The Joint Committee is also depicted in Figure 1 as a point of union between statistical reporting on one side, and prudential and resolution reporting on the other.

converge to the new public-good standards of financial contracts, thus making possible automatic and live provision of data to users. Such granular structured data would truly enable analyses suited for a digital economy, eg based on machine learning and other artificial intelligence algorithms.

5. Conclusions

A major breakthrough in the statistical data collection has been the move towards granular reporting of securities (since 2012, further enhanced in recent years) and of loans through the AnaCredit project completed in 2018. A pan-European register of institutions (RIAD) also plays a key role, notably in matching lending and borrowing entities as well as, in the case of loans, protection providers. This new paradigm has provided central bank analysts and markets with a more accurate picture of banks' exposures and of businesses' indebtedness that enable them to better assess the heterogeneity of the economy. Through the multiple dimensions available and their combination, the datasets have driven recent research efforts in the area of climate change, notably through the assessment of new risks to financial stability as well as monitoring the credit flows for firms ranging from brown to green.

At the same time, the existing data availability is still suboptimal, and several challenges were identified in this paper. The on-going ESCB initiatives in the area of statistical reporting of banks will bear fruits for policy analysis in terms of data content, including a full standardisation of the dictionaries applied across the euro area and EU for statistical reporting and beyond, and in terms of connectivity with reference data on entities and other external datasets.

The overall approach will also facilitate policy work to assess and monitor sustainable finance in an effective and efficient way, while providing all users, analysts, researchers and economists with rich, time-consistent, multidimensional datasets.

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How integrated reporting by banks may foster sustainable finance?*

International Conference on “Statistics for Sustainable Finance”

Paris, 14-15 Sept. 2021

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* The views expressed are solely those of the authors and do not necessarily reflect the opinion of the European Central Bank nor of Banque de France

Content

1. Introduction

Traditional macroeconomic statistics…

- consider economic areas as homogeneous entities
- ignore complex relationships between agents
- have long lead-time and provide little flexibility

… while granular data

- allow to reflect the heterogeneity of economies and can be used for panel analyses
- measure economic phenomena at the level at which they occur
- allow high flexibility by users in handling data
- enable them to drill down from aggregated to institution-level or contract-level data so as to better understand new developments

"…well-established ESCB statistics will continue to provide the "big picture" of economic developments. But we should also offer a magnifying glass."

Mario Draghi, ECB President, 8th ECB Statistics Conference, 2016

2. Recent developments in processing granular data

Securities Holdings Statistics

- since 2013, security-by-security quarterly information on securities held in the euro area, broken down by instrument type, sector and residency area of the debtor, and
- further additional classifications

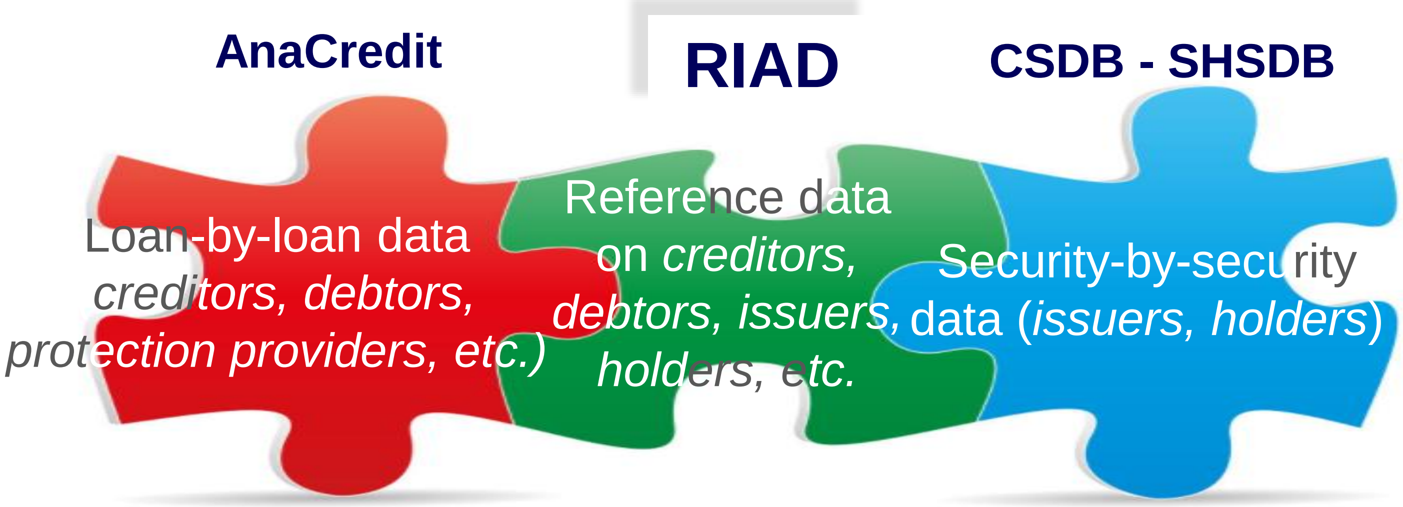
AnaCredit

- pan-European granular database on loans provided by euro area credit institutions to legal entities that models credit intermediation on an instrument-by instrument, counterparty-by-counterparty and protection-by-protection basis
  - ✓ as well as the relationship among these three building blocks
- since 2019, it provides a large set of harmonised and comparable information – ie 88 attributes defined based on the needs of a variety of business areas

2. Recent developments in processing granular data

The role of a repository of legal entities

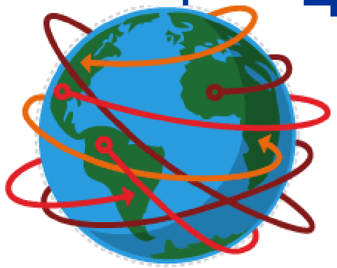
- enrich granular data with information on borrowers and creditors as regards
  - ✓ their characteristics – eg sector of activity, residency
  - ✓ their relationships – eg the actual risk bearer
  - ✓ identifiers to link granular data with each other and other sources
- RIAD as the backbone of all ESCB granular statistics



3. Policy uses of granular data

Monetary policy conduct and operation

- study demand and supply effects in credit markets
- assess the heterogeneity in segments of lenders and borrowers -
  ✓ eg credit market conditions for SMEs
- monitor the transmission channels of standard, as well as non-standard monetary policy measures, eg TLTROs



Macroprudential policies

- assess risk concentrations and propagations
- focus on specific parts of the distributions – eg the tails
- define structural and cyclical macroprudential policies – eg set-up structural or countercyclical capital buffers or to define limits on loan-to-value ratios

Micro prudential supervision

- analyse exposures to specific sectors or individual (groups of) counterparties
- assess the effectiveness and accuracy of internal ratings models of banks
- reduce the burden of stress tests, as data are available to supervisors

4. A closer look at sustainable finance

Climate-related physical and transition risks

- capturing the heterogeneity of the economy calls for an intensive use of granular data
- link risk factors from climate risk drivers, eg based on geolocational datasets or data on carbon footprint, to exposures of banks

Brown vs. green financing

- analyse in detail the nature of counterparties, the *credit allocation and their environmental impact*
- monitor developments *towards green financing*
- EU regulatory framework for sustainable finance, including the EU Taxonomy for sustainable activities

4. A closer look at sustainable finance

Challenges

- Ever rising need for more data, with greater detail and accuracy
- Some remaining data gaps
  - ✓ AnaCredit covers loans of credit institutions above € 25,000, leaving out many banks' counterparties, notably smaller firms, and loans from non-bank financial intermediaries
  - ✓ SHS covers listed ISIN securities and does not foresee the collection of data on holdings of securities from securities and derivatives dealers and captives
- Datasets are collected in national silos and not fully standardised dictionaries
- Still relatively limited connectivity of granular data with external datasets

5. Ongoing ESCB initiatives (1/2)

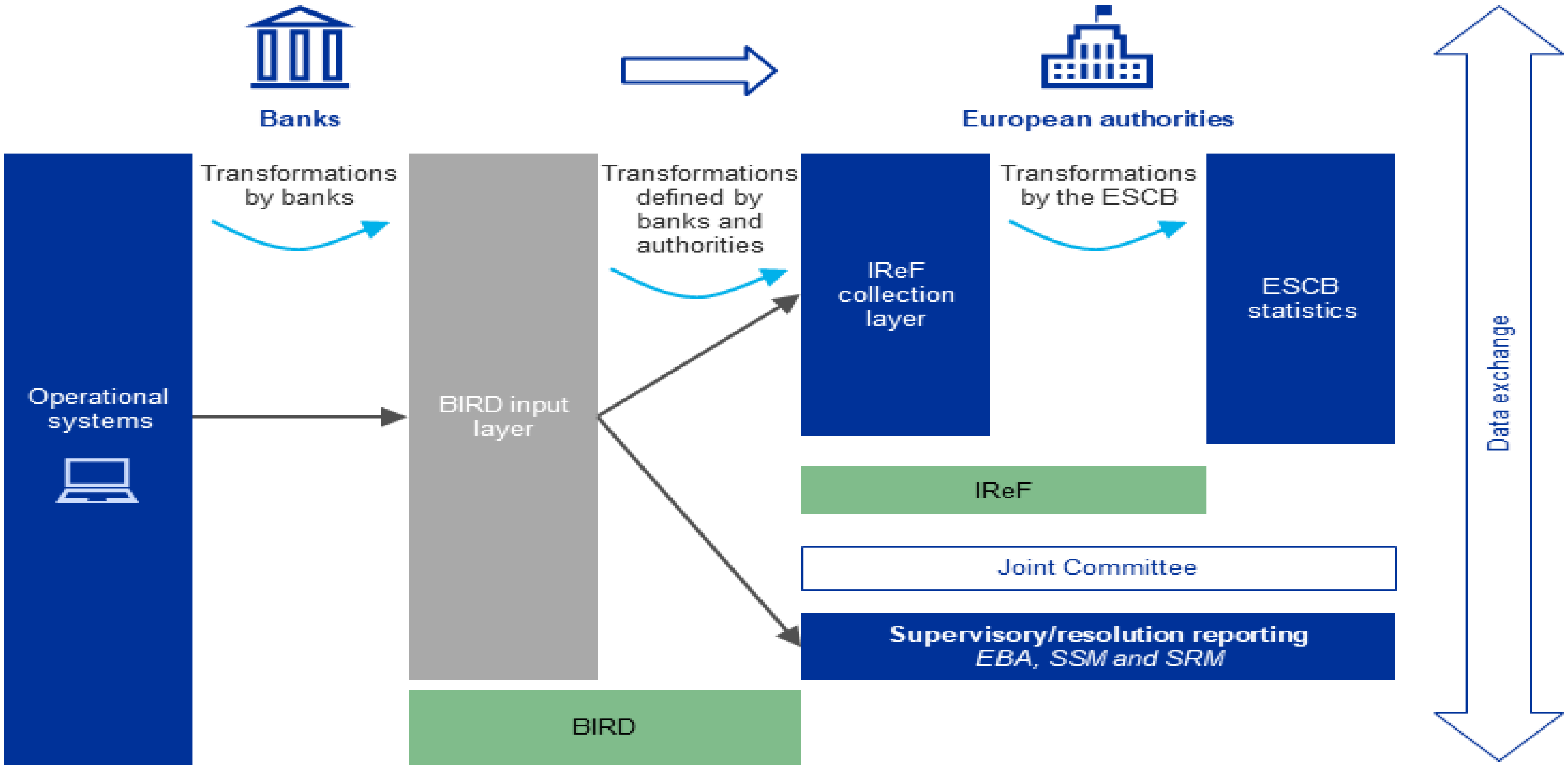
ESCB Integrated Reporting Framework (IReF)

- IReF for banks across countries and across (initially statistical) domains, with a focus on *ECB statistical requirements*
- gaps in granular data will be addressed, as well as existing gaps in master data on entities, eg extension of entities covered in RIAD to all banks' counterparties
- reporting based on a standard data dictionary; potentially shared with prudential and resolution reporting - Article 430(c) of CRR II
- scalable project that can extend granular reporting to other financial intermediaries

Banks' Integrated Reporting Dictionary (BIRD)

- organise data in banks' internal systems in a single redundancy-free 'input layer' as basis for fulfilling the statistical, prudential and resolution reporting obligations
- BIRD moves one step closer to the operational systems of banks
- in the future authorities might be reduce aggregated, eg template-based, reporting towards a more structured (and closer to redundancy-free) granular reporting

ECB broader strategy for statistics: envisaged approach



6. Conclusions

Granular reporting and data standards as a breakthrough

Datasets using ESG criteria to support green financing

Statistics to support researchers at central banks (*and beyond*) by offering services tailored to their needs

- Continuous **dialogue** with *analysts* and *researchers* to define appropriate *data marts* for pre-defined queries; also **banks** to benefit from *feedback loops*
- Ensure **methodological support** – eg consolidate exposures or debt – *correct usage of the data* and interpretation of the results

Thank you!

Questions?

Word-cloud from the AnaCredit Regulation

International Conference on "Statistics for Sustainable Finance", co-organised with the Banque de France and the Deutsche Bundesbank

14-15 September 2021, Paris, France, hybrid format

The carbon content of Italian loans[1]

Ivan Faiella and Luciano Lavecchia,
Bank of Italy

[1] This presentation was prepared for the conference. The views expressed are those of the authors and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

The carbon content of Italian loans

by Ivan Faiella and Luciano Lavecchia[1]

Climate-related financial risks top the financial supervisors' agenda

Climate modifications, extreme climate events, and climate policies all affect the financial system through multiple channels (Carney, 2015; Batten et 2018; Breeden 2020) . More frequent and intense extreme weather events harm fixed capital assets, reducing the ability of borrowers located in the affected areas to repay their debt (**physical risk**). Energy and climate policies designed to achieve a transition to a carbon-free economy may reduce the value of carbon-intensive assets, especially if these measures are implemented abruptly (**transition risk**).

These risks are on top of the agenda of central bankers and supervisors around the world (Campiglio et al 2018; ECB, 2020; Bolton et al, 2020; Faiella and Malvolti, 2020). Some central banks (BoE, 2015; DNB, 2016 and 2018; ECB, 2019), have already started to analyses these risks or are planning to run comprehensive exercises in the coming years (BoE, 2019). Initiatives such as the Network for Greening the Financial System (NGFS), a voluntary group of central banks and supervisors, are trying to coordinate and harmonize the approaches (NGFS, 2019). But, the quantification of these risks is still limited due to a severe lack of data, the need for a forward-looking approach in evaluating risks (Bolton et al., 2020) and, for some analysts, a 'precautionary' policy approach (Chenet et al., 2019).

Assessing the exposure of the Italian financial system to transition risks

To better understand how transition risks might influence the Italian financial system, our recent paper presents some evidence on the carbon content of Italian firms' loans. We propose a simple and transparent method to define an industry-level indicator for the exposure of firms' credit portfolios to transition risk, with the objective to answer a very simple question: how many grams of greenhouse gases (GHGs) are emitted by a sector-average firm for every borrowed euro? Our method is dynamic and takes into account the development and intensity of emissions as well as the evolution of lending at a sector level.

Our focus on loans should provide a fair proxy for the exposure of the entire Italian financial system. The exposure of banks through their portfolios (equity and bonds issued by climate-exposed sectors) is not particularly significant in Italy and so it is not included. In the end, we disregard around a tenth of total assets, given the predominance of loans and sovereign bonds on bank balance sheets (68 and 11 per cent of their

[1] Bank of Italy, Directorate General for Economics, Statistics and Research and OIPE-Levi Cases. Views expressed are those of the authors and do not necessarily reflect official positions of the Bank of Italy.

assets, respectively, at the end of 2018).[2] In particular, loans to firms totalled slightly less than one-third of all banks' total assets at the end of 2018 in Italy. We also ignore interbank lending, which represents a small share of banks' balance sheets (less than 3 percent of total assets).

Three methods to estimate the carbon content of loans

We employ three methods to measure the carbon content of Italian loans, identifying the most exposed sectors: the already mentioned climate-policy-relevant sectors (CPRS); those with a loan carbon intensity (LCI) greater than the median; and the carbon-critical sectors (CCrS).

The **CPRS approach**, first proposed in Battiston et al, 2017, has been adopted in several studies, though it does not consider some sectors that contribute significantly to total emissions (e.g. agriculture). It collapses each carbon-intensive sector into one of five climate-policy-relevant groups: *energy-intensive, fossil-fuel, housing, utilities* and *transport.* The other two methods combines firms' loans by sector (from the Bank of Italy' Central Credit Register - CR) with total GHGs emissions (from Eurostat' National accounting matrix including environmental accounts – NAMEA).

The **loan carbon intensity (LCI)** is the ratio between emissions and loans for each sector, and it provides industry-level data on the emissions embedded in each euro borrowed. It can be used to compare sectoral emissions within and between countries (the latest using the ECB' Consolidated Banking data).

To overcome some of the drawbacks of the LCI method, we propose to **define a set of carbon-critical sectors (CCrS)**. This method summarizes the relative pertinence of each sector in terms of loans and emissions, identifying the most relevant sectors.

We are aware of the limits of sectoral data, in particular, how failure to consider the actual exposure towards a specific borrower/investment neglects the heterogeneity that underlies the sector-level data. Nevertheless, we think that industry-level information can be a valuable starting point given the present lack of high-quality and comparable firm-level data – the information on direct or indirect emissions of small and medium firms, which represents almost 99 percent of all firms in Europe and half the value added, is missing.

LCI and CCrS have the advantage of using a standard method of classification (the NACE codes) available at the EU level. Moreover, they take into account all sources of GHGs. Finally, they are dynamic in that they directly consider the evolution of emissions and emission intensity. There is only a partial overlap between the sectors considered - CCrS and those with an above-the-median LCI.

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[2] According to ECB evaluations, banks' portfolio exposure to CPRS (equity and bonds only) for the euro area as a whole is around 1 per cent of total holdings (ECB, 2019).

The carbon content of loans in Italy

According to our estimates, the exposure of the Italian financial system in 2018 ranged between 37 (LCI) and 53 (CCrS) percent of total loans, representing 9.9, 12.9 and 14.4 percent of banks' total assets (for LCI, CPRS and CCrS respectively; Table 1).

Exposure of the Italian financial system at the end of 2018

(billions of euros and percentage points)

Table 1

Method	Outstanding loans		% share of total loans		Loans as a share of total assets
	Total	Banks only	Total	Banks only	
CPRS	473.9	323.9	47.5	45.6	12.9
LCI > median	364.2	273.4	36.5	38.5	9.9
CCrS	528.0	372.8	52.9	52.4	14.4

Sources: Faiella and Lavecchia, 2020

The most exposed sectors are, according to the CPRS method, the energy-intensive and housing sectors. Using the Loan carbon intensity (LCI), Electricity and gas, sewage, and air transport are the most exposed sectors. And with the CCrS classification, electricity and gas, agriculture, wholesale and retail trade, and construction are the most exposed sectors.

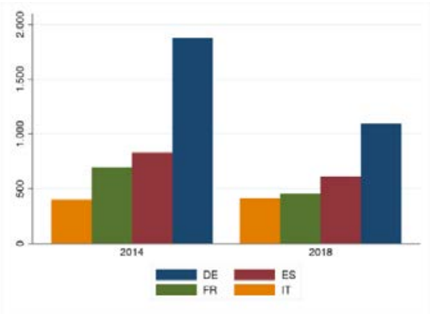
Compared with other EU-peers

Using the ECB Consolidated Banking data, it is possible to compute and compare the loan carbon intensity (LCI) across countries and sectors, merging the NACE level-1 information on loans with NAMEA. Between 2010 and 2018, the Italian LCI was, on average, 330 grams of CO2 equivalent per euro loaned, one of the lowest in the Euro system and largely below Germany's (see figure below).

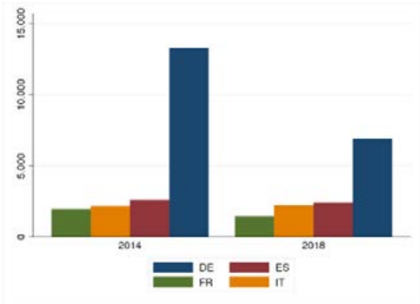
LCI of manufacturing and agriculture in selected European countries Figure 1

gCO2e per €

a) Manufacturing



b) Agriculture



Sources: Faiella and Lavecchia, 2020

As the LCI shows, in Italy, the carbon content of loans is rather small compared to the LCI of other EU-peers There are additional reasons to be optimistic about the resilience of the Italian economy in adapting to these new challenges. Italy has already reached all of its 2020 climate and energy targets (PNEC, 2019); in 2017, emissions were down by almost 21 percent with respect to 1990. Moreover, the carbon footprint of Italy's energy system is quite small compared with other EU countries, thanks in part to the fact it has one of the smallest energy intensities in the OECD countries (IEA, 2016) which is expected to keep getting smaller. Italy has planned to shut-down its coal-powered power stations by 2025 and Italian cars are among the most efficient in Europe with a significant penetration of natural gas in the transport sector (including the plan to use biogas and to extend gas use in tracks and shipping). However, there remains a big potential for improving energy efficiency and renewable deployment in the building sector. Other countries may consider borrowing some strategies from Italy to achieve their own carbon reduction goals.

The carbon content of Italian loans

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International conference on statistics for sustainable finance
IFC BIS-Banque de France-Bundesabank

15 September 2021

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Research question

1. What is the exposure of the Italian financial system towards transition risks?
2. Which sectors are particularly at risk?

Data

1. **Air emissions accounts (Eurostat):** GHG emissions for Kyoto gases (CO2, N2O, CH4, HFCs, PFCs, and SF6); residence principle; direct and indirect emissions from energy use (i.e. scope 1 + scope 2); no product-level emissions (very important but no up-to-date official estimates available plus issues with complexity and quality)

2. **Gross value added (Eurostat);**

3. **Central Credit Registry/Supervisory reports (Banca d'Italia):** granular data on all loans (including syndicated loans) to any institutional units (households and firms) operating in Italy from any bank (including > 80 foreign banks) or financial institutions operating in Italy (<> insurances, pension and investment funds);

4. **Consolidated banking data 2 (ECB):** aggregate consolidated balance sheets of all EU banks, with details per NACE 1-digit sector

Three methods to assess the exposure of loans to transition risk

1. loan carbon intensity (LCI);
2. carbon-critical sectors (CCrS);
3. climate-policy-relevant sectors (CPRS): see Battiston et al. (2017).

Loan carbon intensity (LCI)

LCI answers a simple question:

"How many emissions are embedded in each euro that an average bank lends to a specific industry?"

$$\mathrm{LCI}_{s,t} = \frac{E_{s,t}}{L_{s,t}}$$

where

$E_{s,t}$ Emissions of sector *s* at time *t*

$L_{s,t}$ Outstanding loans of sector *s* at time *t*

Btw 2010 and 2018, industries with an above-the-median LCI accounted for 34 per cent of all loans and 93 per cent of all emissions

LCI varies greatly across industries…

Carbon intensity of the loans' portfolio of the 10 most emitting sectors

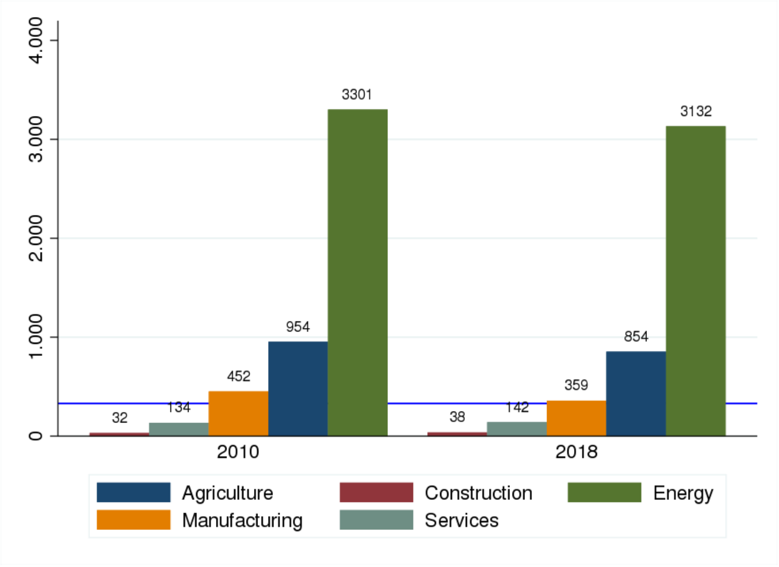
Sector	2010	2014	2018
Electricity, gas, steam and air conditioning supply (D)	3.773	2.510	3.444
Crop and animal production, hunting and related service activities (A01)	960	867	860
Manufacture of other non-metallic mineral products (C23)	2.307	2.082	1.914
Sewerage, waste collection, treatment and disposal activities; materials recovery and Remediation activities and other waste management services (E37-E39)	3.120	2.920	3.069
Water transport (H50)	1.851	1.562	2.831
Manufacture of coke and refined petroleum products (C19)	2.080	3.023	2.788
Land transport and transport via pipelines (H49)	910	973	792
Manufacture of chemicals and chemical products (C20)	1.340	1.351	1.411
Manufacture of basic metals (C24)	1.110	882	747
Wholesale trade, except of motor vehicles and motorcycles (G46)	118	135	126
Total economy	**351**	**318**	**327**

…and it is easy to compute and communicate

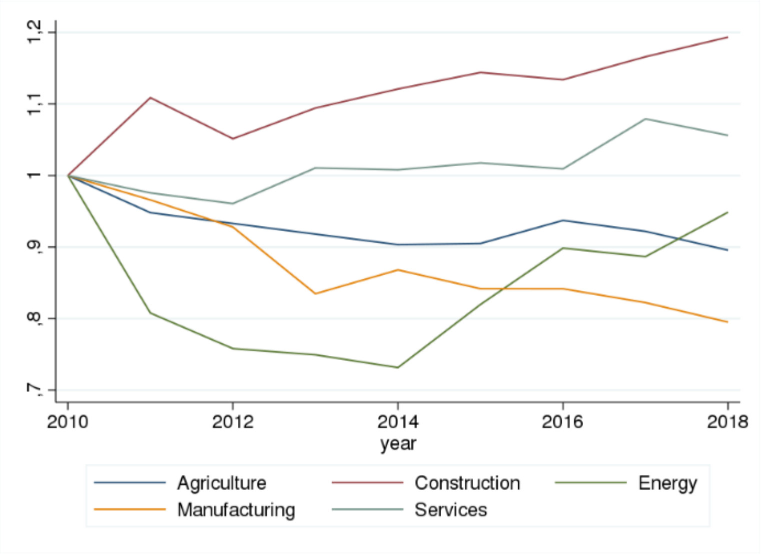
LCI per main economic sector in Italy

(gCO2e/€, base year 2010)

a) LCI in selected years



b) Trend 2010-18



Sources: Based on Eurostat and Bank of Italy's Central Credit Register data.

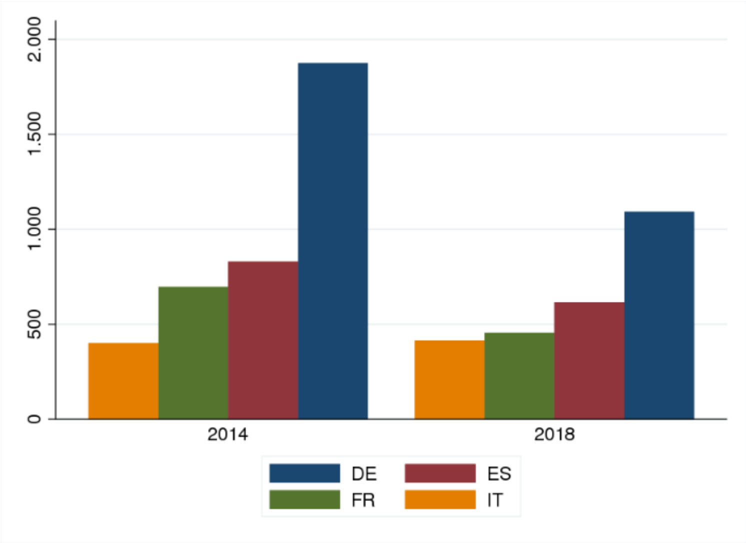
LCI average in Italy between 2010-2018: **330 gCO2e/€**

… allowing also international comparisons

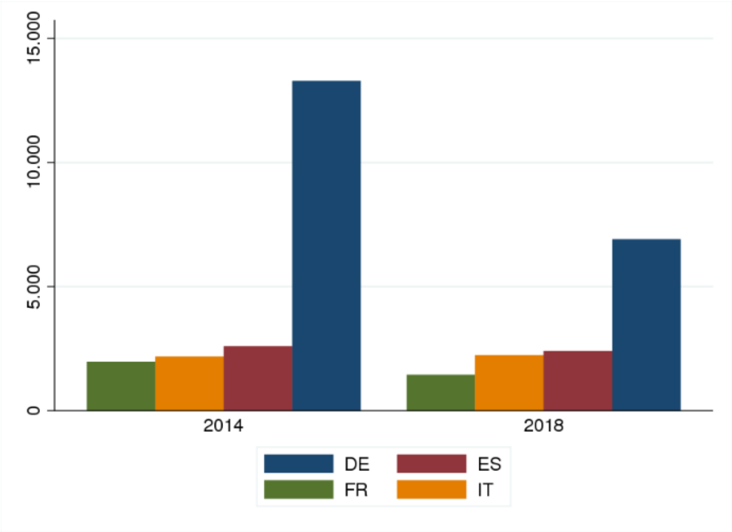
LCI of manufacturing in selected European countries

(gCO2e/€, base year 2010)

a) Manufacturing



b) Agriculture



Sources: Based on Eurostat and ECB data

- the LCI of German manufacturing: 2X Spain, 4X Italy.
- differences decreasing due to a steep reduction of the LCI in Germany
- Similar evidence for the agricultural sector

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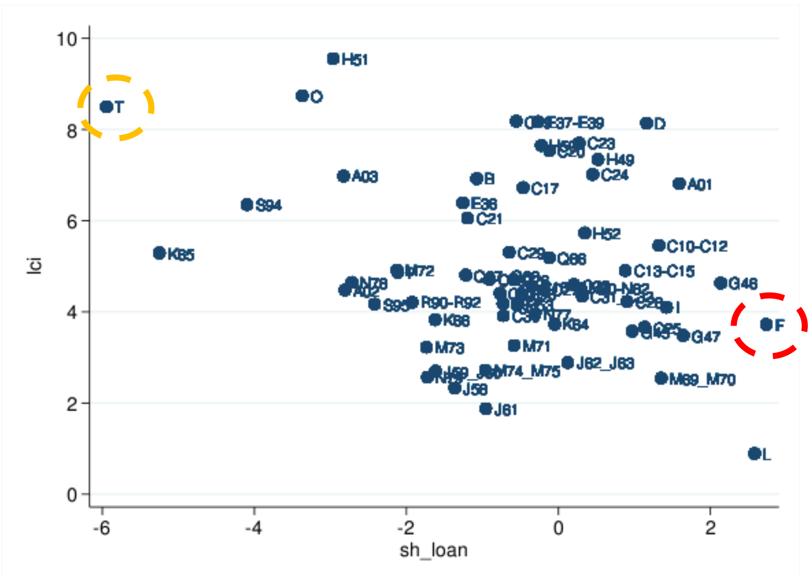
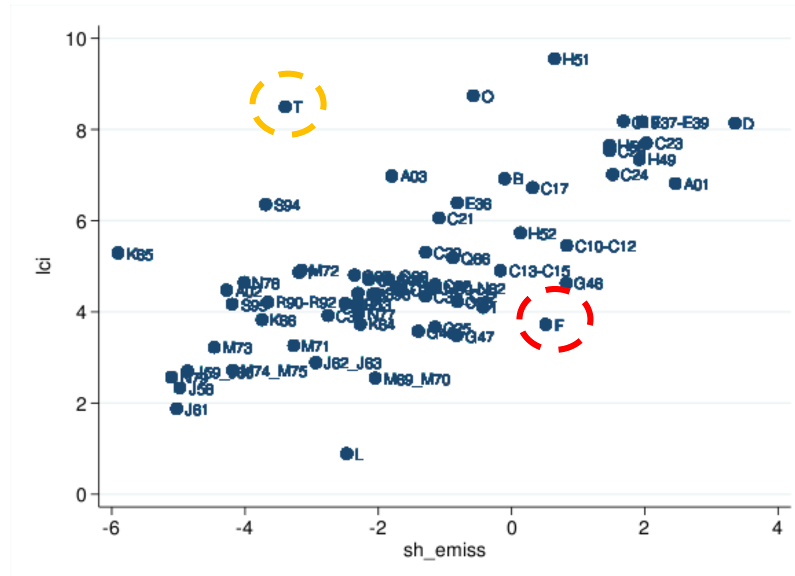
… but it is far from perfect

a) Log LCI vs. log share of emissions

b) Log LCI vs. log share of loans





- Not all countries/sectors rely on loans in the same way
- it mixes up two phenomena (e.g. HHs as employers – T and construction - F)

A possible alternative: carbon-critical sectors (CCrS)

1. Create two separate **rank variables** that provide information on sectors' share of total emissions ($E_{s,t}$) and on the share of total loans ($L_{s,t}$) .

2. Take the **simple average** of these ranks ($avg\_rank_{s,t}$), obtaining a measure of the relevance of each sector in terms of emissions and exposition to the financial sector.

3. Define as carbon-critical sectors (CCrS) those whose average is in the **first fifth** (q_1) of the distribution of $avg\_rank_{s,t}$

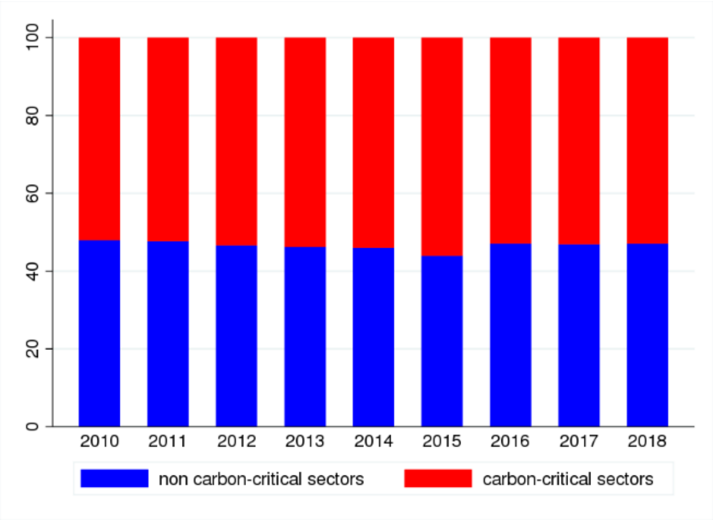
$$\mathrm{CCrS}_s = \mathrm{I}\left\{\mathrm{average}\left[rank_t\left(\frac{E_{s,t}}{E_t}\right), rank_t\left(\frac{L_{s,t}}{L_t}\right)\right] < q_1\right\}$$

CCrS account for a sizable part of loans and emissions

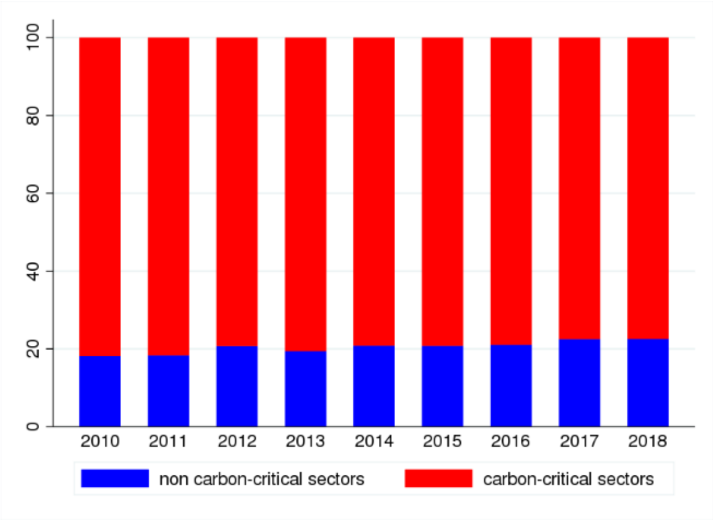
Loans and emissions: CCrS vs. non-CCrS

(billions of euro and millions of tonnes of CO2 equivalent)

a) Loans



b) Emissions



Sources: Based on Eurostat and Bank of Italy Central Credit Register data.

- Concentration: CCrS capture 53% of the loans and 80 per cent of emissions
- Analogue results using carbon GHG per unit of value added for ranking the emissions

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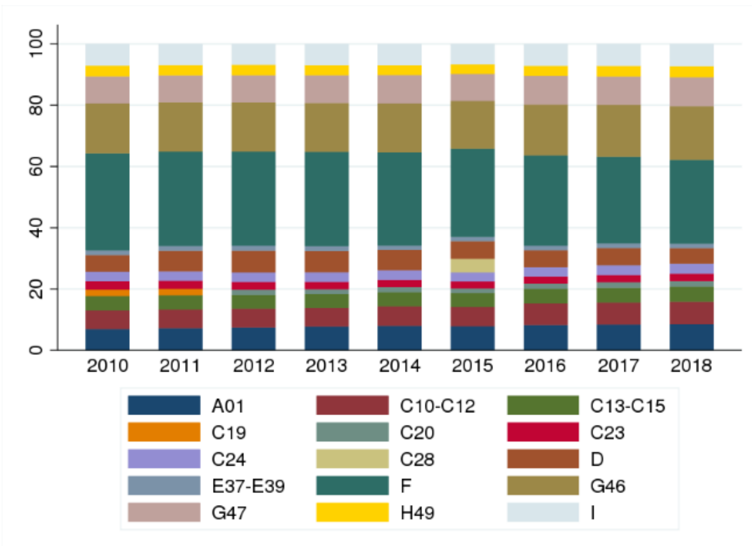
CCrS exposure by detailed sectors

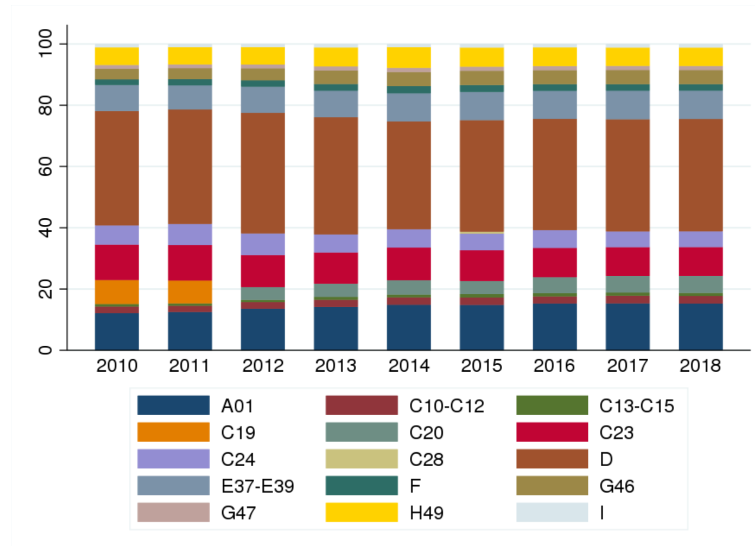
Loans and emissions: CCrS in detail

(percentage points)

a) Loans



b) Emissions



Sources: Based on Eurostat and Bank of Italy Central Credit Register data. The legend of the sectors is in the Appendix.

- Construction (F), Wholesale and retail trade (G46+G47) account for one-third of the loans but less than 6 per cent of GHG emissions
- the three most emitting sectors, i.e. energy (D), agriculture (A01) and the manufacture of other non-metallic mineral products (C23), account for half of the emissions but only a tenth of loans.

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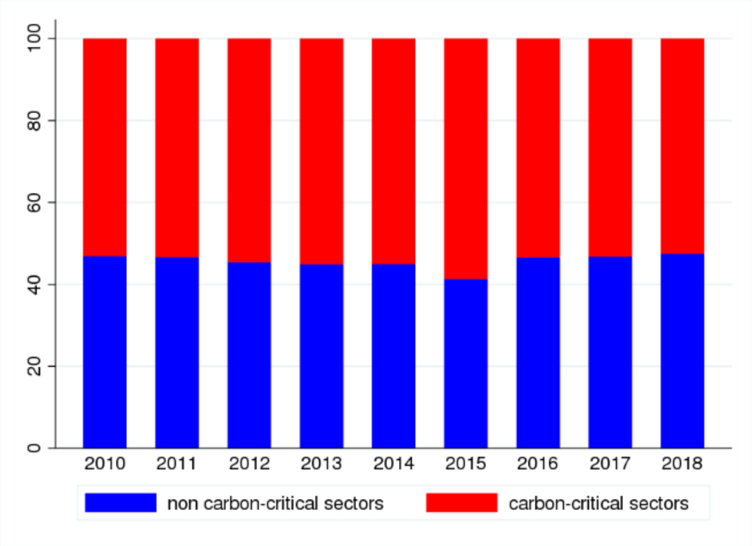
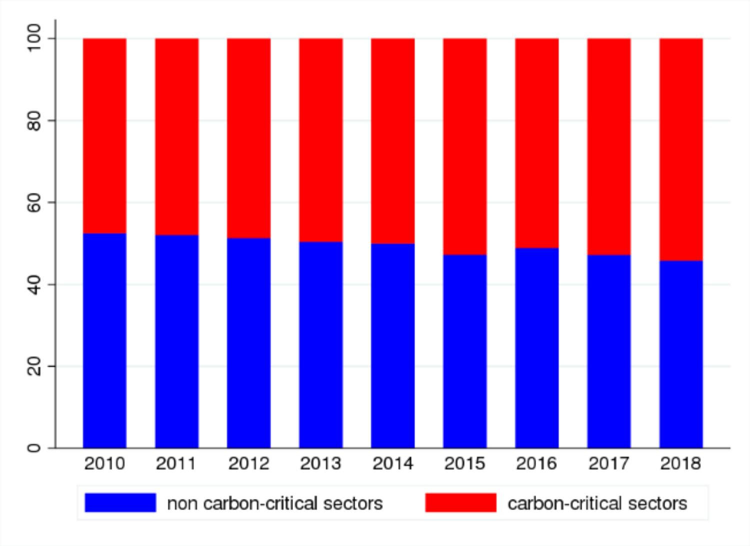
CCrS sector exposure by type of intermediary

Exposure of the Italian financial system towards CCrS – by type of intermediary
(percentage points)

a) Banks



b) Other financial intermediaries



Sources: Based on Eurostat and Bank of Italy Central Credit Register data.

- Slightly decreasing share for banks, increasing for other FIs
- No difference between the 5 biggest groups and other banks or financial institutions

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Summing up…

- Existing literature focuses on equity and bonds; **our work focuses on loans**
- We have devised a simple and transparent method to define an industry-level indicator for the exposure of firms' credit to transition risk.
  - **cons**: sectoral data is a second best;
  - **pros**: most of GHG; dynamic classification, includes loans, scalable to other countries, useful for modelling.
- Results:
  1. Avg. Exposition btw 38% (LCI) and 53% (CCrS);
  2. No difference between 5 biggest banking groups and other banks (or FIs) on average;
  3. sectors more exposed (CCrS): construction, machinery, wholesale and retail trade;
  4. Italy less exposed than other countries (partic. DE);

Ivan Faiella & Luciano Lavecchia (2020) The carbon content of Italian loans, Journal of Sustainable Finance & Investment, DOI: 10.1080/20430795.2020.1814076

Thank you

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Irving Fisher Committee on
Central Bank Statistics

International Conference on "Statistics for Sustainable Finance", co-organised with the Banque de France and the Deutsche Bundesbank

14-15 September 2021, Paris, France, hybrid format

The NGFS (Network for Greening the Financial System) Progress Report on Bridging Data Gaps and beyond[1]

Léa Grisey, Banque de France

1 This presentation was prepared for the conference. The views expressed are those of the author and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

NGFS Progress report on bridging data gaps

Executive Summary

NGFS (Network for Greening the Financial System)

Key messages

Reliable and comparable climate-related data are crucial in order for financial sector stakeholders to assess financial stability risks, properly price and manage climate-related risks, and take advantage of the opportunities arising from the transition to a low-carbon economy.

Persistent gaps in climate-related data hinder the achievement of these objectives. Stakeholders report the need for more forward-looking data (for example targets or emissions pathways) and granular data (for example geographical data at entity and asset-levels). Stakeholders are also calling for some assurance about the quality of climate-related data through verification and audit mechanisms, as well as improvements in data accessibility.

A mix of policy interventions is needed to catalyse progress towards better data, based on the following three building blocks:

i. rapid convergence towards a common and consistent set of global disclosure standards;

ii. efforts towards a minimally accepted global taxonomy;

iii. the development and transparent use of well-defined and decision-useful metrics, certification labels and methodological standards.

Global progress on the aforementioned building blocks that the NGFS is calling for should not prevent better leveraging of already available data sources and approaches (such as e.g. proxies and estimates, qualitative approaches and capacity building), as well as the promotion of new data tools.

The NGFS will continue its evidence-based identification of the most prevalent data gaps – including by further engaging with other stakeholders such as non-financial corporates, data providers and ratings agencies – and to issue recommendations on how to bridge them.

Contents

Climate change and the data challenge

Reliable and comparable climate-related data are crucial for financial institutions (including central banks and supervisors), investors and policymakers to assess financial stability risks, properly price and manage climate-related risks, and take advantage of the opportunities arising from the transition to a low-carbon economy. Such climate-related data are key for microprudential and macroprudential supervision. They also enable financial institutions and investors to gauge the financial repercussions of climate change and increase their resilience to climate-related risks. Moreover, they enable financial institutions to ensure that sufficient capital is made available for the investments needed to achieve the goals of the Paris Agreement.

Persistent gaps in climate-related data hinder the achievement of these objectives. The need to find solutions for data gaps has garnered significant attention and led to a renewed sense of urgency, as pressure continues to grow to address climate change from investors, researchers, regulators and policymakers, as well as NGOs and the general public. These data gaps have multiple causes, which include the time horizon for climate-related risks, the widespread nature of their impact and the high degree of uncertainty surrounding them, as well as the need to translate climate-related risks into financial impacts.

Mandate and work programme of the Workstream on bridging the data gaps (WS BDG)

The Network for Greening the Financial System (NGFS) set up the Workstream on bridging the data gaps (WS BDG) in July 2020 to identify climate-related data needs and data gaps and to propose policy recommendations to bridge such gaps. The WS BDG represents the implementation of Recommendation n° 3 "Bridging the data gaps" issued in April 2019 in the First comprehensive report by the NGFS. More specifically, inline with its mandate, the work of the WS BDG is structured according to the following three-phase approach:

i. Identify data items needed by the financial sector –including central banks and supervisors – for the purpose of climate-related risk analysis and the scaling up of green finance.

ii. Determine whether the data items are available, and if so, identify their data sources and limitations for accessing them.

iii. Provide guidance and recommendations on how to bridge the data gaps identified.

This Progress report forms part of the first phase of the Workstream's work programme and, in setting out the issues that need to be considered going forward, lays the groundwork for a comprehensive assessment of climate-related data needs and gaps. The Workstream completed a systematic literature review, undertook outreach to a variety of international organizations and other relevant stakeholders, and conducted a survey and two closed-door workshops with banks and buy-side firms. Given the breadth and magnitude of climate-related risks, and the urgent need for action, this report is narrowly focused on climate-related data issues, both at a granular level (such as firm-level data and asset-level exposures) and at an aggregate level (such as data on the incidence of natural disasters at the regional or country level). Broader environmental data issues, for example those related to biodiversity, may be addressed in the future. It should be noted that climate change research, methodologies and metrics for application in the financial sector are evolving quickly and further data needs will continue to emerge over time.

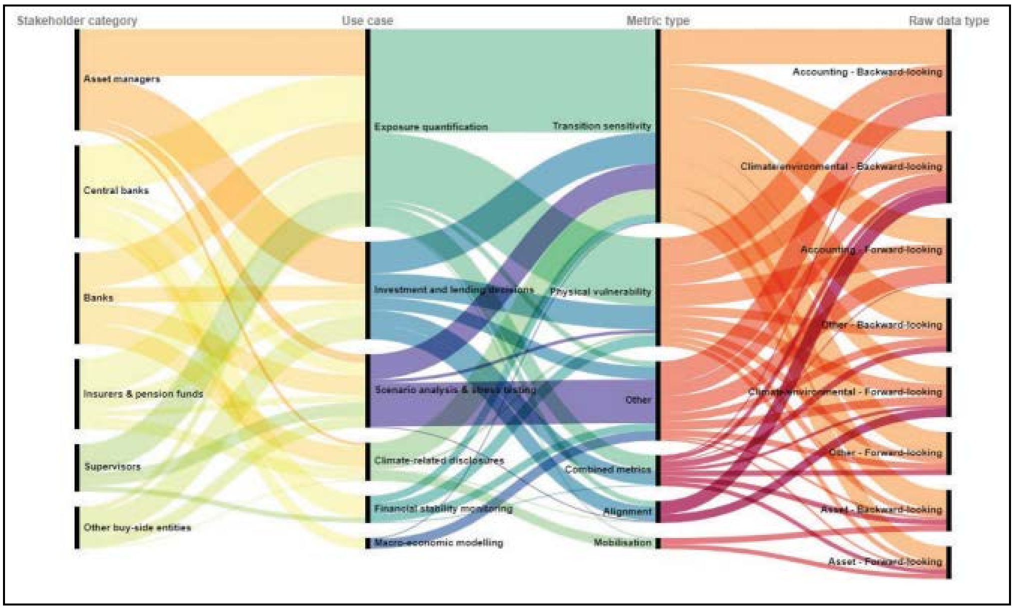
A repository of data needs

The NGFS has adopted a user-centric approach informed by interactions with a vast number of stakeholders[1] from a wide range of geographies and areas of expertise. As data gaps are cross-cutting issues that affect a large number of public and private sector stakeholders, a user-centric approach represents a transparent and open-ended starting point to jointly determine what data are needed across stakeholders. This report proposes a classification of a number of use cases that define the application of climate-related data for key stakeholder groups in the financial sector. Identifying these use cases, understanding what metrics and methodologies support them, and relating them to the raw data items that feed those metrics are key for systematically mapping the data needs, and subsequently, the data gaps. To this end, the Workstream has set up a three-layered repository of data needs in which detailed results for use cases, metrics, and raw data items are recorded. The repository will play an important role in phases 2 and 3 of the work programme and will allow the NGFS to draw conclusions about which data gaps to prioritize. A schematic overview of the data repository is presented in Figure 1.[2]

Interconnectedness of use cases, metrics and raw data items by stakeholder category in the repository

1 Note that, at this stage, the liability side of the insurance sector is not included in this assessment.

2 This figure gives a schematic overview of the data repository: from left to right, it shows the six stakeholder categories, their use cases for climate-related data, the metrics required to support the use cases, and the raw data items that feed the metrics.



Key issues related to data availability, reliability and comparability

Meeting stakeholders' climate-related data needs for the identified use cases is a multifaceted challenge, which warrants comprehensive consideration across three dimensions: availability, reliability and comparability.

With regard to **availability**, stakeholders need climate-related data across asset classes, sectors and geographies, and over different timeframes. In some instances, relevant data sources lack the appropriate granularity, and/or the geographical or sectoral coverage. In other instances, relevant data sources exist, but are not collected in a consistent manner, are not directly accessible, cannot be easily compared or may produce varying outcomes. As for **reliability**, numerous studies[3] have shown that the available data sources and metrics generally produce scattered and inconsistent outcomes. Reliability depends on the quality of the raw data, as well as the auditability and transparency of the providers. For example, more transparency about how ESG scores are determined would enable the sometimes large differences in the scores of different data providers to be better understood. Lastly, with regard to **comparability**, differences in the design and focus of the multiple frameworks for climate-related disclosures, as well as a lack of consistency, can make it challenging for end-users when they need to compare the information reported across different frameworks.

The findings of the interaction with stakeholders suggest that the largest data gaps exist for forward-looking data, such as emissions pathways and companies' transition targets (including interim targets). Given the importance of forward-looking assessments of both physical and transition risks, the current reliance on mostly backward-looking data is unsatisfactory. Stakeholders reported

[3] For more information, please see Box 3 on "Comparability and transparency issues in practice" in the NGFS Progress report on bridging data gaps

that they need to understand the point-in-time performance of an exposure against a transition pathway – hence the need for firms to disclose their transition plans – as well as the impact of adaptation and mitigation measures on the evolution of the risks.

Stakeholders also highlighted the currently limited availability and granularity of "carbon" data (such as Scope 3 emissions, data on avoided emissions) and geographical data on asset locations, to assess both transition and physical risks. Since there are large geospatial differences in the manifestation and evolution of physical risks, it is critical to make asset location data available to determine the variety and severity of the physical threats of climate change.

Building blocks to bridge the data gaps

To ensure the availability of reliable and comparable climate-related data, a mix of policy interventions is needed to catalyse progress. Three building blocks are paramount:

1) **rapid convergence towards a common and consistent set of global disclosure standards;**
2) **efforts towards a minimally accepted global taxonomy; and**
3) **the development and transparent use of well-defined and decision-useful metrics, certification labels and methodological standards.**

Many of the stakeholders with which the Workstream has interacted during the first phase of its work programme have made policy suggestions for bridging the data gaps: policymakers should take urgent steps to improve climate-related disclosures and strive to converge towards a set of consistent global standards and disclosure requirements. They should also aim to achieve a minimally accepted global taxonomy to enhance reliability, availability and comparability of reported data. Moreover, relevant and consistent metrics and methodological standards are important for the development of disclosure standards.

Disclosure frameworks

While some progress has been made in recent years, climate-related disclosures by financial and non-financial companies are still limited, fragmented and inconsistent across economic sectors. Financial institutions stress the degree to which they rely on disclosures from the wide range of corporates that they invest in, lend to or insure. It is essential for them to have access to information regarding the climate risks and opportunities faced by the corporates they are exposed to. Meanwhile, corporates also face challenges in providing climate-related data to their stakeholders amid a fragmented landscape of still largely voluntary disclosure frameworks. The main issues identified relate to the voluntary nature of disclosure frameworks, the fragmentation in the landscape, the absence of technical guidance and independent verification, and the lack of a common approach to materiality. Moreover, different definitions and thresholds for materiality with respect to climate issues also affect the availability of climate-related data.

Convergence towards a global disclosure framework, alongside progress towards a globally consistent set of minimal climate disclosure standards and requirements is likely to improve the availability and comparability of climate-related data. A stronger push for consistency across sectors and regions, and an appropriate scope for disclosures is a prerequisite for an adequate disclosure framework for the financial sector. Notably, at the beginning of 2021 the IFRS Foundation announced a plan to establish a sustainability standards board with support from IOSCO and building on existing frameworks, such as the Task Force on Climate-related Financial Disclosures (TCFD) and the prototype developed by the "group of five", namely the Carbon Disclosure Project (CDP), Climate Disclosure Standards Board (CDSB), Global Reporting Initiative (GRI), the International Integrated Reporting Council (IIRC) and the Sustainability Accounting Standards Board(SASB).[4] This will pave the way for greater consistency and the convergence of sustainability-related financial reporting standards, with climate standards being prioritised.

Mechanisms for verifying and auditing climate-related financial disclosures are essential to make data reliable and comparable. The development of sufficiently granular methodological standards that prescribe how data items are defined and how metrics are to be computed is a precondition for assuring the quality of disclosures. In turn, external assurance of such information facilitates the appropriate application of standards and definitions. Some stakeholders have called for an assurance framework similar to the one for financial statements and its integration in mainstream financial reporting.

Taxonomies

Taxonomies are another building block in improving data reliability and comparability, and therefore providing financial institutions and investors with relevant information. Many stakeholders consider developing taxonomies as a prerequisite for consistent collection of data and comparable analysis based on these data. Currently, different jurisdictions are establishing different, separate taxonomies for green finance, including pathways and targets that are relevant in their regional context. Many stakeholders point to the need to recognize transition pathways in taxonomies, as a way of catering for differences in regional starting points and facilitating transition financing for companies and other economic players that aim to improve their environmental impact. Other stakeholders questioned the added complexity this would bring to the task of developing a minimally accepted harmonized taxonomy and suggested that disclosing the pathways and distance to targets would be an easier way forward. There is therefore a need for cross-regional discussion on taxonomies. Efforts towards developing a globally agreed upon taxonomy could help ensure worldwide comparability of raw data. The convergence of different taxonomies over time will be important in ensuring consistency in climate-related disclosures.

There is a need to intensify and coordinate the development of taxonomies across the globe, and to examine the possibility of harmonizing them over time. Such efforts need to be intensified and well-coordinated, especially in regions where taxonomies do not yet exist. These are important steps towards the development of

[4] For information on the prototype developed by the "group of five", see Reporting on enterprise value, Illustrated with a prototype climate-related financial disclosure standard, December 2020.

a global taxonomy. Limiting the scope to that of a climate-related taxonomy first (as opposed to including issues such as biodiversity which could well be added as a next step) may be a pragmatic way forward. For example, the International Platform on Sustainable Finance has created a dedicated working group on taxonomies to comprehensively compare existing European and Chinese taxonomies for environmentally sustainable investments and identify commonalities and differences in their respective approaches, criteria and outcomes.

Certification labels, methodological standards and consistent metrics

Certification labels[5] and harmonized methodological standards are key to improving data reliability and comparability. They can make it easier to identify climate-related data and construct datasets (for example, energy efficiency certificates). Certification labels should be harmonized across regions and the information they certify should be made comparable, homogeneous and easily available.

Data comparability is also enhanced when financial market participants harmonize their approaches. The methodologies and disclosure frameworks observed by the NGFS often rely on different computation methods, even for key metrics used across stakeholders and geographies. Such divergences can hinder the comparability of climaterelated data, with a profound effect on the outcomes of analyses, especially as transparency regarding the methods adopted is limited. For example, De Nederlandsche Bank has recently shown that inflation and exchange rate effects can have a substantial impact on the outcomes of relative carbon footprint metrics.[6] If inancial market participants adopt harmonized approaches, this supports the comparability of data. It is worth noting that a number of initiatives have led to open source methodologies and voluntary methodological standards being produced which are then widely used. For example, one such methodological standard is the attribution methodology for the computation of financed emissions by the Partnership for Carbon Accounting Financials (PCAF), which has been embraced by the Greenhouse Gas (GHG) Protocol.

Leveraging existing data sources and approaches

The NGFS notes that there is substantial scope for financial institutions to better leverage already available data sources and approaches. Notwithstanding the need to make progress on the three aforementioned building blocks, financial institutions can also make better use of proxies and estimates, as well as qualitative approaches, while they build up capacity to enhance their ability to process climate-related data. Moreover, many existing approaches might be usefully applied in any of

5 A certification label is a label or symbol indicating that compliance with standards has been verified. Use of the label is usually controlled by the standard-setting body. Where certification bodies certify against their own specific standards, the label can be owned by the certification body. Examples are Energy Performance Certificates or ISO standards.

6 See Janssen, A., Dijk, J. and Duijm, P., "Misleading Footprints, Inflation and exchange rate effects in relative carbon disclosure metrics", DNB Occasional Paper, Vol. 19(1), 28 January 2021.

these building blocks. For instance, voluntary standards developed in the markets might provide to be valuable building blocks for harmonized disclosure frameworks.

The promotion of new data tools and analytics, and more generally digitalization, as well as repositories to make data collection more transparent are also useful. The development of new data tools can provide technical solutions for accessing data, and repositories could be helpful in pointing to existing climate-related data. Indeed, many stakeholders emphasized that they often face technical obstacles when working with climate-related data. Access to existing climate-related data is often difficult, because data are scattered across different sources and/or only available via private data providers. Publicly available repositories could be helpful as a way of pointing to existing climate-related data and informing users on how best to access relevant data sources. Solutions such as open source architecture for data collection and distribution and machine learning techniques may also play a role in making scattered information available in a more structured format. However, more work needs to be done to make existing data more broadly available to policymakers and investors. To date, several initiatives have been launched with a view to pooling climate-related raw data in a single point (see Box 10 in the Progress report on bridging data gaps for a case study in Mexico). It would be worth examining how these can improve data availability and comparability.

Next steps

Identifying and prioritizing data needs: use cases, metrics that serve the use cases and the raw data items needed for those metrics

The NGFS will further expand its engagement with stakeholders and, using the data repository, aims to draw evidence-based conclusions about which data needs should be prioritized. To this end, the NGFS will:

- engage with a broad set of stakeholders, including non-financial corporates (which constitute the first input in the data chain), central banks and international financial institutions (whose statistical functions are key to help bridge the gaps), data providers and rating agencies, in order to determine whether the data needs identified can be addressed and, if not, how the gaps can be bridged;
- further assess the types of metrics that are most suited to support the different use cases identified in the first phase. style, paragraph style, paragraph style.[7]

Meeting data needs across three main data dimensions: availability, reliability and comparability

Going forward, the NGFS will:

- examine possible recommendations for increasing data availability, including initiatives that make data available free of charge or at nominal cost to cover data processing;

- consider the types of verification scheme that could enhance the quality of raw data items, and issue recommendations for achieving greater transparency and comparability on methodologies.

Developing policy recommendations to help bridge data gaps

The NGFS will, in liaison with relevant stakeholders:

- identify how the progressive harmonization of metrics and methodological standards, certification labels and taxonomies can contribute to the reliability and comparability of data, together with a wider implementation of mandatory disclosures in financial statements. In doing so, the NGFS will engage with relevant stakeholders, including non-financial corporates and methodologies providers;
- examine how publicly accessible databases can improve data availability and comparability. In doing so, the NGFS will reach out to initiatives that pool climate-related raw data in a single point and to relevant stakeholders in thefield of geospatial data, paying specific attention to the use of new technologies (such as artificial intelligence).

International Conference on "Statistics for Sustainable Finance"

The NGFS Progress Report on Bridging Data Gaps and beyond

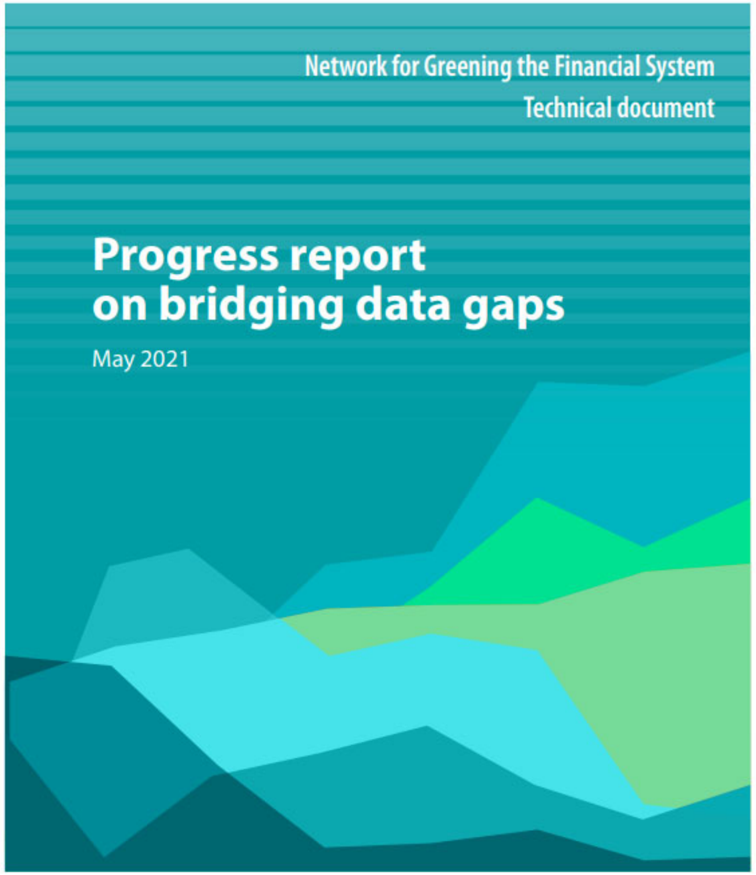
THE NGFS AND THE WORKSTREAM ON BRIDGING THE DATA GAPS

– Established at the Paris "One Planet Summit" in December 2017.
– **Coalition of the willing** comprised of **95 members** and **15 observers**, from all 5 continents.
– **Defines and promotes best practices** and **conducts analytical work** on the management of climate-related risks and on green finance.
– Main publications: First comprehensive report issuing 6 non-binding recommendations, practical guides, two vintages of 'NGFS scenarios'…

- In the recommendation #3 of its First comprehensive report (April 2019), **the NGFS stated "to see merit in setting up a joint working group with interested parties to bridge existing data gaps".**

- The **Workstream BDG** was set up in July 2020 to turn this recommendation into practice. It is aimed at **identifying and prioritizing climate-related data needs and gaps**, and at **proposing policy recommendations** to bridge these gaps. It is co-Chaired by **Fabio Natalucci** (IMF) and **Patrick Amis** (SSM/ECB).

OVERVIEW OF THE PROGRESS REPORT ON BRIDGING THE DATA GAPS



The Progress Report:

→ is based on a systematic **literature review**, an **outreach** to other NGFS workstreams, a variety of IOs and other relevant stakeholders;

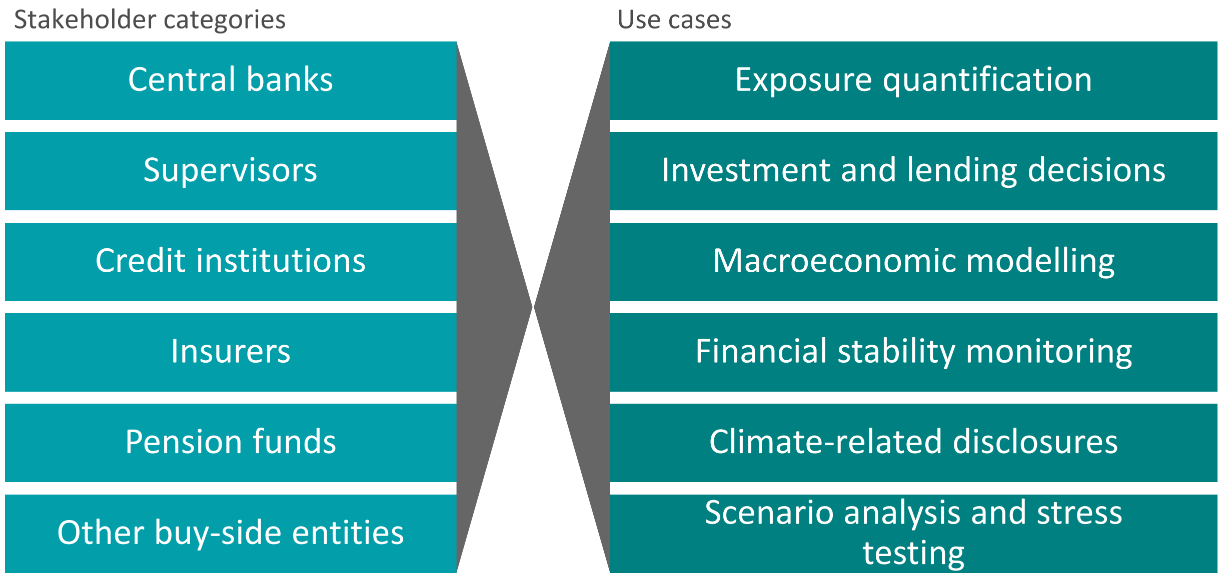
→ incorporates information gathered through a **survey** and **two closed-door workshops** with banks and buy-side firms;

→ lays the groundwork for a **comprehensive assessment of climate-related data needs and gaps**.

THE WORKSTREAM APPROACH (1/3)

- We adopted **a user-centric approach** – informed by the literature review's findings and interactions with stakeholders – aimed at **identifying in a systematic way the needs of climate-data users** in the financial sector.

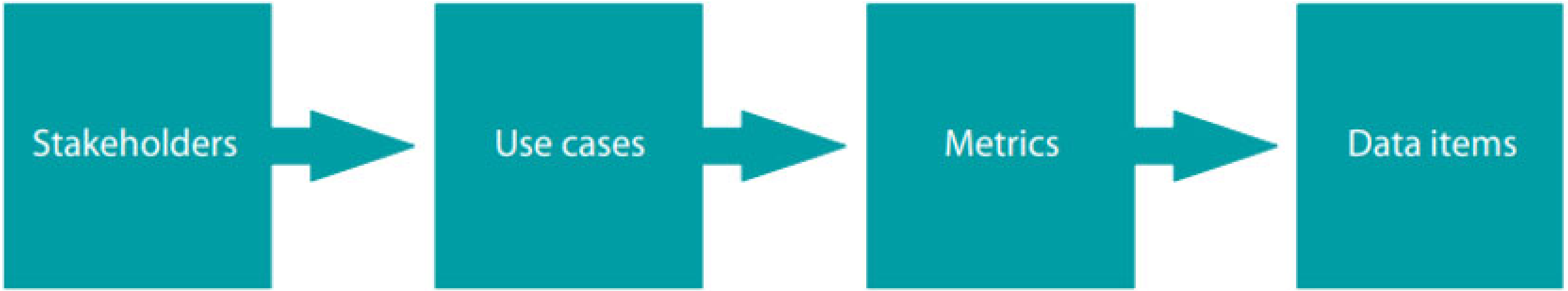
- The Progress Report proposes **a classification of six stakeholder categories and six main use cases** for which stakeholders have indicated climate-related data needs.



THE WORKSTREAM APPROACH (2/3)

- The BDG has set up **a three-layered repository of data needs**, in which we recorded detailed results for use cases, metrics and raw data items across the six main stakeholder categories.

Schematic overview of the layered structure of the repository



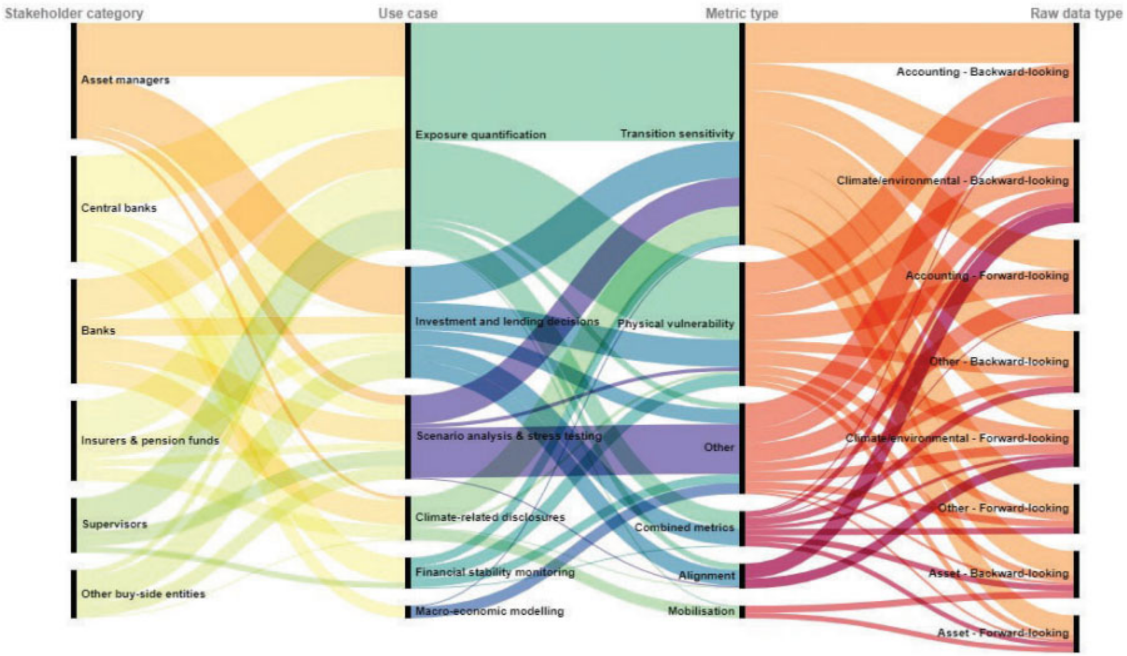
- Going forward, the repository is aimed at **providing an evidence-based overview of climate-related data items that need to be bridged with priority.**

THE WORKSTREAM APPROACH (3/3)

- The figure below shows the **interconnectedness** of use cases, metrics, and raw data items by stakeholder category in the repository.

- While preliminary, **it gives a sense of commonalities in use cases and data needs among stakeholders,** and of how the repositary can be used to **highlight priorities**.

Schematic overview of the repository



WHAT WE HAVE LEARNED SO FAR

- Meeting data needs for the identified use cases is a **multifaceted challenge** that warrants comprehensive consideration across **3 dimensions**: **availability, reliability and comparability.**

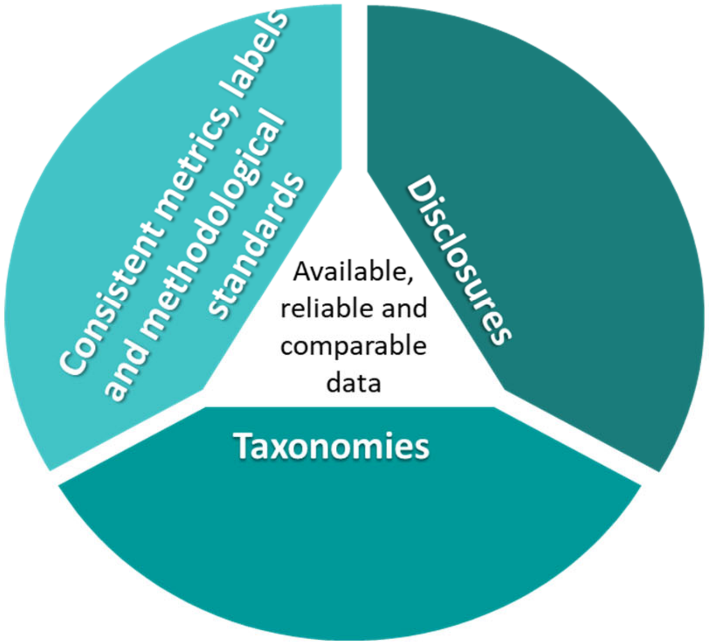
- **Main data challenges highlighted during interactions with stakeholders**:
  - **largest data gaps exist for forward-looking data** (e.g. emissions pathways, targets);
  - **limited availability and granularity of “carbon” data** (e.g. Scope 3 emissions) and of **geographical data on asset locations** to assess both transition and physical risks;
  - stakeholders are also calling for some **assurance about the quality of climate-related data** through verification and audit mechanisms, as well as improvements in data accessibility.

BUILDING BLOCKS TO BRIDGE THE DATA GAPS (1/2)

- To ensure the availability of reliable and comparable climate-related data, a mix of policy interventions is urgently needed to catalyse progress and foster global convergence.

- **Three building blocks** are paramount.

Three main building blocks to bridge the data gaps



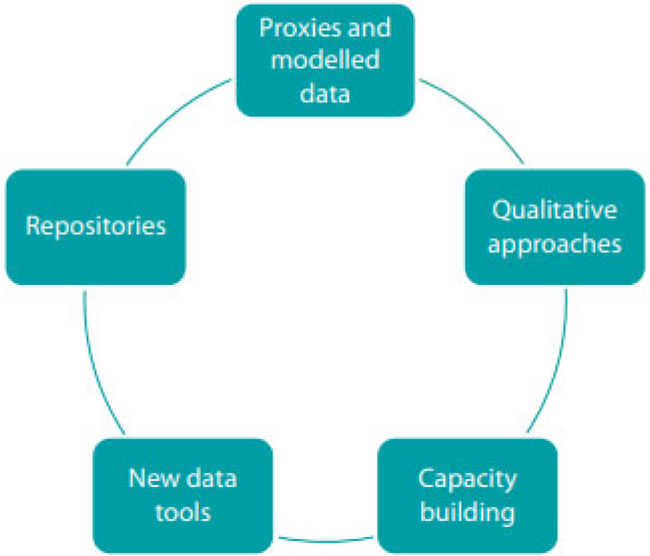
KEY POLICY MESSAGES
Rapid convergence towards a common and consistent set of global disclosure standards.
DISCLOSURES
Efforts towards a minimally accepted global taxonomy.
TAXONOMIES
Development and transparent use of labels and methodological standards. Work towards a common set of well-defined and decision-useful metrics
CONSISTENT METRICS, LABELS AND METHODOLOGICAL STANDARDS

BUILDING BLOCKS TO BRIDGE THE DATA GAPS (2/2)

- Building a proper architecture for climate data information around the three building blocks should not **prevent leveraging the existing data sources and approaches**.

- **Promoting new data tools and analytics (e.g. open source repositories, AI)** to make data collection more transparent is also useful.

Leveraging existing sources and approaches and promoting new tools



NEXT STEPS

- The next stage of the WS BDG's work will be very much focused **on finalizing our repository,** with the aim to **making it a tool that maximizes the public availability of climate-related data for the financial sector.**

- <u>To this end we will</u>:
  - **expand** the repository to take further stock of data needs and establish the link to their (un)availability. To do so we have started to reach-out to rating agencies, methodology providers, and data providers (both public and private);
  - once gathered, **analyze the results of all input**;
  - use the finalized repository **to draw evidence-based conclusions about which data needs should be prioritized**;
  - **disclose** the repository in some way (still exploring options).

International Conference on "Statistics for Sustainable Finance", co-organised with the Banque de France and the Deutsche Bundesbank

14-15 September 2021, Paris, France, hybrid format

Private financial institution perspectives on climate and nature data[1]

Michael Hugman, Children's Investment Fund Foundation

[1] This presentation was prepared for the conference. The views expressed are those of the author and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

WHY A CLIMATE & NATURE SOVEREIGN INDEX (CNSI)?

Investors and macroeconomic policymakers urgently need a single, coherent framework in which to understand long-term climate and natural capital risk, at a macroeconomic, country level.

Without a fully integrated macroeconomic assessment, it is impossible to gauge company climate exposure in a framework such as TCFD or the BoE stress tests. Individual company risks can be overwhelmed by the broader risks to inputs, fixed assets and markets, and to sovereign financing shocks.

Ultimately policymakers and investors will need to undertake growth, debt and FX reserve modelling for all countries will have to incorporate climate and natural capital risks. Financial market responses to physical and transition risks may be non-linear i.e. sudden stops in capital for countries at risk if positive action is not taken today.

To provide a concrete initial solution to these challenges (whilst a broad coalition is brought together to undertake detailed macro-modelling) we believe a cross-country climate and nature sovereign index (CNSI) is urgently needed. This would capture the various structural economic and financial factors that would be later elaborated in country-specific modelling. **This requires a different approach to environmental risk index construction to those currently available**.

Such a macroeconomic framework needs to encompass natural capital as well as climate, the two are interlinked at a country/macro level, and over the next 5 years there will be a greater policy focus on natural capital. It is likely there will be a TNFD[1] to accompany TCFD in the near future.

The Bank of England stress tests and UNEP FI pilot set out a path in this direction, but the absence of robust macro modelling, with the full range of necessary real-time measures across the majority of countries, will constrain progress.

To maximise the value of this index and build towards fully fledged economic modelling the future, the index will incorporate real-time data and forward-looking projections made possible by ongoing work in geospatial modelling and remote sensing. In particular, we have focused on indicators based on modelling from the CIMP5 IPCC climate model ensemble where relevant, avoiding indicators based on older vintages of climate models.

The CNSI is complimentary to policy oriented indices such as the Yale Environmental Performance Index, as we propose a greater breadth of economic and financial indicators to provide linkages on materiality for investors (in particular in fixed income). To summarise, the proposed CNSI:

1. Uses real-time and forward projections wherever possible;
2. Covers natural capital and transition risk exposures, as well as climate risks traditionally measured in indices;
3. Makes explicit the channels of economic and financial linkages to maximise the value of the index to investors and policymakers, using a taxonomy aligned to investor needs:
    a. Biodiversity and natural capital;
    b. Physical risk (atmospheric, water and agriculture);
    c. Transition risk;
    d. Resilience.

[1] Task force for natural capital-related financial disclosures.

INDICATOR SELECTION AND STRUCTURE

This CNSI would build on the work of ND-Gain and Moody's amongst others, whilst enhancing the set of indicators to increase its applicability to portfolio risk assessment. This would create an index which would facilitate cross-country comparison, and to allow for assessment of company exposure to risks in their physical sources of production and demand.

This index would also allow the direct scoring of sovereign assets within portfolios.

The proposed set of indicators is shown in detail further below (Appendix 1) and is designed to capture overall economic and financial channels of exposure to both physical and transition risk from climate and natural capital deterioration. Indicators are chosen to be real-time or forward looking wherever possible, and to reflect the full breadth of economic and financial impacts that will have to be further developed in subsequent country-level economic modelling.

Given the inherent uncertainty of measurement of environment risk, in particular future projections, we have taken an inherently ensemble approach to index construction in two dimensions. First, from underlying data sources build on statistical models, we have taken ensemble means of those models. Second, we have included more than one approach to measuring certain key environmental risk channels such as heat and drought, in order to try and reduce uncertainty through model averaging.

1. **Biodiversity and natural capital - Degradation or loss in ecosystems/biomes (natural capital)** and ecosystem services which undermine existing economic functions e.g. pollinators, coastal biomes, water yield

    a. Level and trends of loss of natural capital, including real time deforestation data.
    b. Data on level and trends of protection of ecosystems and biomes, terrestrial and marine.
    c. Geo-spatially based estimates of long-term economic loss of natural capital degradation.

2. **Physical Risks (both chronic and acute)**

    a. Atmospheric – current trends and projected impacts of acute climate events and long-term global warming, droughts.
    b. Water – acute risks from flooding, chronic risks from sea level, impact on groundwater
    c. Agriculture – risks to food production capacity

3. **Transition risks**

    a. Energy production and exports exposed to 'inevitable policy response' in global trade policy.
    b. Capacity to adapt to positive trends in decarbonisation, ecosystem preservation.

4. **Resilience**

    a. Resilience in sovereign credit rating, fiscal space
    b. Resilience in balance of payments and FX reserves
    c. Resilience in existing socio-economics outcomes e.g. health

CALCULATION AND WEIGHTING

1. **Materiality must be embedded in the index calculation** – two countries with roughly minimal exposure to a particular risk should both score close to zero for that measure. Hence a cross sectional standardization per measure, scaled to 0-1, will be taken from each metric. All indicators are transformed such that 1 reflects maximum risk, 0 a minimum.

2. **Outliers retained** - given the widespread documentation of the non-linear impact and costs (loss and adaptation) of climate and natural capital, outliers will be retained to reflect countries that face extreme tail risk from one or more factors.

3. Where possible all **measures are scaled relative to a base** e.g. GDP, total revenue for cross-country comparability.

4. In order to avoid further complexity, in terms of arbitrarily determining country by country materiality, we have selected approximately **equal numbers of indicators across the different sub-components of the index** set out above.

5. In order to reflect the importance of non-linearities in environmental risks, we will then apply a **geometric mean**[2] in each subcomponent, and across the overall index as a whole. Geometric means penalise countries with similar simple arithmetic means but greater dispersion, as one of two very weak scores suggest particularly acute risk which should carry a higher weight.

6. In order to deliver on all of the above aims of index construction, a specific approach has been developed to achieve 0-1 scaling in a way which ensures approximately equal contributions from each indicator, where we define equal contributions as the cross sectional arithmetic average of that score between 0.3 and 0.7. This is achieved by applying the following formula to generate score S_i for country i from raw metric X_i:

   $$S_i = \frac{X_i - Percentile(X,k)}{Percentile(X,k) - Percentile(X,j)}$$

   Where $k = \{1, 0.99, 0.9\}; j = \{0,0.01,0.1\}$

   (noting that variables must be inverted where (i) a higher score signifies lower risk (ii) where scores sits partially or entirely <0).

7. Further issues around calculation and updating are covered in Appendix 2.

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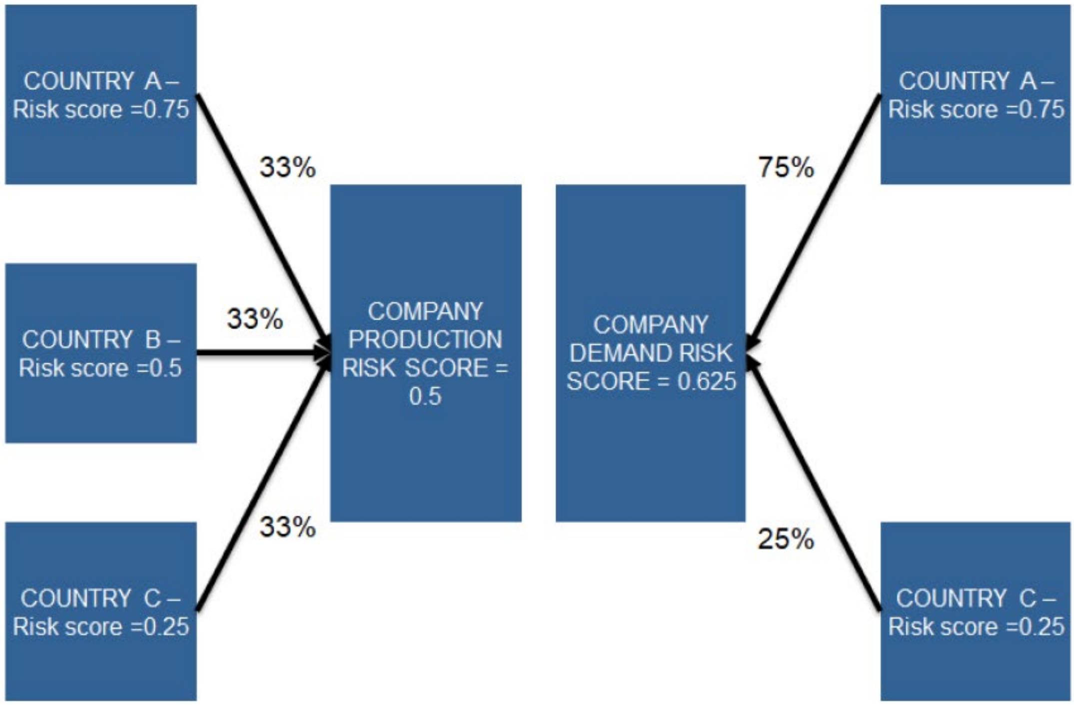
[2] https://mathworld.wolfram.com/PowerMean.html

APPLICATION TO PORTFOLIOS

1. Direct score can be obtained for sovereign asset exposure as weighted sum, should be duration adjusted to reflect greater long-term risks from both physical and transition, which are non-linear in time[3].
2. For corporate exposures, Bloomberg functionality providing geographical mapping of country production and revenue mix can be used to create a spatially weighted measure of each corporates production and revenue risks:



At present, complexities and interactions/non-linearities/feedback loops present difficulties in distinguishing which exact factors will have a greater impact on production vs demand risks on each company. E.g. A manufacturer producing in a country which faces high exposure to physical or transition risks relating to the agricultural sector and wetlands may appear less exposed initially. However, over the long-run that company may face significant increases in tax burden or sovereign funding risks as indirect channels. So even though that manufacturers direct business may have less short-term environmental exposure, longer-term those risks can come through sovereign financing risk or other channels. Companies based in countries with poor energy grid mixes will have to declare under TCFD, again creating new risks for companies which initially appear moderately exposed.

Hence the proposed index would be applied uniformly as a measure of production and demand risk as a first stage application.

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[3] Further work will be required on a country by country basis to look at the temporal distribution of risks and potential tipping points both in the underlying macroeconomic outcomes and in financing e.g. sudden stops and climate insolvency.

Appendix 1 - Indicators

	Source
NATURAL CAPITAL/BIODIVERSITY	
Forest rents as % GDP	World Bank, OECD
Deforestation trends over last decade	GFW
GLAD weekly deforestation where avaible	GFW/WRI
Land cover change	https://www.protectedplanet.net/c/world-database-on-prote
Land cover change within KPA	https://www.protectedplanet.net/c/world-database-on-prote
Land cover fragmentation	https://www.protectedplanet.net/c/world-database-on-prote
Land cover fragmentation within KPA	https://www.protectedplanet.net/c/world-database-on-prote
Land productivity	https://www.protectedplanet.net/c/world-database-on-prote
Land productivity within KPA	https://www.protectedplanet.net/c/world-database-on-prote
2050 GDP growth loss from pollination	WWF/Purdue/Minnesota
2050 GDP growth loss from coastal protection	WWF/Purdue/Minnesota
2050 GDP growth loss from water yield	WWF/Purdue/Minnesota
2050 GDP growth loss from pollinators	WWF/Purdue/Minnesota
2050 GDP growth loss from pollinators	WWF/Purdue/Minnesota
2050 GDP growth loss from pollinators	WWF/Purdue/Minnesota
Mining rents as % GDP	WDI
Mining as % exports	WDI
% terrestiral area in protected areas	IUCN
Ocean biodiversity	OHI
PHYSICAL RISK - ATMOSPHERIC	
Hurricaine/Typhoon risk	INFORMA
Projected economic loss from temperature change	Burke, Davis, Diffenbaugh (2018)
Days of extreme heat	World Bank Climate portal
Heatwave risk probability	World Bank Climate portal
Drought probability	World Bank Climate portal
% land exposed to drought by 2050	Isipedia - Lange et al 2020
% population exposed to drought by 2050	Isipedia - Lange et al 2020
Ocean carbon storage	OHI
PHYSICAL RISK - WATER	
Population impacted by riverine flood risk	WRI
Population close to sea level	WDI
Projected sea level rise risk	Coastal DEM
WRF - Scarcity & drought risk	WWF
WRF - Flood risk	WWF
WRF - Water quality and impairment risk	WWF
WRF - Ecosystem service loss risk	WWF
Freshwater withdrawal rates	Aquastat/WDI
Water productivity	Aquastat/WDI
Improved sanitation	WDI
Clean Ocean waters	OHI
Coastal protection	OHI
Extreme rainfall probability	World Bank Climate Portal

PHYSICAL RISK AGRICULTURE/FOOD	
Agri/Forestry/fisheries as % GDP	WDI
Agri/Forestry/fisheries as % exports	WDI
Agri/Forestry/fisheries as % employment	WDI
Rural population	WDI
Agri/Forestry/fisheries export taxes as % GDP	WDI
Projected change in agricultural output RCP 2.6 vs 8.	IFPRI/Harvard
Expected population change	HNPStats
Food import dependency	FAOStat
Agriculture productivity capacity	FAOStat, WDI
Sustainable Nitrogen management index	https://epi.envirocenter.yale.edu/epi-indicator-report/SNM
Malnutrition stats	WDI
Global food security index	https://foodsecurityindex.eiu.com/
Marine food security	OHI
Extreme rainfall risk	World Bank Climate portal
TRANSITION RISK	
Oil & gas as % GDP	WDI
Oil & gas as % exports	WDI
Oil & gas as % employment	WDI
Oil & gas export taxes as % GDP	WDI
Coal rents as a % GDP	World Bank
Dependency on imported energy	WDI
Current carbon intensity per capita	EDGAR, PRIMAP
share of renewables	https://www.irena.org/Statistics
Hydro share of electricity generation capacity	WDI
Electricity production from coal	World Bank
Potential for renewable investment	BNEF
Green complexity potential	Uni Oxford INET
Coastal economic health	OHI
Coastal tourism and recreation	OHI
RESILIENCE	
Debt/GDP	Moody's
Headline deficit/GDP	IMF WEO
External debt/reserves	Moody's
Interest/revenue	Moody's
external debt/exports	Moody's
Subsidies & other transfers % expenses	WDI
% population in slum dwellings	MDG/SDG
Urban concentration	WDI
% revenue from grants/aid	WDI
% health services provided from external resource	WDI
Age dependency	WDI
Infrastructure quality	WDI, WEF
WRF - sector-weighted operational risk	WWF
Disaster preparation	HFA National progress

Appendix 2 - Index Update Frequency and long-term aims

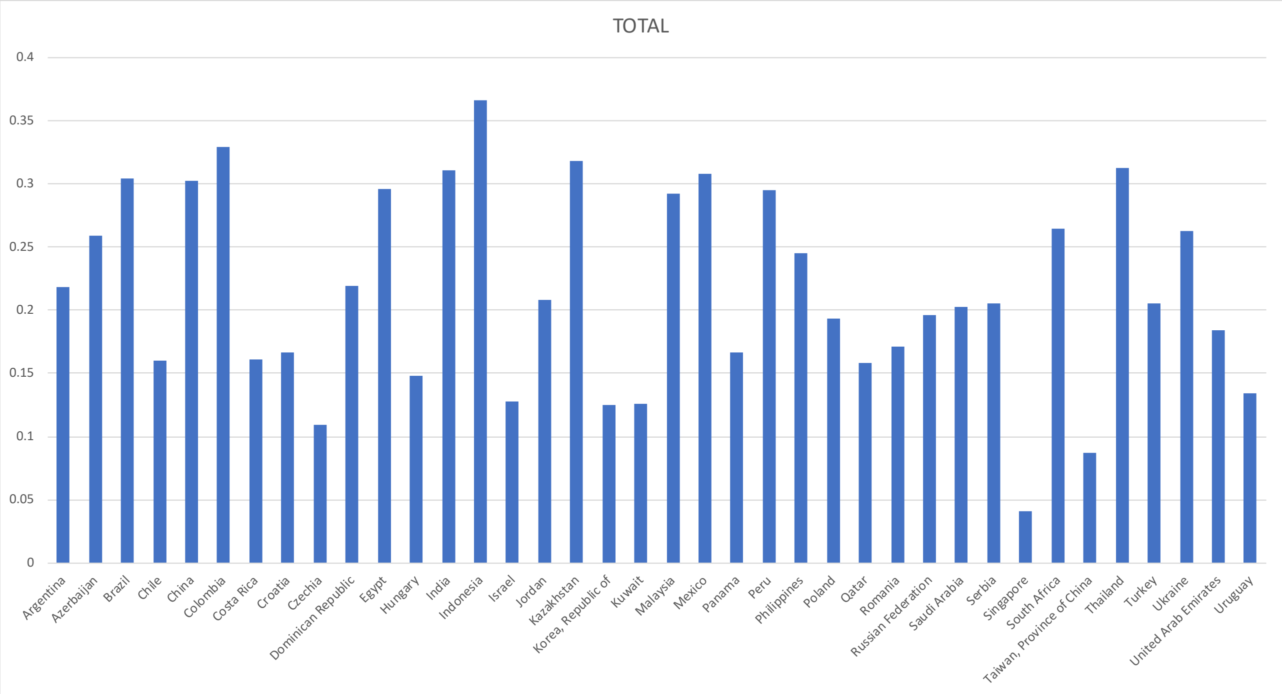
1. Initial aim to create proof of concept and index estimate.
2. Focus on ensuring initial estimate is as real-time as possible
3. Next step – increase the scope of 'real time' indicators sourced from GIS and remote sensing e.g. monitoring of biomes, KPAs etc.
4. Next step – ensure that forward looking e.g. 2050 RCP 8.5 forecasts and projections are based on models which can be updated annually and not end up stale within the index.
5. Next step – establish platform, financing and broad corporate/institutional support for hosting, maintenance and dissemination of index.

Headline index results - EM

We focus here on a sub-set of the total emerging markets universe which is captured in this data set, analysing 38 countries which are either (i) investment grade (ii) issue substantially in local current sovereign markets (iii) make up a significant portion of EM hard currency indices.

Our main findings are:

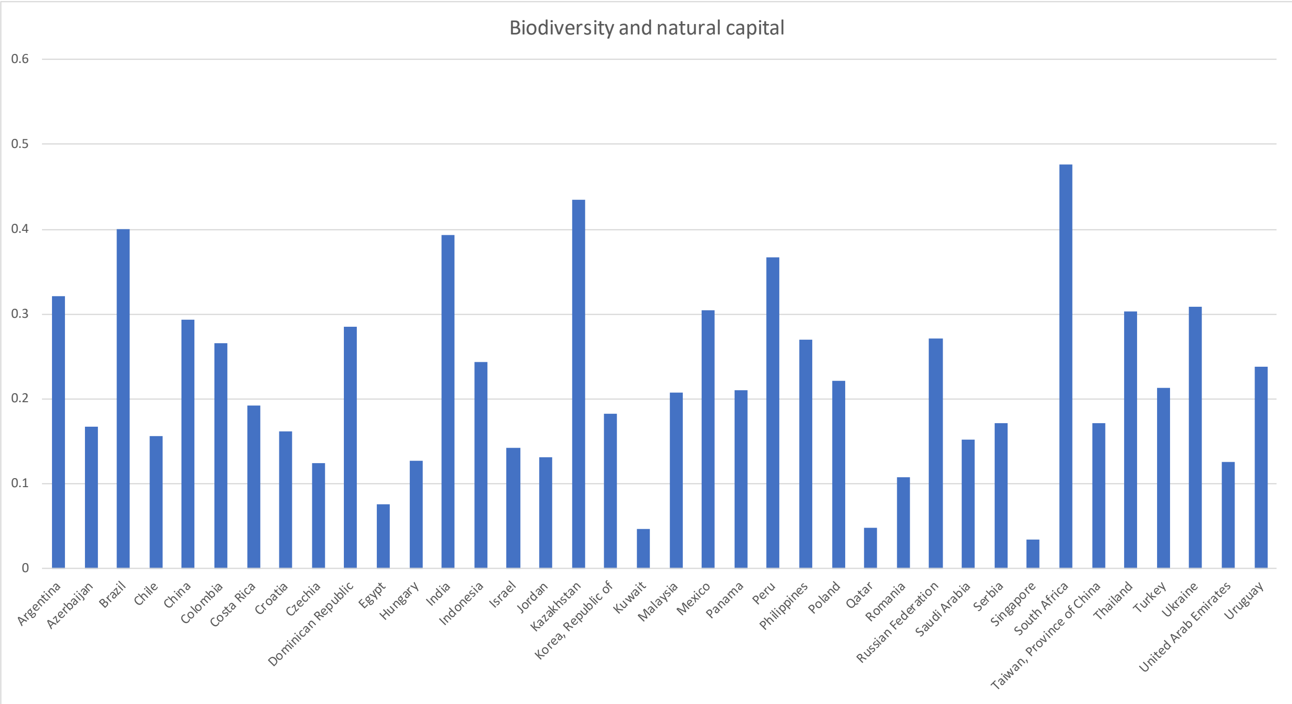
1. Outside of frontier markets and Sub-Saharan Africa in particular, risk cases are concentrated in Latin America and Southern Asia, with one or two former CIS countries also showing high and sustained risk across the sub-categories.
2. Despite this geographical pattern, countries with strong institutional policy responses such as Chile, Singapore, Uruguay and Costa Rica were able to demonstrate much lower forward-looking risk.
3. Central European markets, including Russia, see specific weaknesses offset by the drastically less negative implications of atmospheric and agricultural physical risk trends in that region.



Sub-component index results - EM

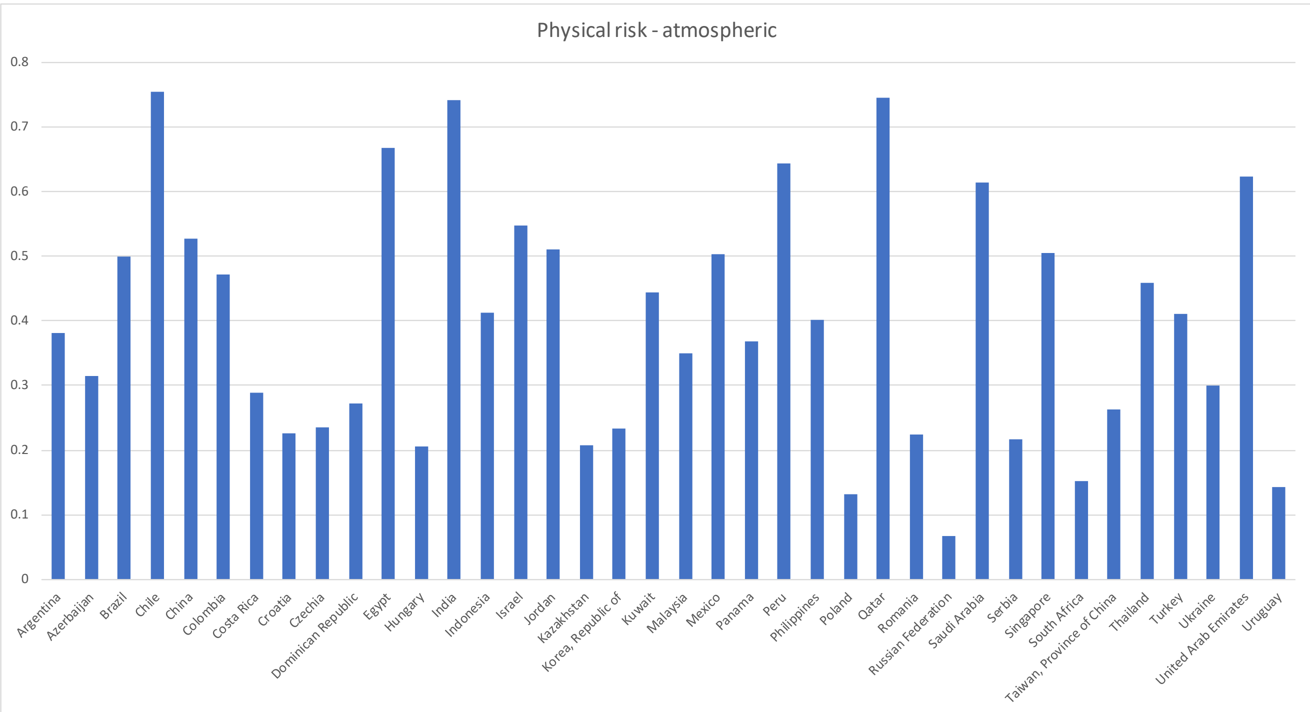
Biodiversity and natural capital:

1. There is a strong association of countries with significant mining industries to greater biodiversity risk, which shows up in both current and forward-looking projections.
2. This is further exacerbated when combined with industrial farming and soft commodities, with Brazil, Peru and South Africa displaying the highest risk scores.
3. The high risk measure for India is concentrated in the very severe risk the country faces from the deterioration in ecosystems relating to water asset decline.
4. By construction, GCC countries with minimal natural capital endowments have limited risk, although by definition then very little opportunity for improvements via policy or investment.



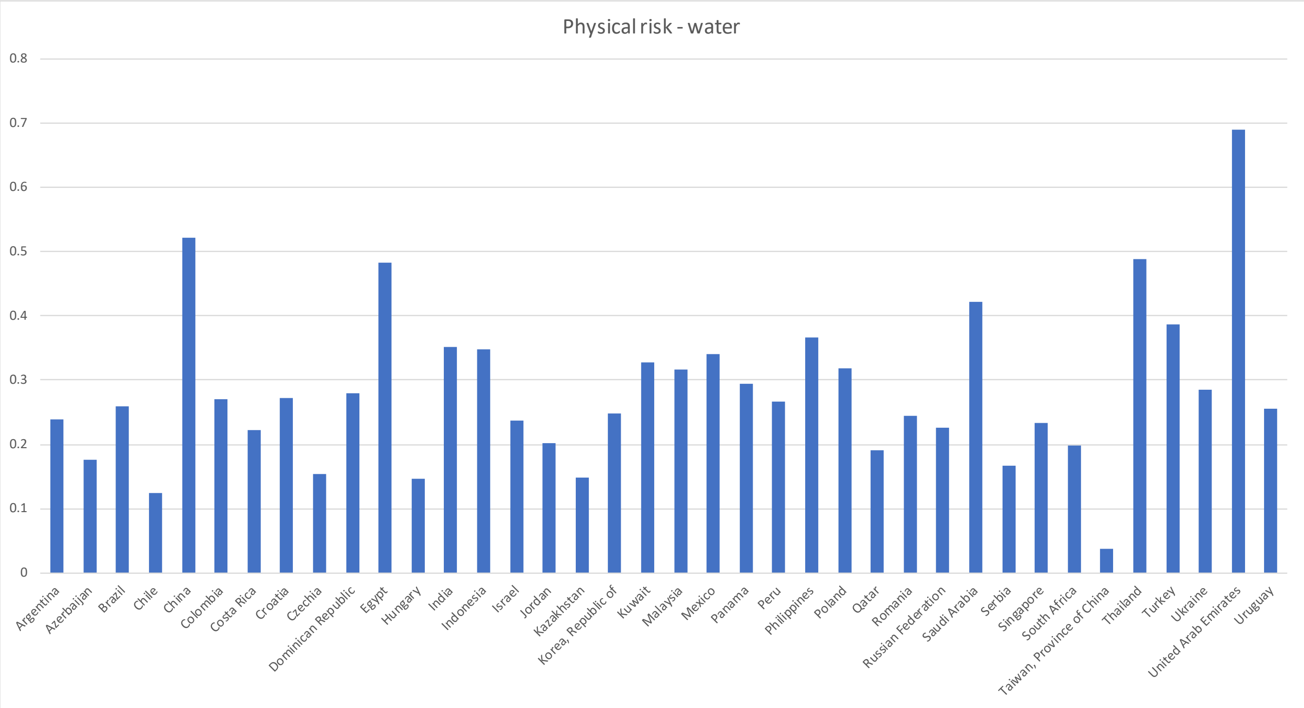
Physical risk – atmospheric

1. In contrast, CGC countries are amongst the highest risk from physical atmospheric risks, given their proximity to thresholds for economically feasible temperatures.
2. Some parts of Southern Asia are also at risk from this feature, in particular India.
3. A third set of countries also exposed are those on the Pacific coast of Latin America, where temperature changes are set to be significant, and pollution is also a material problem.



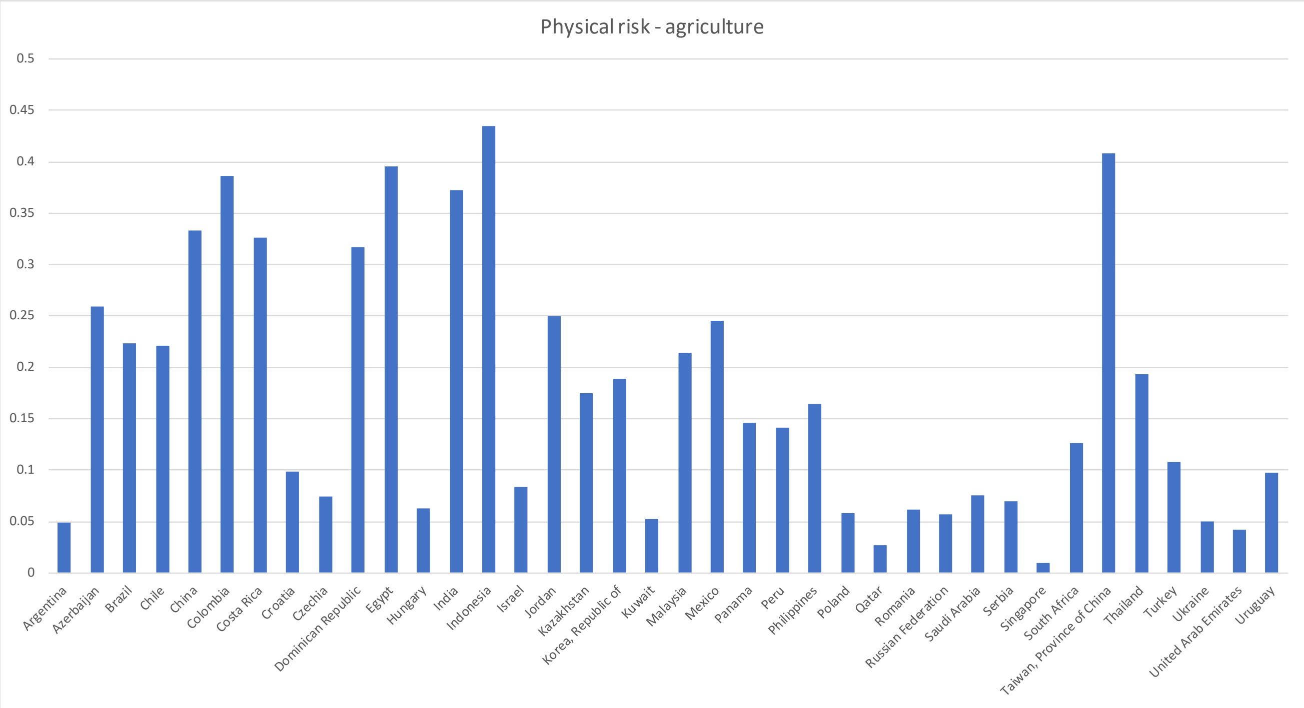
Physical risk – water

1. Unsurprisingly, GCC countries appear exposed to broad water risks.
2. Alongside the Gulf countries, China and Thailand also exhibit significant risks. In China, coastal areas are amongst the most exposed globally to sea level and other maritime risks, whilst inland there are significant areas of water stress and damage to water quality.



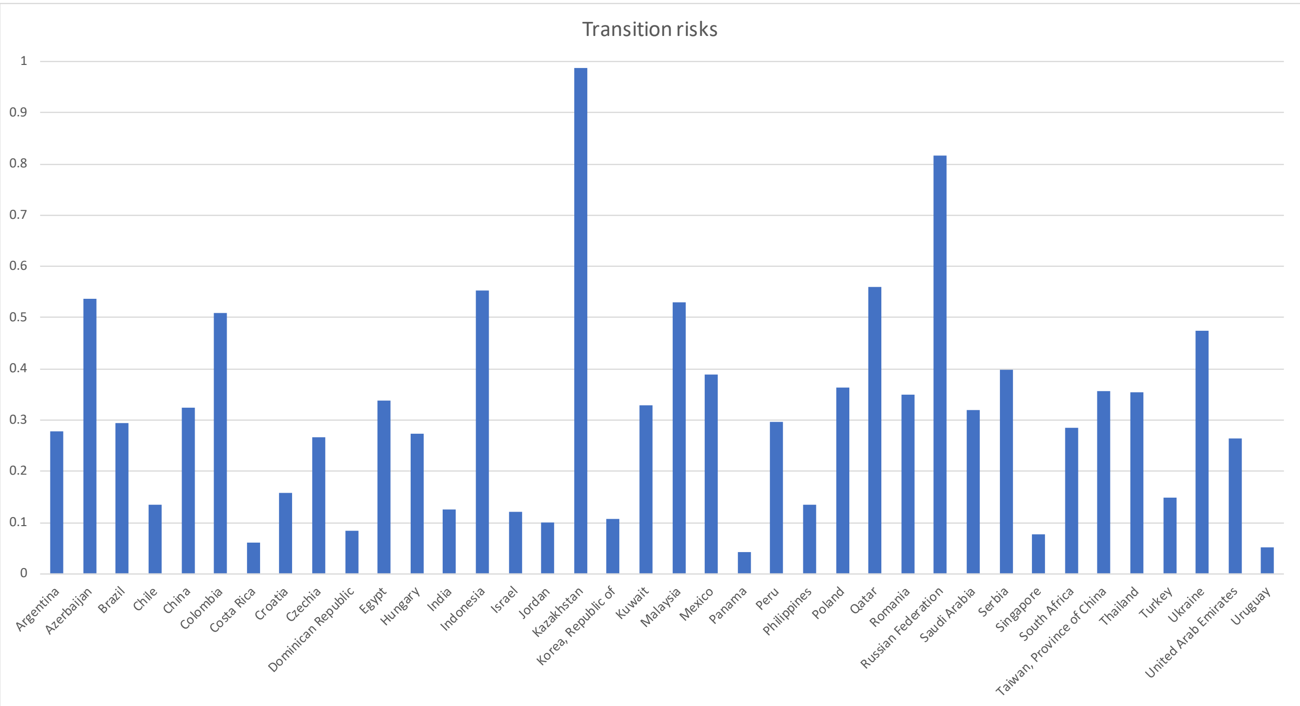
Physical risk – agriculture

1. Southern Asia, in particular India and Indonesia again look very exposed. In India this is particularly via the large, informal rural economy which itself faces risks from both temperature and water scarcity. In Indonesia exposure is clearly via the impact of industrial soft commodities production.
2. Also broadly exposed to risk are the soft commodities sectors of Colombia and the Carribean region.



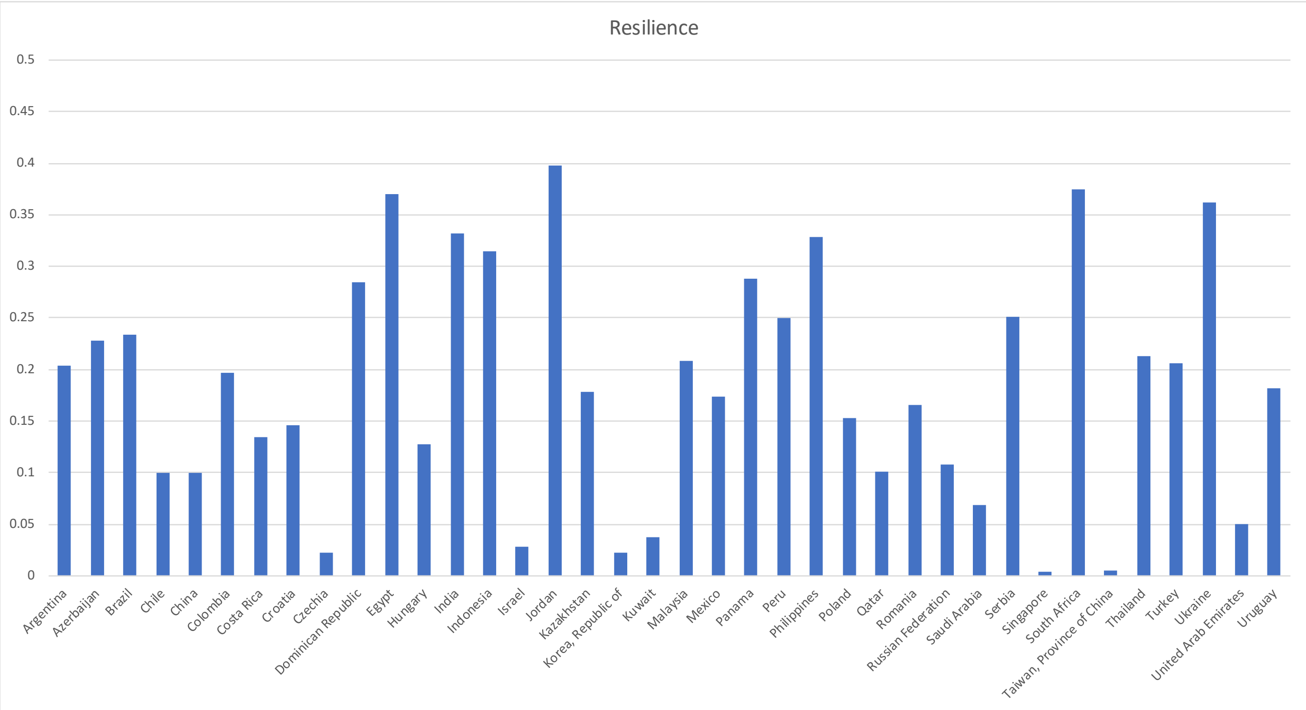
Transition risks

1. Transition risk scores are dominated by the hydrocarbons producers, in particular those also producing a lot of coal.
2. In general, few emerging markets have sufficient investment and R&D to suggest any positive transition dynamics outside China and Israel and in specific sectors such as tourism, outsourced services and trade.



Resilience

1. Interestingly, there is a strong correlation between those countries with weak indicators in terms of fiscal and financial resilience, which also have relatively weaker scores on their physical resilience in e.g. infrastructure.
2. Relatively older populations in Latin America together with weak infrastructure also drag investment grade markets such as Peru and Mexico towards weaker scores.

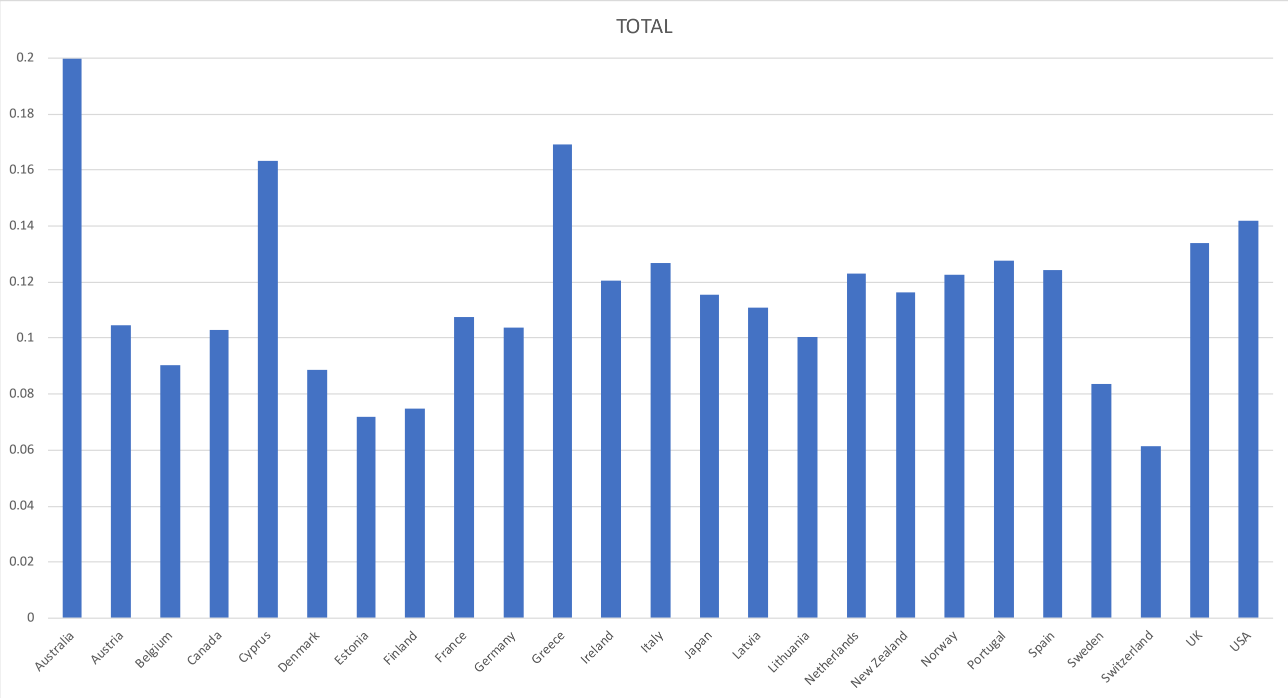


Headline index results - DM

We focus here on developed markets as classified by IMF/World Bank but excluding those which are classified as emerging markets for fixed income investment purposes e.g. Singapore. We include those developed markets which are IG and HY, also including the Baltic states.

Our main findings are:

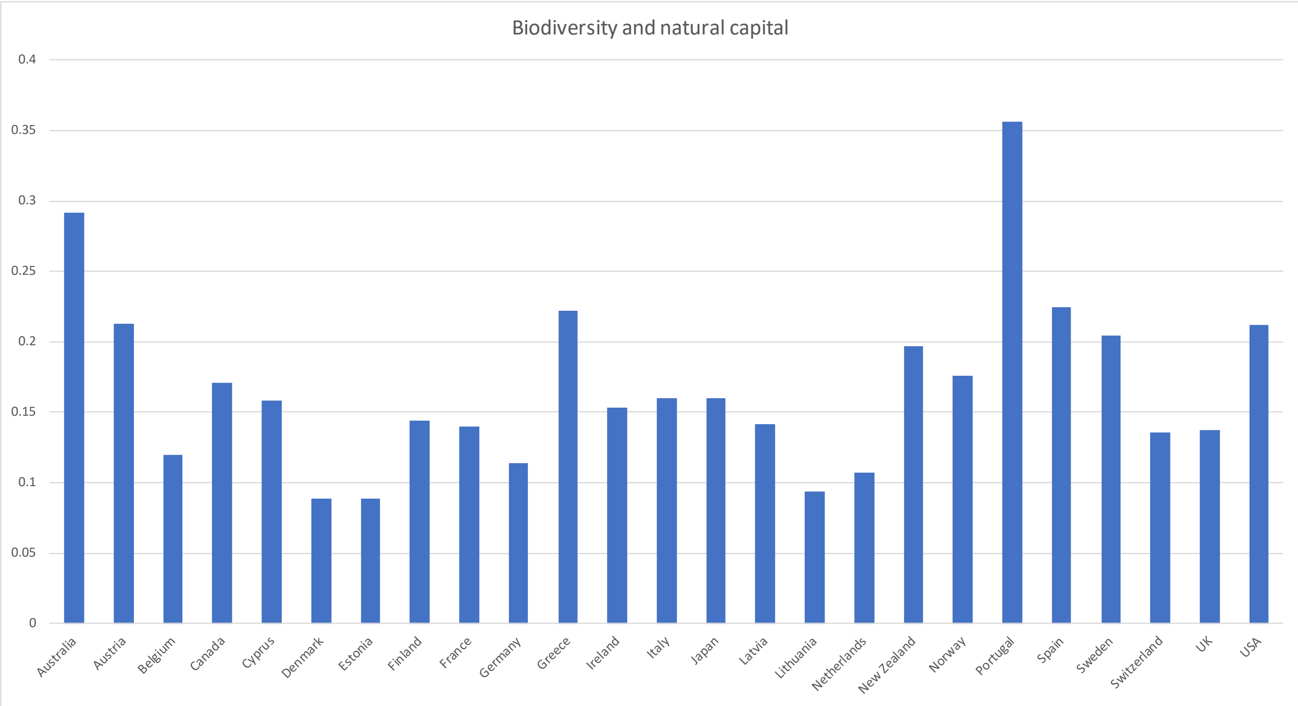
1. Australia is the stand-out DM risk market on the total score, together with the smaller and economically less resilient Mediterranean countries.
2. The US and UK also score poorly on several metrics such as atmospheric and flood risk.
3. Switzerland has the best score on our overall index, with the Nordic and Baltic countries also scoring very well across the board, with the exception of somewhat higher exposure in Norway.



Sub-component index results - DM

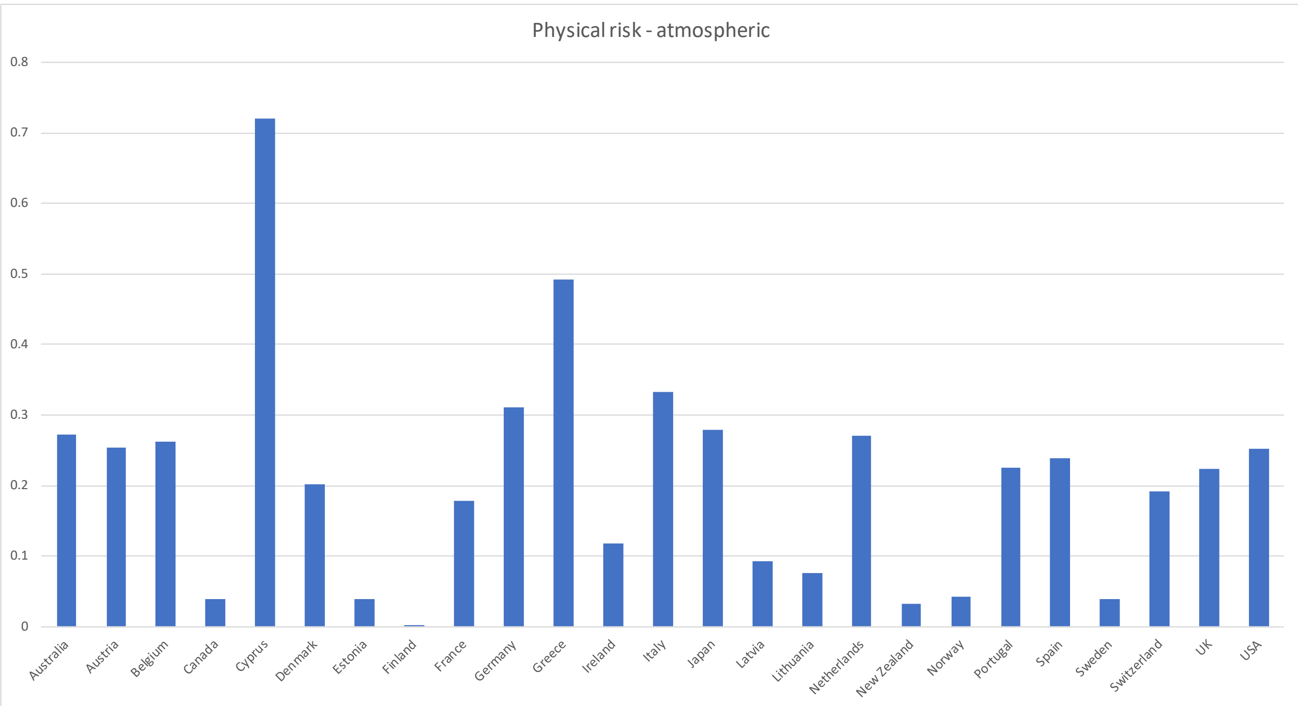
Biodiversity and natural capital:

1. In Europe, Portugal stands out as having seen much more negative trends materialising in deforestation and land use, whilst also showing greater long-term vulnerability to economic loss from coastal biome erosion.
2. Australia is exposed across a wide range of indicators, with falling land productivity projected to continue up to 2050.



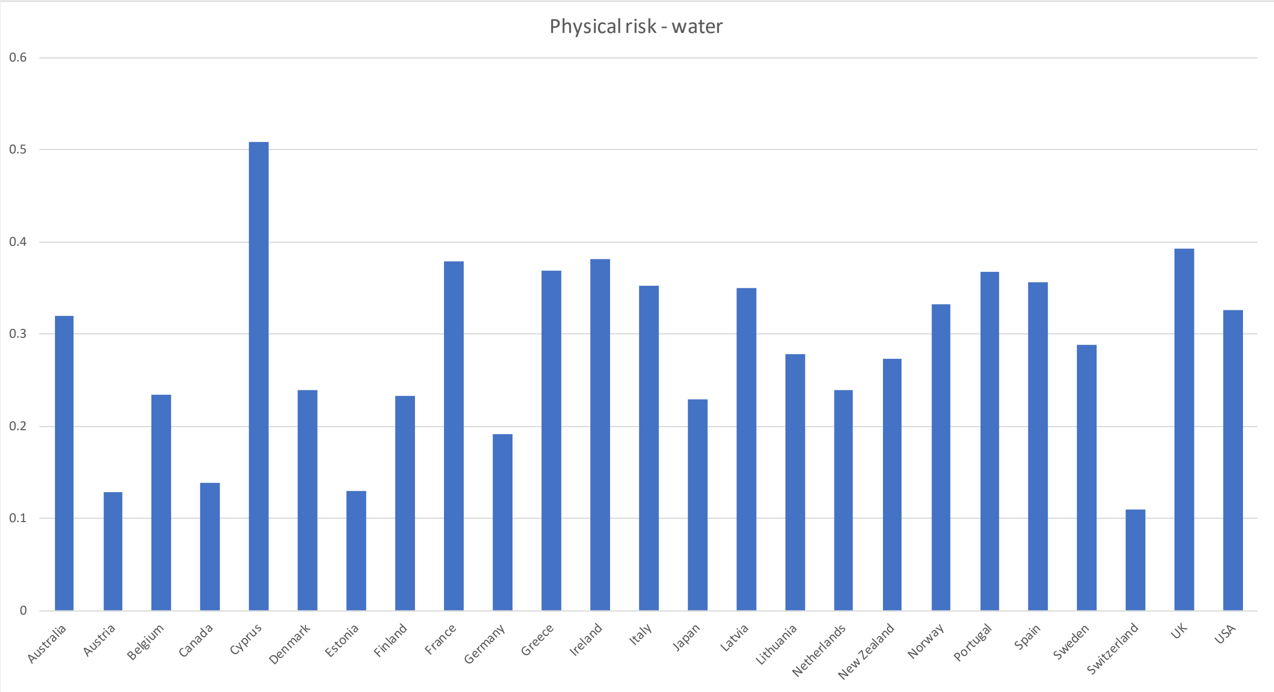
Physical risk – atmospheric

1. Here the greatest exposure and risk is clearly in the Mediterranean, with Greece and Cyprus particularly exposed to the impacts of temperature through several channels, especially drought.
2. Italy faces exposure to similar risks, albeit somewhat more moderately, but with additional exposure to risk from storms and flooding.



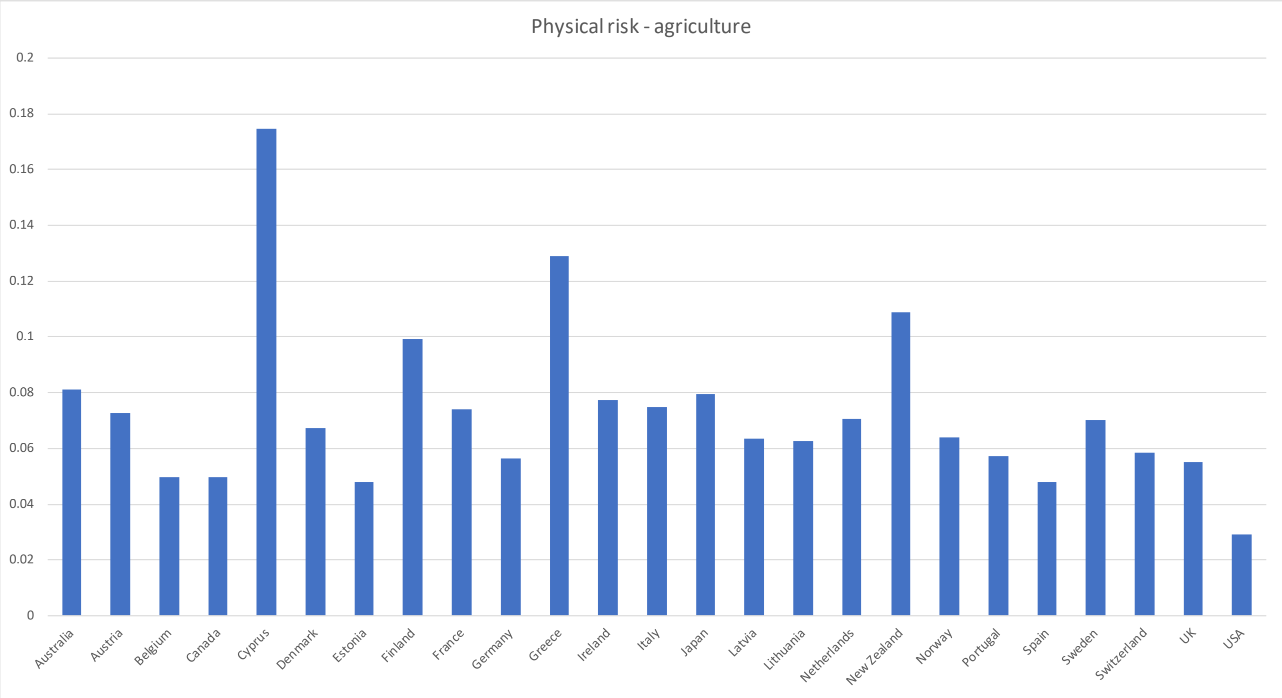
Physical risk – water

1. Water risk is also high across many Southern European countries given the stress on domestic water assets anticipated together with higher temperature captured in the prior subcomponent.
2. A number of developed countries face particularly high exposure to water risk from flooding and seal level changes, the UK being a prominent example.



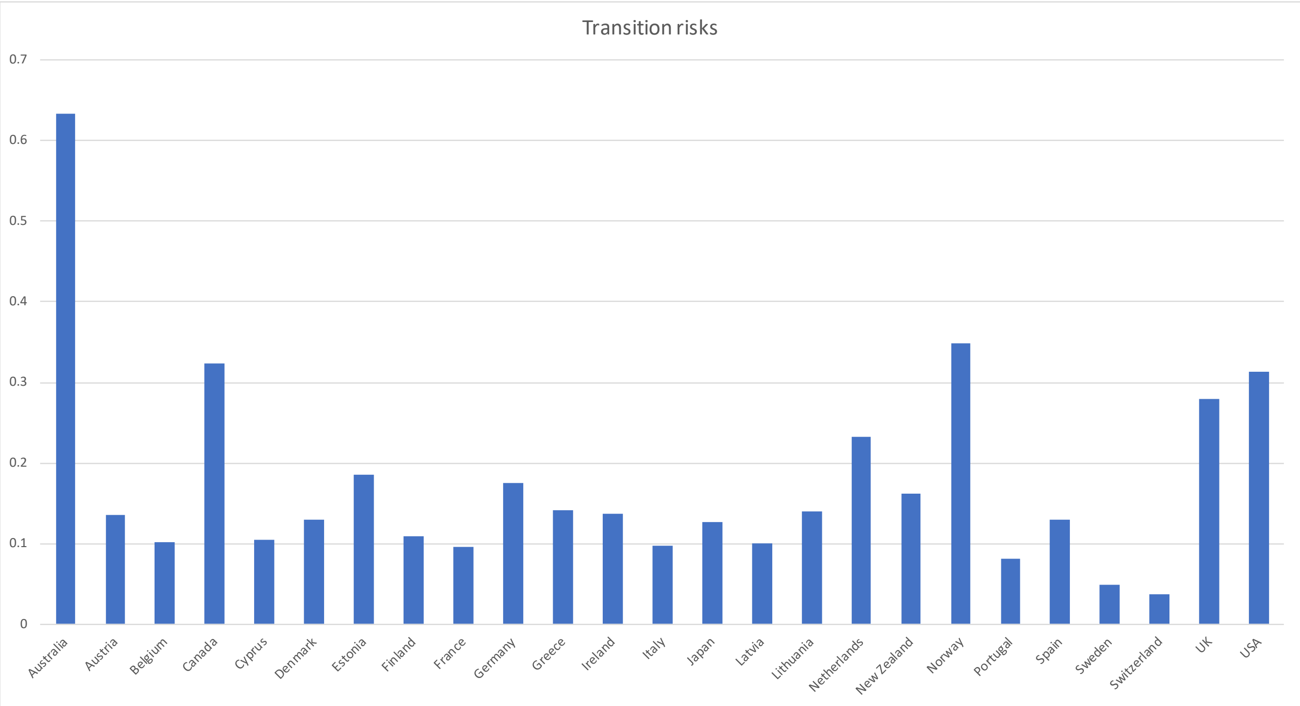
Physical risk – agriculture

3. Again, the countries of Southern Europe with material agricultural sectors – Cyprus and Greece – see this risk interact with their poor scores for other forms of physical risk.
4. New Zealand shows some exposure, despite the lower projected impact of global climate change, the sheer scale of agriculture in New Zealand's economy raises the risk score.



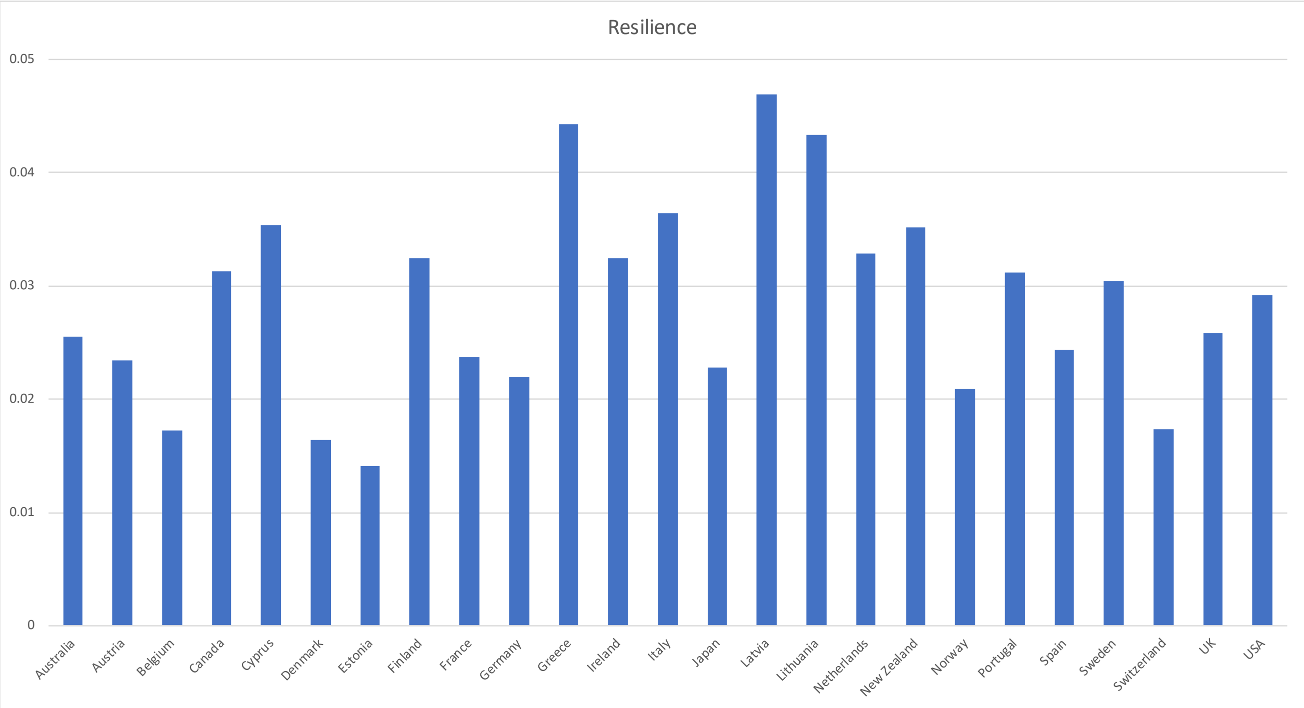
Transition risks

1. Australia, with its highly commodity intensive economic model, is by far and away the most exposed economy in aggregate to the transition risk indicators we score.
2. Other economies with material hydrocarbons exposure similarly flag risks here, but at less than half the relative magnitude of Australia.



Resilience

3. In general the resilience risk score for most of DM is neglible relative to EM, even for high yield markets such as Greece given the umbrella provided by the EU financially and in terms of resilient infrastructure and services.



Implications for our ESG scores

The ESG scoring process at NinetyOne has the same status as other areas of research into traditional drivers of asset returns, with investment professionals responsible for research and scoring with support from centralised ESG data and expertise. Regular meetings are held to discuss and update scorecards, and crucially our process focuses on forward-looking rates of change, especially in policy but also in medium-term risks.

Consequently, it is very positive to see the high degree of correlation between our positive research scores for countries like Chile, Singapore and Costa Rica. Likewise, challenging dynamics in our ESG assessment of environmental policy in countries like India and Indonesia are reinforced by the CNSI.

However, the CNSI also challenges positive scores in our process for countries such as Thailand and Peru, as well as frontier markets such as Vietnam. Whilst our overall ESG scores are based on a view on the forward-looking change and delivery of policy, clearly the hurdle to effectively mitigating environmental risk and achieving climate goals is going to be higher in countries with more challenging initial conditions. Our ongoing engagement with those

Opportunities and implications for green and SDG bond issuance

As discussed earlier in the report, this CNSI should be seen not only, or principally, as a measure of risk, but also of the opportunities available to allocate capital to the highest marginal returns available in environmental investment. Given the CNSI metrics, we note a number of potential opportunities and urgent trends which need to be developed in climate and SDG bond markets:

1. Chile has been an active early issuer in EM green bond markets, and given specific risks around physical risk for the country, such instruments would seem to offer investors a strong opportunity to contribute to future sustainable growth.
2. A number of other larger emerging markets have been discussing and laying the ground-work for green and SDG bond issuance, and we believe the CNSI offers strong guidance on the priorities that governments should focus on in growing these markets:

    a. For India and China, which have made strong progress in renewable energy, there is further upside from additional financing in those areas (with China also set to improve its green bond taxonomy.) However, bond issuance focused on water infrastructure appears if anything an equally high priority in terms of allowing investors to provide capital to high marginal growth investments.
    b. A number of countries in Latam America are actively looking to follow Chile, with Brazil, Colombia and Peru developing plans. Issuance to address biodiversity as well as climate would appear to be of very high marginal value for those countries, tied into address the physical risk to their agricultural sectors.
    c. Similarly in Indonesia and Malaysia, planned green bond issuance should be complimented by issuance designed to address risks to natural capital and the agricultural sector. Such bonds could also tie into SDGs related to inclusive growth and sustainable infrastructure.
    d. Issuance in GCC and former CIS would appear to be best focused on addressing transition risks over the medium-term related to hydrocarbons tied together with atmospheric physical risk, and again Colombia also looks like a strong candidate for such issuance.

Private financial institution perspectives on climate and nature data

September 2021

Michael Hugman
Director – Climate Finance

Children's Investment Fund
Foundation

Overview

- Two case studies of NGOs and private investors collaborating to solve sustainable data challenges:
  - WWF Climate and Nature Sovereign Index
  - Assessing corporate climate transition plans
- Common challenges addressed:
  - Loss of information – traditional data sets often reflect a single common factor
  - Forward-looking information scarce despite being vital in a regime of persistent structural breaks
  - Applications:
    - Impact/KPIs
    - Engagement
    - Portfolio risk management when facing systemic risk

WWF Climate & Nature Sovereign Index

- Real-time and forward-looking projections
- Spans natural-capital and transition-risk exposures, plus ‘traditional’ climate risks
- Makes explicit the economic and financial linkages
- Taxonomy aligned to investors’ needs:

For illustrative purposes only.
Source: Ninety One and WWF. As at July 2020.

Index includes 85 indicators, including many forward-looking and novel data points

Biodiversity and natural capital

Annual deforestation trends - 10y
2y real-time deforestation trends
Total land cover change
Land cover change in protected areas
Total land cover fragmentation
Land cover fragmentation in protected areas
Total change in land productivity
Change in land productivity in protected areas
GF economic growth risk - pollination
GF economic growth risk - coastal erosion
GF economic growth risk - water yields
GF economic growth risk - forestry services
GF economic growth risk - marine fishing stocks
GF economic growth risk - other ecosystem services
Mineral rents (% GDP)
Mining Exports (% Goods Exports)
Protected area coverage % landmass
Ocean hazard index - biodiversity

Physical risk - atmospheric

Natural Hazard Risk (0-10) (10 = highest risk)
2050 GDP loss from RCP8.5 temperature change
World Bank 2050 median projected days of extreme heat under RCP 8.5
WB annual probability lethal heatwave by 2050 at RCP 8.5
Land area exposed to drought RCP 8.5 by 2050
Population exposed to drought, 2050 under RCP8.5
World Bank 2050 drought risk indicator
Ocean health index carbon storage potential
OECD Population exposure to particulate matter, µg/m3
OECD Population exposed to pollution levels above WHO guidelines, %

Physical risk - water

Population impacted by riverine flood risk (0-5) (5=highest risk)
Population close to sea level
Climate central projection of economic cost of Sea Level Rise
Freshwater withdrawal as % total water assets (Aquastat)
Water productivity ($ GDP per unit water, Aquastat)
WWF Water Risk Filter - drought risk
WWF Water Risk Filter - basin flooding risk
WWF Water Risk Filter - water quality measure
WWF Water Risk Filter - ecosystem risk
Access to sanitation WDI
Projected 2050 extreme rainfall deviation
Ocean health index - clean water score
Ocean health index - Coastal Protection

Physical risk - agriculture

Agriculture, Forestry & Fishing, Value Added (% GDP)
Agricultural Exports (% Goods Exports)
Employment in Agriculture (% Total)
Rural Population (% Total)
IFPRI/Harvard modelling of climate impact on crop volume production
Population growth % (2050 vs 2020)
Sustainable Nitrogen Management (100 = target)
Prevalence of undernourishment (% population)
Global food security index
Ocean health index - marine food security
World Bank 2050 growing season change

Bold = forward-looking/real time

Transition risks

Oil rents (% GDP)
Natural Gas rents (% GDP)
Fuel Exports (% Goods Exports)
OECD environmentally aligned tax % GDP
OECD environmentally aligned tax % revenue
Coal Rents (% GDP)
Net Energy Imports (% Energy Use)
Carbon intensity (CO_2 Emissions per $1k of GDP)
Carbon intensity (GHG Emissions per $1k of GDP)
Demand-based CO_2 emissions per capita, t per capita
Production-based CO_2 productivity, USD/kg CO_2
Ex-Hydro Renewables Production (% total electricity production)
Hydro Production (% total electricity production)
Production from Hydrocarbons (% total electricity production)
Climatescope score on renewable energy potential
Green complexity index - proximity density
Number of environmental patents, thousand patents relative to PPP GDP
Ocean health index - livelihoods
Ocean health index - tourism

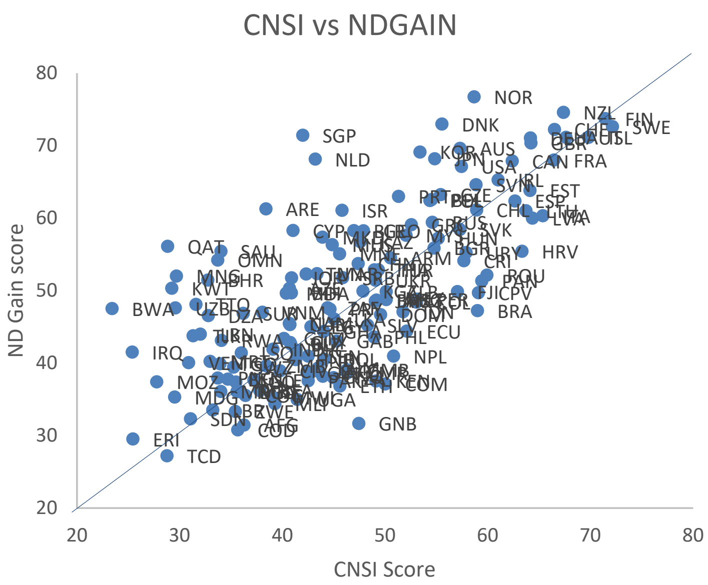
Resilience

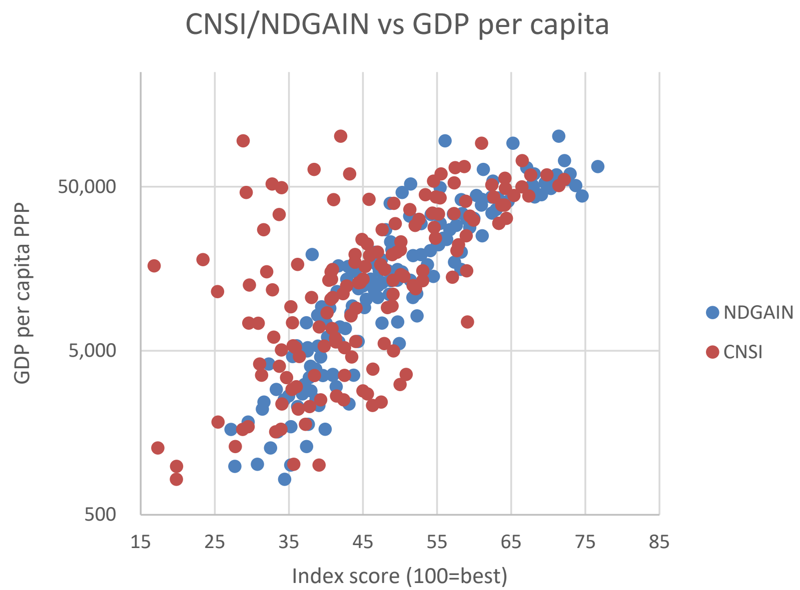
Gross government debt/GDP
Headline deficit 2021 IMF WEO
External debt/reserves
Government interest/revenue
External interest/CA receipts
WDI Subsidy + transfers % total government spending
Urban population living in slums (% Total)
Rural Population (% Total)
Aid Dependency (0-10) (10 = highest risk)
External Health Expenditure (% Total)
Age Dependency Ratio (% Working age population)
Physical Infrastructure (0-10) (10 = highest risk)
WRF Operational water risk
Disaster Risk Reduction (0-10) (10 = highest risk)

Source: Ninety One, Jan 2021

How does it compare to other climate risk indices?

CNSI latest climate modelling + transition risks, highlights greater dispersion in climate related risks

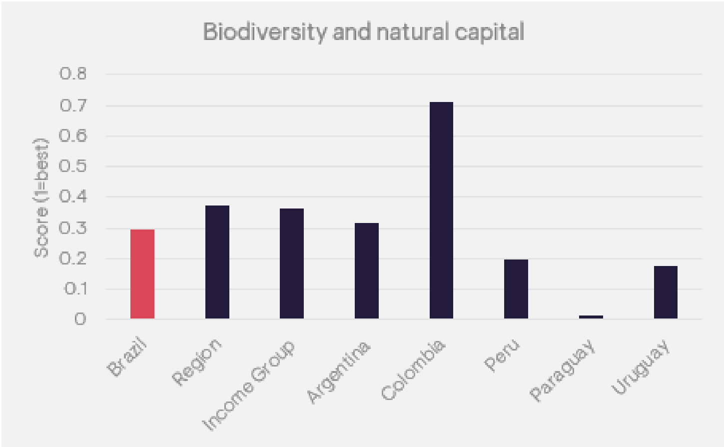


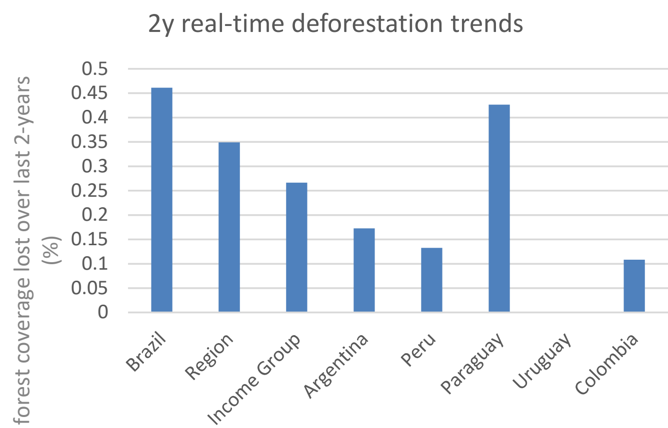


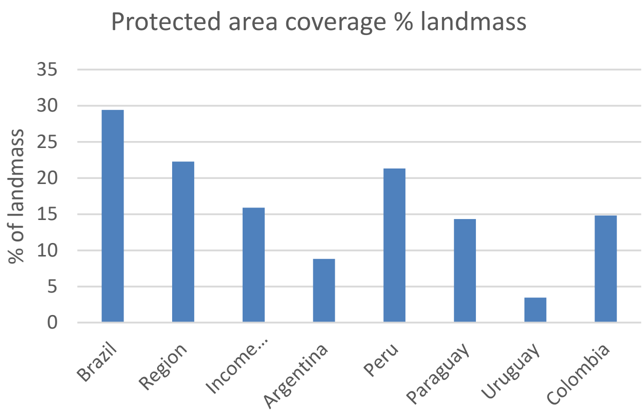
Climate risks still correlated with income levels, but much less so than traditional indices

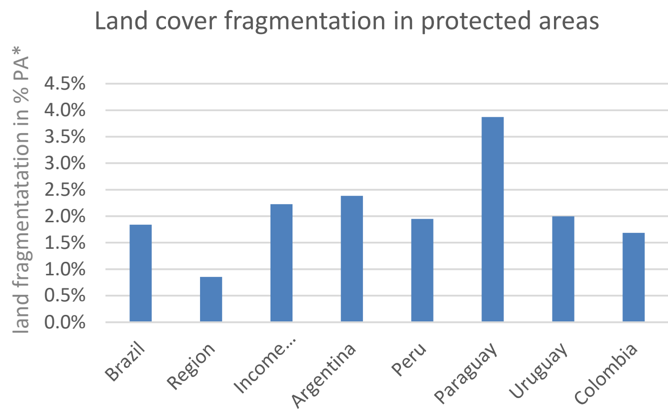
Source: Ninety One, WWF, Notre Dame Global Adaptation Initiative, Haver. Jan 31 2020

Brazil – Biodiversity & Natural Capital and selected indicators



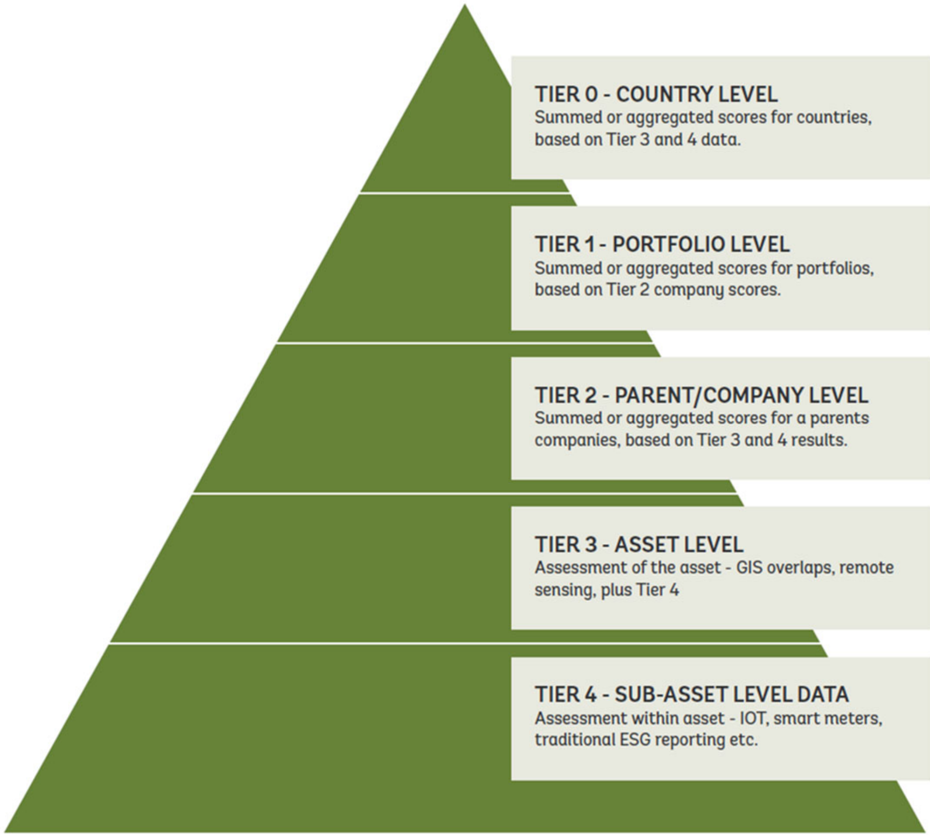






*over five year period to end 2015

Geo-spatial ESG: project ,corporate, portfolio and sovereign risk analysis



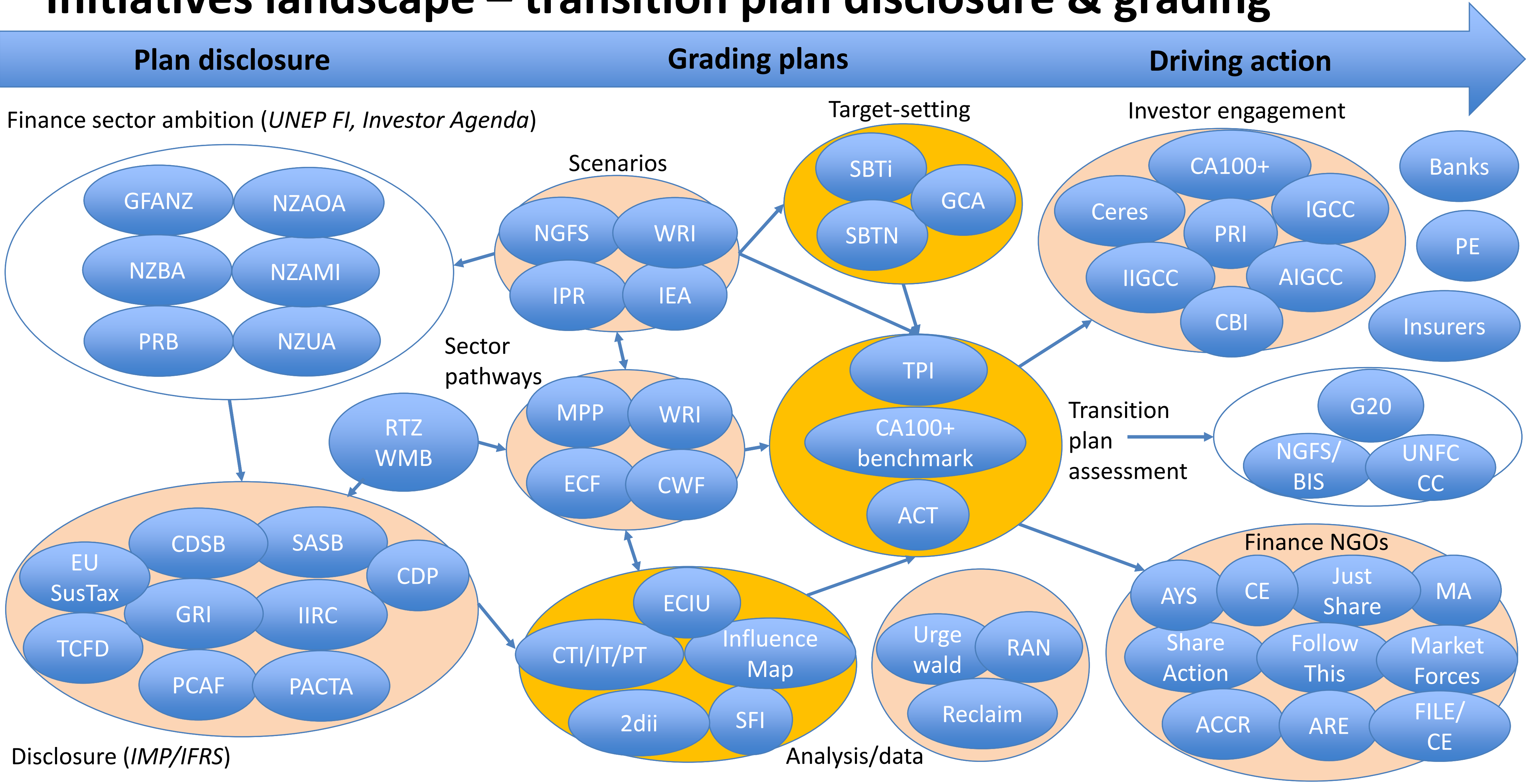
Source; WWF

Essential disclosure in a corporate climate action plan

- Short-term targets required: 5 year and 5-10 year plan*
- Average absolute Scope 1-3 emissions reduction of 7-8% pa to 2030
- Phase out fossil fuel use and production, no financing of new supply
- Executive compensation, strategy and lobbying aligned with plan*
- Necessary capex commitments*
- End deforestation, credible use of offsetting only if strictly necessary
- Independent auditing of emissions*
- Annual performance reporting to shareholders

* Indicator included in CA100+ net-zero company benchmark: https://www.climateaction100.org/progress/net-zero-company-benchmark/

Initiatives landscape – transition plan disclosure & grading



Climate action plans are key to financing the transition

Action	Climate disclosure	Climate risk & governance	Long-term (2030, 2050) Climate goals	5-year Climate action plans	Delivery of plans (performance audit)	Public Policy Capital flows
Frameworks	CDP, PCAF SSB/IFRS	TCFD	Science-Based Targets Initiative	CA100+ ACT	CDP TPI	Taxonomies BIS, G20
		Coordination: data, scenarios, pathways, benchmarks, monitoring				
Ecosystem	• SASB, CDSB, GRI, IIRC => IFRS • PCAF/PACTA • EU taxonomy	• TCFD, TNFD • Scenarios: NGFS, IEA, IPR, WRI	• SBTi • SBTN • RTZ, WMB • GFANZ/UNEP: NZAOA, NZBA, PRB, NZUA, NZAMA	• CA100+ bm: CTI/ITI/PTI, TPI, 2dii, IM • ACT, WBA • CBI • RMI/CWF/MPP/WRI	• CDP • TPI • SFI (3rd party verification) • VCMI (offsets)	• GFI • ECF • CWF • WWF

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Irving Fisher Committee on
Central Bank Statistics

BIS

International Conference on "Statistics for Sustainable Finance", co-organised with the Banque de France and the Deutsche Bundesbank

14-15 September 2021, Paris, France, hybrid format

Statistical data needs on sustainable finance for central banks[1]

Sabbah Gueddoudj,
Central Bank of Luxembourg

[1] This presentation was prepared for the conference. The views expressed are those of the author and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

Statistical Data needs on sustainable finance for central banks

Sabbah Gueddoudj[1]

Abstract

The negative impact analysis of the climate change on the whole economy is particularly relevant for the central banks since they produce and use data before implementing the monetary policy to ensure the financial and prices stability and therefore mitigate the systemic risks in order to participate to build a healthy and resilient financial system. The goal of this paper is to discuss the development of sustainable finance database in accordance with the central bank's needs and propose some key recommendations at least in the short run to partly overcome the database lacuna. After having attempted to capture the notion of sustainability and briefly describe the ESG (Environment, Social and Governance) criteria, we justify why the central bank needs reliable sustainable financial data for their potential monetary policies to fight against the climate change, for instance. From this definition attempt, several important conclusions have emerged such as the harmonized taxonomy unavailability and the lack of reliable data to measure with accuracy the climate change impacts on the financial and economic sectors, for instance. To reduce the data gap, there are different European initiatives, and more particularly Luxembourgish ones, aiming at building sustainable bonds database to capture the nature and the size of such sophisticated financial tools. The sustainble bonds are financial instruments that permit to finance investments in line with the ESG criteria. We have found that there is an exponential development of the sustainable bonds market, witnessing the increasing investor's interest, and this rising trend has been taking shape in Europe since 2013. All European individual efforts against data lacuna are, of course, welcome and useful; however, they should be ordered and targeted according to the users' needs and the economic, financial, sanitary and social context to define and develop at the very short term a public, detailed and comprehensive ESG data repository (at granular and aggregated levels); since the reliable database existence is the cornerstone of any regulation and policy. Finally, as the climatic warming is global, the data storage project should lead to an international collaboration to define a common set of standards, to benefit from the scales and synergies advantages and to limit the redundant initiatives.

Keywords: sustainability, surveys, users statistical needs, central banks, Luxembourg sustainable bonds, recommendations.

JEL: C81, C82, E58.

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[1] This article should not be reported as representing the views of the Central Bank of Luxembourg and the Eurosystem. The views expressed are those of the author and may be not share by the statistics and research staff. For helpful remarks and suggestions, we would like to thank (without implicating) in alphabetical order Alexandre Carreira, Lucia Mengoni, Roland Nockels, Romain Weber and in a general manner we thank the statistics department staff.
We also would like to thank experts form the STC CCS (Statistics Technical Committee Climate Change Statistics) and TF Sufir (Task Force Sustainable Finance and Climate Related Risks) groups for their valuable and enriching discussions during the different meetings.

Contents

1. Introduction

The 2008 Global Financial Crisis (GFC) followed by the sanitary crisis has demonstrated that the funding system of production has reached its limits. Moreover, several climate reports warned governments about risks to continue to finance real sphere without controlling for the CO2 emissions, for instance. The most important decision was to reduce the high carbon production to limit the climate change and to ensure an optimal ecological transition. Since the COP21, the climate target is to reduce the increase in global temperature by 2100 (below 2°C above pre-industrial levels and even further to 1.5°C according to The Paris Climate Agreement, 2016). The Paris Agreement (PA) entered into force on 4 November 2016 and it has been signed by 195 countries[2]. It defines guidelines to achieve the climate targets and proposed a calendar. The PA considers that a negative externality, such as pollution is a wheel to the economic growth. Quite a few theories have shown that the natural resources are engines for growth. One of the most ancient approaches is the physiocraty theory. The Nobel Price economist in 2018, William Nordhaus has analyzed the role of climate change in the economic growth during the years. He was a pioneer in this field and his works have clearly described the channels between the economic growth and climate change. Nowadays, there are various attempts to describe and find solutions for a greener finance system based on empirical analysis (Nordhaus and Tobin, 1973; Nordhaus, 2006; Abraham and Mackie, 2006; Aglietta and Rigot, 2012; Jeffers, 2015; Kempf, 2017; Muller, 2014 and 2019; Belloni et al. 2020; Ehlers et al. 2020; BIS 2020; IMF, 2020; Gilchrist et al. 2021). However, the first difficulty is to accurately define the sustainable/green finance. There is until now no consensus on the definition and no definitive taxonomy. Currently, the sustainable activity may be summarized by several private or public agencies approach. "Financial products & services that consider environmental factors throughout the lending decision-making, ex-post monitoring, and risk management processes, to promote environment-responsible investments and encourage low-carbon technologies, industries and businesses" (Pricewaterhouse Coopers Consultant, 2013). In 1987, the United Nations Brundtland Commission defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs. These two definitions are similar but raise the question of the development of metrics to capture the size of the sustainability.

The current perimeter is too broad and therefore not very relevant for users and may develop free riders behaviours. For instance, there is no official set of variables to measure accurately the degree of "greenness" or more globally sustainability. In addition, the development of scoring agencies assumed to evaluate the level of greenness reveals that there are plenty acceptance thresholds for the notion of low-carbon, for instance. Some projects would be classified as low carbon projects by some rating agencies whereas for other agencies, they would be considered dangerous for the planet. Such a diversity in classification raises the concerns about free riding behaviour and the quality database?

During years central banks have saved the financial system by using and defining traditional and non-conventional tools, namely quantitative easing; low (even negative) interest rate policy etc. They have also enlarged their missions after the last financial crisis by guaranteeing the financial stability. Given the history and the role of the central banks during the financial crisis, it is normal that the central banks tackle the climate change; however, they should not be alone for this task. Despite the several debates on the central banks missions, it is obvious that they can fully play their role of regulators as underlined by Frank Eldernson, member of the executive board of the ECB, "the ECB's environmental action is fully

[2] https://www.un.org/en/climatechange/paris-agreement#:~:text=The%20Paris%20Agreement%20formally%20entered,189%20have%20ratified%20the%20Agreement.

in line with its mandate". Moreover, there are an explosion of statics production from the central banks and this trend is reinforced by the last sanitary crisis since during this specific context, an important need of timely and reliable database in order to define their policies aiming to support economic growth. Indeed, according to Tissot and De Beer (2 020), the consequences of the last sanitary crisis on public statistics have demonstrated the necessity to develop reliable databases for all users, and more particularly for the central banks that are the main actor to save and stabilize the financial system and *in fine* support growth and promote employment. Central banks have a very long and qualitative experience of producing reliable data and providing transparent information on the data definition, scope, metrics etc. This COVID-19 episode has shown us how it is important to provide qualitative, flexible and transparent statistics in order to fully understand the interaction of variables to propose adequate policy, for instance. One of the most important challenges for the central banks is to develop the statistics scope and publish on a regular basis several sustainable statistics to be used by policy makers, analysts and academics. The development of hubs including all sustainable actors is suitable to create a real dynamics and improve the production and the use of statistics.

This paper starts by examining the concept of sustainable finance. Soon, we face the difficulty to define the socially responsible finance. Should we use a broad definition or a taxonomy approach? Here, the fundamental question is also how to measure with accuracy the sustainable finance scope. The third section exposes why the central banks (CB), or legal authorities should, as financial and prices stability guarantors, cope with data gap. It also underlines the necessity to develop the database to assess/monitor the evolution of the sustainability perimeter to satisfy the users' needs that are paramount. The same section describes some data building initiatives to improve the availability of the sustainable bonds database. In the last section, we propose some recommendations (on approaches, on metrics, on tools, etc.) to deal with the data gap that handicaps the development of reliable empirical works to support the green finance, for instance and it proposes a provisory road map. However, given the relative new problematics, several improvements are expected, particularly in the period length and scopes. The last section also concludes on the next steps to reduce the data gap, to reinforce the quality of the available databases and to share the databases with all users. This point also raises the questions of the international cooperation as the climate change is global, moreover, the nations will benefit from the scales and synergies advantages.

2. How to apprehend the sustainability notion: definition vs taxonomy

The aim of this section is twofold. The first one is to demonstrate that sustainable finance debate is still developing under a context of the emergency of the climate change. This statement has contributed to a recognition that we cannot be passive towards the environmental risks in particular toward the threats of climate change. This awareness has developed plenty of initiatives both private (scoring agencies) and public (central banks, International and European institutions, Non-Governmental Organization, States etc.). Rapidly, various criteria assumed to characterize sustainable finance have emerged. Among the most famous criteria, we present the Environmental Social and Governance (ESG) criteria. Nevertheless, we have noticed that notwithstanding the world efforts to delimit the perimeter of the green finance, there is a disparity between countries in the green finance landscape. The most illustrative example is the Carbon prices that should be used to set up a tax policy. The World Bank dashboard launched in 2017 has shown that several methods exist and not all countries have a carbon price. Thus, it may contribute to a creation of free rider cases. With the electricity growth demand, it is obvious that it is tempting to set up where there is no (or weak) carbon price.

The second goal is to provide a clear framework of the green finance scope. A broad depiction to capture the complexity of the sustainable finance does not make sense since the devil hides in details. Nevertheless, the development of a harmonized taxonomy is assumed to be the best approach to fit the sustainable finance. We have to welcome the efforts of European Commission that have presented a pioneering taxonomy in its last green report published in March 2020. However, this taxonomy is far to describe the green finance heterogeneity and complexity.

There is still a long way to address the climate change and environmental risks that are a threat for the economic stability. The linkage between economic growth and sustainable finance cannot be fully understood if we do not agree beforehand on criteria of sustainable finance (clear, harmonized, accepted by all). The traditional finance has always played an important role in shaping the economic development. We should understand the ins and outs of the sustainable finance to analyze the impacts of green finance on Gross Domestic Product (GDP). When this is done, theoretical and empirical works in this field should skyrocket. Indeed, according to Hurley (2019), fixed-income investors have underlined that the lack of reliable ESG data is a barrier to taking into account in their portfolio this kind of financial assets.

2.1. Sustainability Background: Towards a Recognition of Sustainable finance

Sustainable finance takes into account environmental, social and governance (ESG) criteria relative to firm's decisions and investment strategies. It incorporates many issues from climate changes and pollution to labor practices, consumer habits, and firm's competitive behaviour etc. The following table provides information about the ESG issues.

ESG Issues Table-1-

Environment Issues	**Social Issues**	**Governance Issues**
Climate change and Carbon emissions	Customer satisfaction	Board composition
Air and water pollution	Data protection and Privacy	Audit committee structure
Biodiversity	Gender and Diversity	Bribery and Corruption
Deforestation	Employee engagement	Executive compensation
Energy efficiency	Community relations	Lobbying
Waste management	Human rights	Political contributions
Water scarcity	Labor standards	Whistleblower schemes

Source: Chartered Financial Analyst (CFA) Institute, Environmental, Social, and Governance Issues in Investing, A Guide for Investment Professionals, 2015, Page 4, Retrieved from: https://www.cfainstitute.org/-/media/documents/article/position-paper/esg-issues-in-investing-a-guide-for-investment-professionals.ashx

Efforts to introduce these kinds of concerns in finance began at least 30 years ago but nowadays there is an acceleration of the need to protect the planet. This increasing trend is likely related to the

Copenhagen Conference in 2009 and the Paris Climate Agreement (2015) and the will of most countries to reorient the "brown" production system towards a green one. Indeed, quite a few meetings/conferences and reports from international institutions have shed the light on the urgency to deal with the climate change and environmental degradation. The European Commission has called for a better respect of sustainability criteria to reduce environmental risks and avoidance of a systemic crisis (EC Report 2017)[3]. The EC's conclusion of the report is that the climate change has to be a priority. Indeed, in 2009, at the Copenhagen conference, some countries agreed to tackle the problem of climate change. They have proposed a target for the temperature evolution (less than 2 degrees Celsius, above 1880 levels). Scientists have noted that the world has experienced a warming of 0.8°C. Besides, recent reports produced by the Intergovernmental Panel on Climate Change (IPCC, from 2013 to now) have provided the scientific assessments. The reports have confirmed that natural systems is changing because of the greenhouse gas emissions (GHGs) that were particularly high between 2000 and 2010. Without further efforts, the planet will experience an increase of temperatures, from +3.7 to +4.8 degrees Celsius by the end of the century. The impacts on earth are obviously dramatic. An elevation of temperature has a direct implication in the agricultural sectors and the water availability. In 2013, the World Bank has ordered works to analyze the potential impacts of an increase in temperature of 4°C (World Bank Report, from 2012 to 2019). The results and conclusions are alarming. Concisely, in many cases, extreme heat waves, rising levels of the seas, more intense storms, droughts and floods will threaten the world in particular the poorest and the most vulnerable people[4]. In 2015, the governor of Bank of England, pronounced a discourse entitled "Horizons Tragedy Breaking the tragedy of the horizon – climate change and financial stability"[5]. This presentation echoed the "Tragedy of the common" written by Hardin in 1968. He shed light on the overuse of common resources since they were public goods. In his discourse, the governor has stated three types of risks related to the climate change. The physical risks appear when the climate change affects the production and financial spheres. Climate change creates new economic risks, namely negative evolution of the firms' productivity. Recommendation assets portfolio. The second risk is the transition risk. For instance, when a firm develops a low carbon strategy policy, the results are random. The effects on the economic growth and the financial system are long run frameworks. The third risk is the liability risk. The occurrence of natural disasters' trials is the main cause. The insurance sector is in the front line. Currently, the framework relative to the resilience of the insurance sector assumes that a low probability and a high severity have characterized catastrophic risks (Louaas and Picard, 2018). With the climate change, this hypothesis should be reconsidered. Today, the probability of a natural disaster is not so low and in the future, it will increase significantly. This assumption should be introduced in the insurance literature to elaborate worthy stress tests, for instance. Louaas and Picard (2018) have measured the insurance resilience to climate change risk. Stress tests are also interesting tools to quantify accurately how the financial and economic systems are harmed by an extreme weather events such as typhoons, earthquakes, for instance (EIOPA's dashboard, 2020)[6].

These quantitation exercises should take into account all institutional sectors and countries since they are all interconnected and the climate change is a global issue.

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3 https://ec.europa.eu/environment/enveco/sustainable_finance/pdf/studies/Defining%20Green%20in%20green%20finance%20-%20final%20report%20published%20on%20eu%20website.pdf

4 https://apps.who.int/iris/bitstream/handle/10665/134014/9789241507691_eng.pdf

5 https://www.bis.org/review/r151009a.pdf

6 https://www.eiopa.europa.eu/content/pilot-dashboard-insurance-protection-gap-natural-catastrophes_en

The three risks[7] mentioned above should be correctly analyzed to avoid the systemic risks. The climate change threats henceforth the financial and economic stability. Recognition of the emergency climate-related risks led to the creation of working groups, hubs or workshops. We can cite the initiative of the Financial Stability Board (FSB) in 2015. The FSB at the request of the G20 (Group of Twenty) created a task force dedicated to the analysis of the climate change (Task Force on Climate-related financial Disclosure (TFCD)). It has provided recommendations and disclosures to economic agents, such as investors, insurers, lenders, etc. In 2017 the central banks and Supervisors Network for Greening the Financial System (NGFS) appeared. In April 2019, the NGFS published a report[8] that states six recommendations in order to green the financial system. Four recommendation dedicated to supervisors, CBs, and the policy makers. The supervisors' recommendations deal with, roughly speaking, the incorporation of green micro and macro prudential tools in their missions and the development of a harmonized, accurate and reliable database. The information transparency and the data/ knowledge sharing is also required. The decision makers should develop a taxonomy of the green activities and should participate actively to the reliable climate and environment-related disclosure and guarantee the respect of climate rules.

Since December 2019, Christine Lagarde underlined the necessity to recognize the importance of climate-related risks. She also detailed three areas where the ECB should intervene (macroeconomic perspective, banks and financial portfolio). The ECB should introduce green variables for the forecasting growth exercises. It should advise banks on how to evaluate correctly the climate change risks. Stress testing exercises for banks are crucial for the financial stability. The ECB should privilege green assets in managing its pension portfolio. It is obvious that the EU is trying to find solution with ambitious policies, package and narrow collaboration with international partnership as reflected in the EU Green deal that aims to fight against climate change. The sanitary crisis demonstrates how the role of central banks is essential to guarantee the financial stability. Different measures have been urgently rolled out to preserve the proper functioning of European economies. The ECB has not hesitated to support actively and gradually European countries to counter the negative impacts of a potential systemic crisis, as witnessed by the ECB actions since the COVID-19 occurrence (Benigo et al., 2021).

All these initiatives have demonstrated that the urgency of the climate-related risks is publicly recognized. Nevertheless, the facts do not illustrate the urgency. Indeed, there is a kind of "ratchet effect". We are aware of the ecological risks but the CO2 emissions do not decrease drastically. Indeed, "the dataset (EDGARv5.0_FT) shows that global anthropogenic fossil CO2 emissions increased by 0.4% in 2016 compared to 2015 and a further 1.2% in 2017 compared to 2016 reaching 37.1 Gt CO2".[9] In addition, some works discuss the CO2 metrics and demonstrated that until now this variable is under evaluated in financial portfolio (Janssen et al., 2021). This means that the ecological transition will take time; it is a structural change. Remind that during centuries investors and firms have thought that the main engine of their wealth is the short-term profits perspectives. Firms and investors seek for maximum profits. The main factor to invest is the short-term yield. The financial component (F) is the principal motivation of investors. Investors and firms have to switch from a short-term profit maximization perspective to a long-term profit optimization perspective (Jeffers, 2015). The firms and investors should also take into account the ESG criteria in their optimization programs. A "mentality revolution/change" in favour of ecology is necessary. The sustainable development (SD) is function of at least three components (and not only financial motives).

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7 The European Commission considers there are two risks (physical risk and transaction risk) since the liability risk is included in the physical risk.

8 https://www.banque-france.fr/sites/default/files/media/2019/04/17/ngfs_first_comprehensive_report_-_17042019_0.pdf

9 https://edgar.jrc.ec.europa.eu/

$$f(SD) = f(F, Ec, S)$$

With F = Financial concerns Ec =Ecological concerns and S = Social concerns.

Investors and firms should search for sustainability for at least three reasons. Sooner or later, the environmental taxes will exist in all countries (for example, the carbon tax). In addition, they have to program in advance their transition to Sustainable Development Goals (SDG) by 2030. Therefore, they should start to anticipate the new regulations. The second reason is the recognition of the importance of ecological and social risks by consumers and other non-governmental organizations (NGOs). The last reason is the moral responsibility that raised the question of liability risks. The costs of planet damages are huge and the taxpayers for fairness motives cannot always pay them (Jeffers, 2015).

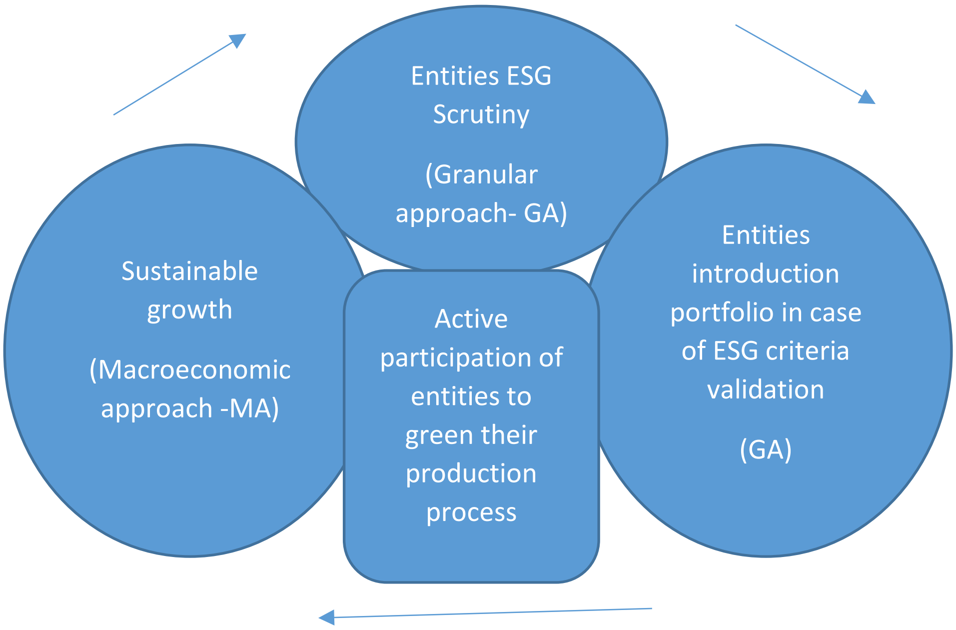
Nowadays, it is obvious that we cannot continue to produce without taking into account the negative externalities of the pollution, for instance the carbon overused in the world industry. The notion of growth's sustainability should be the leitmotiv of both producers and consumers. Behind the notion of sustainable growth, people are aware that the current economic growth is using services such as greenhouse gas-emitting energies, whose production gradually degrades the ecological environment. People are also aware of the fact that the depletion of natural resources or the very rapid deterioration of the planet threatens the future in terms of financial and economic stabilities. To restore sustainability, it is necessary to act on the demand for these services, or to intervene on the supply side by finding a more efficient way to produce. Likewise, the optimal composition of these two types of shares (demand and supply) depends on the comparison of demand elasticities for these services on the one hand, and substitutability degrees between green capital and natural resources, on the other hand (Bureau, 2014).

In addition, many studies have explored the notion of green production based on a new calculation of the GDP. Environmental accounts attempt to capture the interaction between production and environment. The environmental accounting tends to evaluate the depletion of resources or the planet degradation due to human (anthropocenic) activities (Apergis and Payne, 2010; Xu et al. 2010; Dubrocard and Prombo, 2012; Song et al. 2019). The cost of pollution is crucial for these kinds of exercises.

In all cases, ethical growth requires a reliable picture and an appropriate price signal for the damages caused by the firms and a granular approach is highly recommended. The green finance could fully develop if the concept of sustainable production had already existed. Most of the studies have encountered pollution valuation's problem hitherto. Yet, there is no consensus on the greenness level of production.

All points developed above are the matters of the policy makers and especially regulation and supervisory authorities. Their role in the environmental policies is important. Nevertheless, it is also necessary to monitor the redistribution's issues and guarantee the financing under good conditions of ESG investment. Hence, these policies should create a virtuous cycle of ecological investment (Figure-1-).

Sustainable investments virtuous approach	Figure – 1 –



Source: Author

Figure-1- displays the elements of the virtuous approach that finances firm's projects and in the end stimulates the sustainable economic growth. The corner stone of this process is the depiction of "green activities". How could the sustainable finance relaunch economic growth? This is not a marginal interrogation; for several years, we observe sluggish growth in Europe, despite the conventional and unconventional measures adopted by the European Central Bank (ECB) since the last financial turmoil. This situation may be recurrent. Indeed, the economic growth is not linear or endless. Some economies have weak growth rate because innovations are not sufficient to permit them to switch towards higher steady growth path. We call this kind of approach, the endogenous growth models. Before these models took prominence, the Solow (1956) and Swan (1956)'s theories have partly dominated the economic literature. However, soon also these models encountered the obstacles. Indeed authors assumed the convergence of all economies towards a unique equilibrium. The growth factors are exogenous such as population growth, for instance. The endogenous models are more flexible since internal forces, such opportunities to develop technological knowledge, govern the long-term economic growth. The equilibrium paths of growth are not unique and evolve each time there is a technical progress, for instance. To switch towards another equilibrium growth path, economies introduce externalities. The innovation is one of the best illustrations to materialize the externalities. Aghion and Howitt (1992) and Grossman and Helpman (1991) have proposed a version of innovation-based growth theory inspired by the Schumpeterian framework. This latter has insisted on the "quality-improving innovation" that destroys the old products because of its advanced obsolescence. For Schumpeter (1942), it is the process of "creative destruction". For decades, growth theorists have considered financial intermediation and innovation as externalities assumed to generate the economic growth. For illustration, Bencivenga and Smith (1991) have developed an endogenous growth model. They have introduced diverse assets with different degrees of liquidity. According to their model, the financial intermediations have promoted growth and have reduced the unnecessary liquidation of capital that strengthens the economic growth. Rapidly, the financial literature has seized this topic and has improved it. Theoretical and empirical studies have incorporated banks, stocks market or any financial innovations in their models to investigate the link between the traditional finance and growth. However, the results are puzzling. Indeed, the interconnectedness between finance and GDP is sometimes positive and sometimes negative (Goldsmith, 1969; King and Levine, 1993; Levine and Zervos, 1998; Beck, Levine, and Loayza, 2000a-b; Xu 2000; Rajan and Zingales 2003; Gupta and Yuan.2009; Stiglitz, 2010; Ang, 2011; Rousseau and Wachtel, 2011; Leaven and Valencia, 2013; Leaven, 2014; Madsen and Ang, 2016; Strieborny and Kukenova 2016; Sbia et al., 2017; Gueddoudj 2017, 2018; Nyasha and Odhiambo, 2018; Eryılmaz et al. 2018). This ambivalence of conclusions should not be surprising since the economic growth depends on the financial development. Above a certain financial development threshold, the economic growth is slowing down and then decreases. This means that the finance and growth couple's interconnectedness is not linear. The recent literature tends to demonstrate that the traditional finance in the developed countries have a small impact on GDP. Indeed, since years in Europe, there is a sluggish growth (CNBS, 2020[10]; Jeffers and Goldman, 2021; Goldman and Zhang, 2021). A Schumpeterian framework may relaunch the debate of sustainable growth funded by financial ethical innovations.

Nowadays lots of studies and international reports underline the danger to continue to finance growth without taking into account the green perspectives (Aglietta and Rigot, 2012; Jeffers, 2015; Tirole, 2017; IMF Report, 2018-2019; World Bank Report, 2020; IPCC Reports. 2020-2021; Summit Common Good 2021; Green Swan 2 virtual conference, 2021; Blanchard and Tirole, 2021). As noticed above, the Schumpeterian theory may bring some theoretical explanations on the sluggish growth of European countries. The traditional finance may have reached its limits or it has likely reached its Golden Age. It is time now to find another type of financial innovation. Ethical finance may be the next step to recover growth. Nevertheless, both private and public actors should promote and support sustainable finance. Actions to preserve the earth is vital (Noh, 2010, 2018) because of the possible occurrence of systemic risks. Indeed, nowadays plenty of works have sought to estimate the loss of GDP lead by environmental catastrophes. For illustration, GDP losses caused by global warming are evaluated to 5% to 20% (IPCC, 2013; Stern, 2006). Moreover, the Joint Research Centre (JRC)[11] report has demonstrated that if there is no climate change measure to mitigate greenhouse gas emissions or finance the ecological transition. It has shown that the southern countries are more exposed and the climate change impacts are costly and irreversible. In addition, the EIOPA has proposed a provisory climatic change dashboard to evaluate the cost of the acute physical risks (floods, earthquakes, typhoons etc.).

It is now undeniable that the ecological concerns have skyrocketed in the theoretical framework and among the public. However, it is not sure that the current scope of analysis is optimal to develop the empirical works aiming to define sustainable policies.

The priority henceforth is to find accurate approach to capture the sustainable finance complexity and understand the transmission channels between growth and ecological finance.

2.2. Sustainable Finance Approach (es): Definition versus Taxonomy

Nowadays, we do not have a precise and commonly accepted definition of green finance for different reasons. Firstly, not all studies have provided a clear picture of sustainable finance. Moreover, even if

[10] https://www.cnbc.com/2020/03/04/euro-zone-growth-likely-to-slow-to-a-crawl-over-the-next-10-years.html
[11] JRC PESETA IV

there are incomplete concepts they differ from one analysis to the other. For instance, from 2013 to today, World Bank Group IFC (International Finance Corporation) proposed a bottom up approach to capture the notion of socially responsible (SR) finance. The IFC has enumerated diverse categories to delimit the ESG finance scope (Adaptation (conservation, bio system adaptation); Carbon capture and storage; Energy efficiency (cogeneration, smart grid) etc.)[12]. Seldom is there a unique responsible finance picture because of its multi-faced nature. Nevertheless, some authors or consultant agencies have tried to expose the concept of greenness. Table – 2- displays some definitions[13].

Sustainable finance definitions Table-2-

Authors /Agencies	Definitions
1- Pricewaterhouse Coopers Consultant (2013)	"Financial products & services that consider environmental factors throughout the lending decision-making, ex-post monitoring, and risk management processes, to promote environmentally-responsible investments and encourage low-carbon technologies, industries and businesses"
2- The Climate Mundial (2020)	"Green finance refers to any financial instrument or investment – including equity, debt, grant, purchase & sale or risk management tool (for example: investment guarantee, insurance product or commodity, credit or interest rate derivative, etc.) – issued under contract to a firm, facility, person, project or agency, public or private, in exchange for the delivery of positive environmental externalities that are real, verified and additional to business as usual, whereby such positive externalities result in the creation of transferrable property rights recognized within international, regional, national and sub-national legal frameworks."
3- Höhne et al.(2012)	"Green finance is a broad term that can refer to financial investments flowing into sustainable development projects and initiatives, environmental products, and policies that encourage the development of a more sustainable economy. Green finance includes climate finance but is not limited to it. It also refers to a wider range of „other environmental objectives, for example industrial pollution control, water sanitation, or biodiversity protection. Mitigation and adaptation finance is specifically related to climate change related activities: mitigation financial flows refer to investments in projects and programs that contribute to reducing or avoiding greenhouse gas emissions (GHGs) whereas adaptation financial flows refer to investments that contribute to reducing the vulnerability of goods and persons to the effects of climate change."

12 https://www.ifc.org/wps/wcm/connect/12ebe660-9cad-4946-825f-66ce1e0ce147/IFC_Green+Finance+-+A+Bottom-up+Approach+to+Track+Existing+Flows+2017.pdf?MOD=AJPERES&CVID=lKMn.-t

13 The list of the definitions is not exhaustive.

4- Zadek and Flynn (2013)	"Green finance is often used interchangeably with green investment. However, in practice, green finance is a wider lens including more than investments as defined by Bloomberg New Energy Finance and others. Most important is that it includes operational costs of green investments not included under the definition of green investment. Most obviously, it would include costs such as project preparation and land acquisition costs, both of which are not just significant but can pose distinct financing challenges".
5- Organization for Economic Cooperation and Development (OECD)	Green growth … is about fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies. It is also about fostering investment and innovation, which will underpin sustained growth and give rise to new economic opportunities … policy action requires looking across a very wide range of policies, not just explicitly 'green' (i.e. environmental) policies. (p.18) … the success of a green growth strategy will rest on addressing political obstacles and distributional concerns about the costs of change. (p.20)
6- United Nations Environment Programme (UNEP)	A 'green economy' as one that results in 'improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities (UNEP, 2011, p. 16) … In its simplest expression, a green economy is low carbon, resource efficient, and socially inclusive. In a green economy, growth in income and employment should be driven by public and private investments that reduce carbon emissions and pollution, enhance energy and resource efficiency, and prevent the loss of biodiversity and ecosystem services. These investments need to be catalyzed and supported by targeted public expenditure, policy reforms and regulation changes. The development path should maintain, enhance and, where necessary, rebuild natural capital as a critical economic asset and as a source of public benefits. This is especially important for poor people whose livelihoods and security depend on nature. The key aim for a transition to a green economy is to eliminate the tradeoffs between economic growth and investment and gains in environmental quality and social inclusiveness…the environmental and social goals of a green economy can also

generate increases in income, growth, and enhanced well-being. (p. 16).

Source: Author

The overview reported in Table-2- is too general and does not display an accurate portrait of the green/sustainable/inclusive finance (definitions 1-3). Furthermore, the fourth definition has taken into account the reconsideration of other agency's approach such as Bloomberg or others. Lastly, the definitions 5 and 6, illustrate the varieties of the green concept.

It is obvious that these attempts are far from being adequate in covering the complexity of the sustainable finance and we need more studies about the ethical finance. Why should we condense the complexity of a variable into a unique definition (Lindenberg, 2014)? Is the taxonomy approach more advantageous?

Because of the difficulties to find a universally accepted definition, rapidly diverse institutions have preferred to construct a taxonomy.

The following paragraphs deal with the taxonomy, its goals and its limits in Europe.

Since June 2018, the Technical Expert Group on sustainable finance (TEG) has studied the possibility to set up a taxonomy assumed to describe with accurate the ethical finance. This expert group has been created due to the lack of universal SR finance image and the recognition of the climate change urgency. Indeed, all countries are aware that the global emissions should be divided by two over the next decade. However, the global greenhouse emissions are rising despite the scientists' alarmist reports (IPCC Report (2019)[14]. According to the same report, the impacts of climate change are likely irremediable if we do nothing to stop this trend.

This concerning context has lead several international organizations to define as soon as possible a taxonomy. Before presenting the main results of the EC report published in March 2020, we expose the purposes of a taxonomy. The taxonomy is a set of criteria/rules supposed to elaborate a classification to verify which activities are environmentally sustainable. Table-3- displays what a taxonomy is (or not).

Taxonomy Table-3-

IS	**IS NOT**
A list of economic activities and relevant criteria	A rating of good or bad companies
Flexible to adapt to different investment styles and strategies	A mandatory list to invest in
Based on latest scientific and industry experience	Making a judgement on the financial performance of an investment – only the environmental performance
Dynamic, responding to changes in technology, science, new activities and data	Inflexible or static

Source: European Commission, Retrieved from: https://ec.europa.eu/info/sites/info/files/business_economy_euro/banking_and_finance/documents/190618-sustainable-finance-teg-report-using-the-taxonomy_en.pdf

14 https://www.ipcc.ch/site/assets/uploads/sites/4/2019/12/02_Summary-for-Policymakers_SPM.pdf

The principal advantage of a taxonomy is its flexible nature. The criteria continuously evolve with the context and the knowledge progress. However, it may be not enough to evaluate correctly the risks related to environment since it does not take into account all risks. Moreover, the taxonomy does not cover all economic institutional sectors either.

In line with EC Reports, to be environmentally sustainable, activities have to be in conformity with EC regulation. The EC taxonomy takes into consideration diverse variables related to environment. Candidates for a "green passport" in accordance with the EC have to:

- Participate actively to the one or more environmental objectives defined by the Proposed Taxonomy Regulation (climate change mitigation; climate change; sustainable use and protection of water and marine resources; transition to a circular economy, waste prevention and recycling; pollution prevention and control; and protection of healthy ecosystems)

- Respect other objectives by avoiding to harm them significantly and to be informed about the technical screening for the notion of Doing No Significant Harm (DNSH)

- Be in line with the minimum social safeguards (i.e. the eight fundamental International Labour Organization (ILO) conventions).

These points are the architecture of the EC taxonomy[15] and provides guidelines to converge towards greener activities. The EC report of the published in March 2020[16] shed some light on interesting issues. The TEG was asked to elaborate on recommendations for technical screening criteria for the use by countries. The expert group has hence defined a flexible taxonomy regulation. The EC instructions were to consider only activities related to climate change mitigation or adaptation and to the DNSH's notion. The report currently provides a solid architecture for the economic agent to reorient their activities towards a more sustainable growth; nevertheless, the outstanding works of the EC are incomplete and may raise further issues up ahead. The taxonomy content is based on a questionnaire send to firms related to climate change; the survey, sent in September 2019, took into account 67 activities. Only 830 responses have been reported and "the vast majority of respondents were based in Europe, and 48% were private individuals, 24% were from the general business sector and 10% were from the financial business sector". (EC Report, March 2020, p.11). It is obvious that the coverage is not sufficient but it is an excellent starting point. Moreover, the survey is very oriented towards the climate change, which is not suitable since the climate change is the tree that hides the forest. Today the loss of biodiversity is also a great challenge for our societies. It is clear that a more global vision of the environmental damages is more appropriate. The final version of the European commission taxonomy will be available in 2022, however, in the meanwhile several changes appear; recently gas and nuclear sectors are considered as non-polluting since they do not increase the CO2 emissions level. This kind of orientation should reinforce the idea to enlarge the scope of the taxonomy.

2.3. The role of rating agencies in providing sustainable information

Since the 2000's, new types of rating agencies have rapidly developed. They have used criteria based on non-financial variables. They have also focused on the environmental, social and governance (ESG) field. Their evaluation criteria are not standardized due to the lack of an authoritative common taxonomy or definition. Nevertheless, they consider the international conventions, such as Standard

15 Based on the OECD works (2020), we propose a LU taxonomy framework in appendices.

16 https://ec.europa.eu/info/sites/info/files/business_economy_euro/banking_and_finance/documents/200309-sustainable-finance-teg-final-report-taxonomy_en.pdf

Ethics, which echoes the recommendations of the UN, the OECD and the European Union. Unlike traditional rating agencies, investors, not issuers, pay for the ratings, potentially limiting the risk of conflicts of interest, although companies can still send these agencies for a Solicited Sustainability Rating (SSR). This is the case, for example, with Standard Ethics, a European agency based in London and Brussels[17]. Extra-financial ratings can be used for the Socially Responsible Investment (SRI) funds that incorporate extra-financial criteria into their investment choices before integrating companies into their portfolios.

Unlike traditional rating agencies, the largest non-financial rating agencies are in Europe. However, the most important of the financial rating agencies, Moody's and Standard and Poor's, have decided to enter in the sector, to capture their share in a growing market. Moody's has integrated ESG risks into its rating system and has developed a specific system focused on green bonds, while Standard and Poor's has acquired the UK's Trucost, which has specialized in environmental data, and has provided to investors more than 150 Dow Jones S-P indices that are built by integrating ESG criteria. Moreover, the change of agencies focus is not so recent. Indeed, at the end of 2017, the financial rating agencies realized that environmental, social and governance criteria have had a significant impact on environmental, social and governance criteria observed from June 2015 to June 2017. The conclusion of the survey is clear. In 225 cases, they even reasoned for a change of grade or perspective. Indisputable proof that the ESG criteria are taken into account in the credit rating of companies. ESG concerns are not new. However, there was a real trigger in 2015, with the launch of the UN Sustainable Development Goals (SDGs) and the adoption of the Paris Agreement. Today there is a lot of ESG indices or index families. Table-4- displays some sustainable indices. The list is not exhaustive but it illustrates the stocks index's diversity since years, however for the providers there are common points.

Few sample of ESG indices and their providers Table - 4 –

Providers	Index or Index family
Calvert	The Calvert Social Index
CRD Analytics	Global Sustainability Index, Cleantech 100, Life Sciences
Domini	Domini 400 Social Index
FTSE	FTSE4Good Index Series
EthiFinance	Gaïa Index
Maplecroft	Climate Innovation Indexes
MSCI	MSCI ESG Indices et Barclays MSCI (Fixed Income Indices)
oekom	Global Challenges Index
OWW	Responsibility Malaysia SRI Index, Responsibility Singapore SRI Index
RobecoSAM	DJSI
Sustainalytics	Jantzi Social Index, STOXX Global ESG Leaders Indices

17 http://www.standardethics.eu/

Vigeo	ASPI Eurozone, Ethibel Sustainability Index, Euronext Vigeo
Thomson Reuters	Thomson Reuters Index

Source: Novethic Report, 2014[18], p. 8

Commercial providers are private organizations; the quality of the databases may be questionable since among the private providers, the information is not always transparent. Remind that some entities are classified ESG by some private providers and not ESG by NOG or public rating agencies. More precisely, with the IPCC classification, the Toyota Motor Corporation is listed as a high carbon emissions firm whereas the MSCI ESG Ratings classify the same firm as a low emission company (Choi et al., 2020). These divergences should be avoided at the very short term because they are not consistent. Moreover, they raise again the question of the reliability of private/commercial data providers, which are largely used by academic papers and the central bank's researchers and/or analysts.

Likewise, many Funds certification agencies have appeared in the financial landscape. Amongst them, we can cite Luxflag (Environment and climate change). This Luxembourg non-governmental organisation created in 2014 provides labels based on ESG criteria to classify funds[19]. Other European label entities have played the same role (FibelFin QS for Belgium; FNG-Siegel for Germany; label ISR and Label Green fin for France). Nevertheless, when we compare the methodologies and the thresholds associated with each of the variables, there are slight differences. This means that some funds may be qualified sustainable by some entities and rejected by others (Novethic Report 2019[20], p. 3). In line with the same report, there are also great disparities amongst the types of labels, the targeted variables, the variables' thresholds, and the annual costs (Novethic Report 2019, p. 4 and p.6).

IPPC reports have also noticed that notwithstanding the public awareness there is no drastic reduction of CO2 emissions for instance. This means that the environmental actions are not providing sufficiently strong signals to encourage financial institutions to provide the capital required to achieve their sustainability targets.

As stated in the previous paragraphs several commercial private commercial providers have built indicators assumed to assess the size of the ESG product, this means that the private sector is very dynamic to collect and provide ESG database. Several analysis and research institutes have used their expertise for their empirical works. Indeed, the Joint Research Centre (JCR) published several empirical papers using such databases provided by Bloomberg, for instance. Based on commercial database from Bloomberg, Alessi et al. (2019) have demonstrated that there is a negative green risk premium for the European stock returns and portfolios by using the Bloomberg ESG scores. Authors also resort the database by excluding some firms clearly not sustainable (i.e. HSBC or Allianz), which prove how the private database can be questionable and therefore suggest to not give a public statistics collection mission to private providers. The unique indicator taking into account by the authors is the Bloomberg indicator that might not be enough to capture the firm's sustainability, in particular with respect to

18 https://www.novethic.fr/fileadmin/user_upload/tx_ausynovethicetudes/pdf_complets/2014_Panorama-des-agences-de-notation.pdf

19 https://www.luxflag.org/media/pdf/criteria_procedures/LuxFLAG_ESG_Label_Eligibility_Criteria_June2016.pdf

20 https://www.novethic.fr/fileadmin/user_upload/tx_ausynovethicetudes/pdf_complets/Novethic-Panorama_des_labels_europeens_de_finance_durable-2019.pdf

environmental criteria. This choice has raised the question of the results robustness since the estimations are fully determined by the choice of the ESG indicators; to overcome these bias, authors should use several indices and compare the estimation results stability. It is useless to strengthen that there is an important development of diverse and provisory thresholds criteria to classify financial assets, so it is quite difficult to get definitive and undisputable conclusions given the evolving change in the concepts. The complexity of this diversity has reinforced the idea of the harmonization of related environmental data to ensure comparisons between countries. The rapid explosion of standards and labels compel public statistics authorities to attempt to define in a timely manner reliable sustainable concepts that are the cornerstone of the climate change transition.

Thus, the main limitation is the lacks of harmonization, of reliability and of common guidelines that can be harmful for the countries. One of the most relevant example is the CO2 emissions prices. Indeed, until now, there is no universal price for the CO2 price despite the environment urgency. According to the World Bank (WB) website[21], not all countries determinate the CO2 emissions prices. The WB has published a carbon prices dashboard, which demonstrates that carbon prices vary across countries since different carbon pricing methods exist. There are therefore disparities amongst countries. Moreover, not all countries apply a carbon price. This situation may create a free rider behaviour. If we do not resolve this tricky question, it is not possible to provide efficiently a fair carbon tax. Moreover, it is useless to remind that some firms do not report the scope 3 of their CO2 emissions, which the share reported to the total is significant since for a large company the scope 3 represents more than 80%.[22] Another issue related to fairness may also emerge with the current common CO2 taxes. It can be resolved only if there are reliable granular information about the CO2 emissions per firms. At term and with the development of artificial intelligence (AI), it may be interesting to compel all firms to report their CO2 emissions and implement taxes according to their levels of pollution. Moreover, despite numerous carbon disclosure initiatives, there is no harmonized metrics to measure the carbon footprints (Zimmerman et al., 2020).

To resume, the necessity of harmonizing ESG criteria, definitions, and classifications[23]is crucial and exposed by several European reports (STC CCS Report, 2019; CMFB TF Sufir, 2021, Green Swan reports, 2020, 2021). These divergences should be avoided at the very short term because they are not consistent. Moreover, they raise again the question of the reliability of private/commercial data providers, which are largely used by academic papers (Peillex and Ureche-Rangau, 2016; Alessi et al., 2019; Brière et al., 2020). This point is paramount for the public provider's challenges because public statistics authorities are supposed more reliable given their transparency, integrity, and objectivity characteristics. In addition, it may be interesting to underline that the current European "Green bonds" time series are based on Bloomberg information[24] and we should not neglect the agency theory problem related to the asymmetrical information because of the "principal-agent" relationship where a Financial Regulator risks to be "captured". Central banks or regulation authorities should participate actively to the disclosures of reliable granular database related to ESG problematics. Remind that the role of the central bank is paramount to tackle the tragedy horizon in promoting green finance thanks to monetary and prudential tools but before they have to participate actively to define the green perimeter and collect reliable data to guarantee policy efficiency.

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21 https://carbonpricingdashboard.worldbank.org/map_data

22 https://secrhub.co.uk/scope-3-emissions-your-frequently-asked-questions/

23 For instance, the identification of the low/high carbon firms is still puzzling that is not normal given the climate change emergency. Indeed, according to the Intergovernmental Panel on Climate Change (IPCC) report published in 2019, there are 5 major industry sectors assumed to be highly polluting. However, the classification built by MSCI ESG Ratings, which scrutinize companies' environmental, social, and governance issues, provide contradictory results.

24 NGFS Dashboard, pp.18-22 (Source: https://www.ngfs.net/sites/default/files/medias/documents/dashboard-on-scaling-up-green-finance-march_2021.pdf). This database is briefly presented in the next section.

The major needs are to develop common, harmonized and reliable databases and definitions to ameliorate the works of users and especially of the central bankers to evaluate the impacts of climate change on the financial stability, for instance (Bolton et al., 2020; Green Swan, 2021[25]).

The next section is dedicated to describe the current the existing data gap in Europe and how the central banks as users and as potential producers, have to deal with this problem.

3. Sustainable databases needs and the role of central banks: Some European experiences

The aim of this sub-section is to discuss why the central banks should participate actively to green economies. To reach this target, they need reliable databases to run sustainable and efficient policies. Remind that since centuries, the central banks have to adapt themselves to the economic context and they have innovated in terms of regulation and supervision tools to avoid dramatic crisis repercussions and particularly systemic crisis. Since 2008, the use of conventional and unconventional tools is frequent (Ugolini, 2017, Goldman and Zhang, 2021). In addition, during the sanitary crisis in 2020, the role of central banks has been significant to save the economies; the ECB has not hesitated to set up non-conventional policies and adopt the strategy based on the famous "whatever it takes" (Mario Draghi, 2012)[26].

3.1. Why do central banks need sustainable database?

In this section, we argue the role of the central banks is to ensure the ecological transition; why central banks should be active in the fight against the climate change and how the database should be necessary to ameliorate our knowledge on this topic. We do not need only more database but also qualitative database, the quality is the cornerstone of any serious studies. It is well established now that the climate change has impacts on the stability prices and the financial stability, therefore central banks are athe center of the climate change debates[27].

Different tools are under discussions to "green the financial system". From a (micro and macro) prudential views, they concern variables such as liquidity, capital, reserves and lending thresholds. Crockett (2000) and Borio (2003, 2006) have provided an accurate distinction between the macro and micro-prudential approaches. The macro-prudential tools have been largely proposed by political literature (Borio, 2003, 2006); and have been incorporated in the Basel (I, II, III) requirements. From a monetary optic, we analyze the current debate on the role of interest rate in greening the financial system. We also extend the discussion to others CBs' prudential actions, from the conventional interventions to non-conventional policies, namely the quantitative easing.

Table-5- displays the most implemented monetary and prudential policies tools under debates to support the financial system. These policies are famous and frequently set up by CBs.

[25] https://www.bis.org/events/green_swan_2021/overview.htm
[26] https://www.politico.eu/article/ecb-will-do-whatever-it-takes-to-save-the-euro/
[27] https://www.ecb.europa.eu/ecb/climate/html/index.en.html

Main Monetary and prudential tools			Table-5-
Policy	Tools	Conventional(C)/or Not (NC)	Targets
Monetary	Interest rate Lending control Reserves	C/NC (for negative interest rate)	"Without prejudice to the objective of price stability", the Eurosystem shall also "support the general economic policies in the Union with a view to contributing to the achievement of the objectives of the Union". These include inter alia "full employment" and "balanced economic growth". [28]
Macro-prudential	Capital Liquidity Lending control	C	Short-term target: Avoid or limit the global financial system distress. Long term target: Avoid GDP losses
Micro-prudential	Regulatory standards of financial services	C	Short-term target: Avoid or limit turbulence of individual institutions. Long term target: Consumer protection
Quantitative Easing	Large-scale asset purchases of long-maturity government debt and private assets.	NC	To lower long-term interest rates and consequently boost the economic growth.

Source: Author

A rapid glance at Table -5- shows that these tools could be used to re-orientate the traditional finance system towards the socially responsible finance without huge efforts. The goal of the following paragraphs is to visualize how CBs may contribute to swift from a traditional financial system to another in accordance with the 1,5 degree elevation trial as explored by the Paris Agreement. Remind that climate problematic matters are a component of the environmental distress.

As witnessed the central banks history, their new missions have occurred to save the financial and economic systems (Goldman and Zhang, 2021). Today, the climate change has created risks and uncertainty. Uncertainty always creates instability and particularly financial instability (Minsky, 1998). In accordance with Jeffers and Plihon (2019), climate risks may lead to a systemic risk and this would transform the economic and financial mechanisms of our society (a "Minsky moment").

Additionally, few CBs have introduced the nature preservation in their missions. Indeed, Dikau and Volz (2018) set out different areas of actions for the CB, based on micro and macro prudential regulations to sustain the ecological finance. They highlight micro prudential policies disclosure requirements, the adoption of a standard framework for risk assessment, the environment etc. At the macro-prudential level, climate-related stress tests, capital buffers, for example, are proposed. All of these instruments are popular because they have been using for decades. However, the central banks have yet to define the environmental framework in an accurate and harmonized manner. Dikau and Volz (2018) have also analyzed 133 central banks and underlined that only 12% of central banks explicitly state in their

28 https://www.ecb.europa.eu/mopo/intro/objective/html/index.en.html

missions the support for socially responsible activities ("sustainable economic growth / sustainable growth/ sustainable contribution to economic growth/ sustainable growth of the economy/ balanced and sustainable economic development/achieve and sustainable growth"). This means that many banks will have to redefine their legal framework to implement sustainable policies in the near time. This may be not a complete overhaul of their missions but likely simply an extension to responsible activities.

We start the development of sustainable tools with the interest rate tool presentation. Plenty of theoretical and empirical articles have attempted to explore how the interest rate should be able to orientate optimally financial flows towards sustainable sectors (Kempf, 2017; Muller, 2019). It make sense to define clearly an ecological interest rate since climate change has negative impacts on natural interest rate and economic growth. This adjustment variable should take into account externalities that green gas emissions have produced since decades, for instance. The rates should be very low when the project is sustainable and higher in case of brown projects. The sustainable interest rate is a very interesting topic in a normal context. However, it is not sure that its implementation is feasible within the low (even negative) interest rate framework. Indeed, this pro-climate policy is not suitable in the case of unconventional monetary policy (negative rates) since, more often than not; a CB uses it because the interest rate instrument is no more efficient, since the interest rate has reached its lowest threshold. However, this point is questionable. Some papers have attempted to demonstrate that during a long period of low interest rate (even negative) the QE tools have failed to "feed" the economic growth because of headwinds and the non-linearity interest rate effects. When the interest rate is close to its effective lower bound (ELB), it may have costly effects on the financial stability (Borio and Hofmann, 2017; Borio and Zabai, 2018). Within a Bayesian Structural Vector Auto-Regression (SVAR) framework, Lhuissier et al. (2020) have found that in a specific case, the easy money has a positive impact on growth even during the period of very low interest rate (close to 0). This result should also be balanced with a negative rate.

Globally, the macro-prudential tools are based on reserves, capital, credits control and liquidity. For this latter, several tools are defined in the Basel III requirements: the Liquidity Coverage Ratio (LCR) and the Net Stable Funding Ratio (NSFR). The LCR is assumed to provide information about the short-term liquidity whereas the NSFR takes into account the long-term perspectives. These two ratios should be modified to develop sustainable activities since as they are calculated they penalize long-term projects and privilege the short-term investments. The socially responsible activities need long-term investments and lower liquidity ratios are welcomed (European Banking Federation, 2018). For the credit, it should be suitable to give the priority of sustainable projects. A credit classification related to ceilings according priorities should be built (Fry, 1995; Volz, 2017). Support for environmental credits at the expense of brown credits should be a recommendation (or better still an obligation) to financial institutions (Fry, 1995; et al., 2015; Schoenmaker and Van Tilberg, 2016). The capital requirement (CR) should also be revisited according the sustainable activities since the CR encourages brown activities given their short-term horizons. The risk weighted assets necessary to calculate the CR should introduce the climate risks for instance. Furthermore, differentiated reserve requirements in favor of banks that finance sustainable projects should be established (Volz, 2017; Jeffers and Plihon, 2019, 2020).

All these tools may be useful to promote sustainable growth if they are well calibrated[29]. However, we need more analytical studies based on reliable data to evaluate correctly the impacts of green tools on economic growth and financial stabilities.

[29] Artificial intelligence (AI) may help to provide a better calibration; however, AI is energy consuming leading to an increase in CO2 emissions in a climate change emergency context.

For the micro-prudential optic, according to Dikau et Volz (2018) the regulators should offer regulation standards oriented towards sustainable activities, provide strict disclosures rules and define a clear legal framework to protect the consumers (depositors and investors).

Regarding the unconventional monetary policy, namely the Quantitative easing, it may be interesting to launch European Green purchase program to promote sustainable sectors and limit or stop financing brown activities. In the debate on greening the financial system (see the NGFS work) and promoting climate-related financial disclosure (see the TCFD work), there is a growing attention on the Quantitative Easing by zooming on Corporate Sector Purchase Program (CSPP). Diverse papers have sought to track the purchase and identify the sectors supported by the CSPP and found they create distortions in favour of carbon intensive sectors (Schoenmaker, 2019). In addition, the outstanding works of Battiston and Monasterolo (2019) based on 1557 securities issued by 282 firms have concluded that more than 60% purchased equities have financed brown firms (production and distribution of fossil energies, automobile sectors, electricity production). Their analysis has also found that Bundesbank and Banca d'Italia are exposed to automotive and fossil firms.

Besides, there is a gap between the climate change and the capital aligned with climate change goals. The main cause of this misalignment, which represents a systemic risk, is a lack of harmonized definition/taxonomy and a kind of lethargy because of the long-term horizon. The famous adage "we have time" is likely responsible of the lacks of actions. Furthermore, most of EC's works expose guidelines, proposals and recommendations. There is no coercive measures. Besides, the different surveys (BIS[30], ECB[31]) on the data availability have demonstrated that there are lacks of quality, of harmonization/standardization, of coverage etc.

In addition, to evaluate the impacts of green/sustainable policies mentioned above, we also need to have an accurate idea of the physical and transition risks since currently the central banks' user needs on climate related aspects are priorities. Once we define and measure correctly the climate change risks, they can serve as warning indicators to activate or prudential tools and provide information on exposure on financial institution though their asset portfolios (even the real estate assets), on the carbon footprint of the asset portfolios, the development of sustainable financial instruments issued (bonds or loans, for instance) at both aggregated and granular levels. The calculations of physical, transition and liability risks probabilities become the next step once we get qualitative database[32].

These risks are multifactorial both scientific and economic then it means a perfect collaboration between economists and scientists; and in a global manner, climate change is matter of all researchers whatever their fields (economics, mathematics, physics, biology, health etc.)

3.2. Databases available for users and their main common limits: Some relevant examples

As briefly evoked in the previous developments, there is an arsenal of data related to the environment concerns that could be used to analyze the impact of the climate change on the financial stability guaranteed by the regulation authorities such as central banks, but the quality is questionable (Section 3.1). Moreover, the length of the time series are not always significant and we record several non-available observations for some variables and/or indicators. This subsection aims at describing the

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30 https://www.bis.org/bcbs/publ/d502.htm and https://unece.org/sites/default/files/2021-03/S4_5_CC_and_financial_Fortanier.pdf

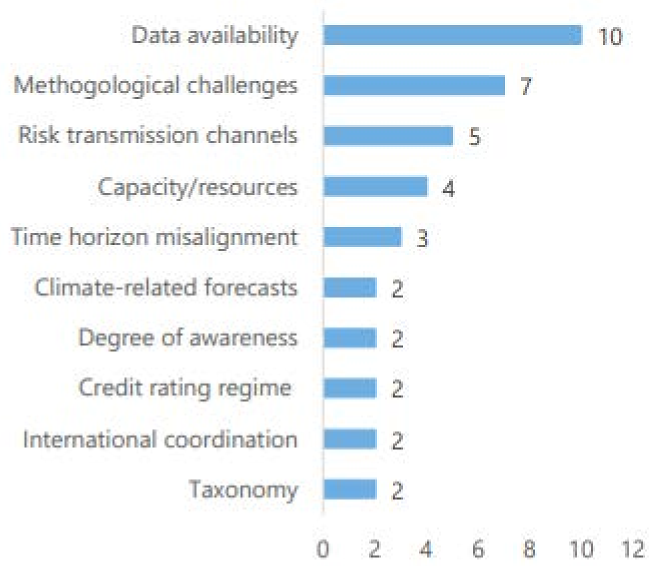
31 EG STC CCS

32 See Annexes Figure. A.1. A simplified example of the tool's activation.

availability of some sources providing data, which permit to measure the physical and transition risks. These risks are fundamental to study any environmental potential crisis. Many sustainability information are available and it is not the goal to cite them all. However based on surveys and a sample of examples, it is largely demonstrated that currently the database have some limitations in terms of availability, harmonization, standardization, low coverage, data inconsistency, common identifiers etc.

In this subsection, we describe briefly two main surveys launched by the EG STC CCS and the BIS in recent periods. The BIS Survey was launched in 2020 by the high-level Task Force on Climate-related Financial Risks (TFCR) to provide information on the sustainability concerns from several jurisdictions[33]. The questionnaire is composed by 8 questions related to the climate change risks. Unsurprising, the survey reveals that the lack of data is the main central banks concerns followed by methodological challenges and the risk transmission channels, however, surprisingly, the necessity to set up a reliable and commonly accepted taxonomy is at the bottom of the concerns while the taxonomy is the cornerstone of the sustainability (Chart-1-).

Challenges identified by number of jurisdictions — Chart-1-



Source: Basel Committee

The EG STC CCS questionnaire relative to climate change studies has been sent to all the members of the STC, the national and central banks and EIOPA in 2020 to collect information about analysis of the climate change undergone by the central banks, for instance. The main results of this survey is that amongst 81 studies, there are 53 published studies and 28 ongoing works, meaning that central banks are highly involved in the ESG issues. A more detailed survey analysis has shown that 1/ works deal with mainly with the financial sector (40%) followed by the non-financial company (15%); 2/ most of works

[33] List of participating Basel Committee members and observers: Argentina, Australia, Belgium, Brazil, Canada, China, European Banking Authority, European Central Bank, European central Bank, France, Germany, Hong Kong, Indonesia, Italy, Japan, Korea, Malaysia, Mexico, Netherlands, Russia, Saudi Arabia, Singapore, Spain, Sweden, Switzerland, United Arab Emirates, United Kingdom, United States.

are oriented towards transition risks (63%) followed by transition and physical risks (22%) and by physical risks (10%). These research/analysis trends reveal that central banks have already defined their priority, namely the study of transition risks.

Moreover, the main common conclusion deduced from the both surveys is the priorities orientation towards reliable databases relative to physical and transition risks, meaning that data in this field should be rapidly produced in a qualitative manner and spread to all users. Then, variables assumed to participate to the physical and transition risks formalization should be a data collection priority.

The transition risks variables, particularly the CO2 emission are on the top of the priority for several reasons. The first one is the CO2 emissions is the principal cause of the global warming, the second reason is more related to climate change metrics since this variable is the cornerstone of the CO2 taxation that is a puzzling issue today. However, it is not possible to fight against the global warming without having an accurate and reliable measure of the CO2 emissions. The next paragraphs are dedicated to three variables, oriented towards pollution problematics, aiming at measuring of CO2 emissions that are crucial for the development of supervisory tools, stress tests, anti-green washing instruments etc.

The European Pollutant Release and Transfer Register (E-PRTR)[34] is a source of database contributing to increase the data offers for users, however some improvements are required for an optimal utilization.

The register furnishes annual data since 2007 based on more than 30,000 industrial facilities covering 65 economic activities. The environmental data take into account the amounts of pollutant releases to air, water and land as well as off-site transfers of waste and of pollutants in waste water from a list of 91 key pollutants. For air pollution, the dataset includes greenhouse gases (carbon dioxide, nitrous oxide or methane etc.). Other gases are also delivered as well as different sorts of heavy metals or pesticides, that are also crucial categories for the consideration of pollutant releases to water and land.

The first reason of creating the register was for the purpose of environmental policies, thus not for statistical purposes; hence, it does not include relevant information, which could facilitate its use for statistical goals. For illustration, there is no ID (identification) such as LEI (Legal Entity Identifier) for the parent companies of the facilities or any relevant Nomenclature of Economic Activities (NACE)[35] code. This limit should be treated in a very short term to improve the supervision and the quality of the data. Remind that the lack of quality is an important wheel for the use of the database. Moreover, the coverage scope and the harmonization are not enough, which represent actually a weakness.

For the CO2 emissions related to the transaction risks, it may be interesting to take into account the database related to the EU ETS[36] (European Emissions Trading System). The EU ETS is based on a cap and trade system and it allows emissions allowances exchanges. This is the major instrument to meet the Paris agreement targets, and to fight against the climate change and its negative damages on earth and on economic systems. This tool takes into account around 11 000 power stations and industrial plants in 31countries including airports flights. The benefices of the cap-trade system is undeniable (controlled quantity, flexibility and efficient cost-benefices system). Several fields in economy and finance could use this information to complete and improve the works studying the role of the climate change policy to tackle the horizon tragedy. However, as already mentioned earlier, ETS tool has some limitations. Indeed, the scope is still limited; a NACE classification is welcome since the most important pollutant sectors are building and transport according to IPPC report published in 2019; there is a lack

[34] Regulation (EC) No 166/2006. E-PRTR replaces the former European Pollutant Emission Register (EPER).

[35] https://stats.oecd.org/glossary/detail.asp?ID=1713

[36] https://ec.europa.eu/clima/sites/clima/files/docs/ets_handbook_en.pdf

of standardization; few entities have a ID (ex. LEI) that increase the monitoring difficulty etc. These limits also constitute the future challenges of the statistics authorities to meet the needs of the users and especially those of central bankers.

In a general manner, there are several data that are not consistent given the lack of quality control; as already underlined the quality of the commercial data is not optimal and most of analysts/researchers use them to write their articles or reports and few of them precise these fundamental limitations.

All these limitations should be the next challenges agenda for any authorities engaged in the understating of the sustainability problematics and aiming at promoting green finance and defining regulation policies.

3.3. Some specific initiatives from central banks: the sustainable bonds database for Luxembourg

The first green bond was launched by the World Bank in 2007. Soon thereafter, in 2008, the European Investment Bank (BEI) launched the first European Green bond that has been listed on the Luxembourg Stock Exchange and that is considered a reference product in this new category of financial instruments.

Although, the functioning of Green bonds is very close to that of traditional bonds, their main characteristics differ since the underlying assets have to match the ESG criteria. Since the initial launch in 2008 by the EIB, the green bonds market has skyrocketed in Europe. Indeed, over the years, green bonds have become a key tool for greening finance as well as all other economic sectors. The Green Bond Principal (GBP) from the International Capital Market Association (ICMA) has established a standard procedure allowing issuers to raise capital in order to increase the environmental benefits thanks to an administrative guidance (GBP DIWG, 2017). In 2016, "Luxembourg Launches World's First Green Stock Exchange: LGX" (Medland, 2016).

Over the years and particularly in 2015, there has been an acceleration of the green finance development. This trend is related to several multi-dimensional factors. One of the most important factor is the growing awareness of the need to reduce the CO2 emissions and to protect the planet. The Agreement of Paris in 2015 has been a corner stone for several policy propositions to tackle the climate crisis. The European green bonds evolution has demonstrated that Green bonds have skyrocketed and this trend reinforces the idea that the sustainability concerns are nowadays more concrete, even if there is no consensus on the definition. However, the financial literature provides some relevant conclusions on the drivers and the transmissions channels for the sustainable bonds.

The database[37] is built thanks to several sources. All ESG criteria are taken into account to avoid the scope limitation. We are interesting in the debt securities issued by ESG companies. To detect these firms we rely mostly on the classification of the Green Luxembourg Exchange, which is a reliable provider (137 issuers). To complete this data source, we compare with other sources such as ECB (21119 issuers) Refinitiv, formerly Thomson Reuters (2 448) and Euronext (384 issuers). All International Securities Identification Number (ISIN) codes[38] have been cross-checked with the Centralised Securities Database

[37] A. Carreira and S.Gueddoudj (2021). "Sustainability bonds and their main features in Luxembourg from 2013 to 2021: An experimental approach. Forthcoming.

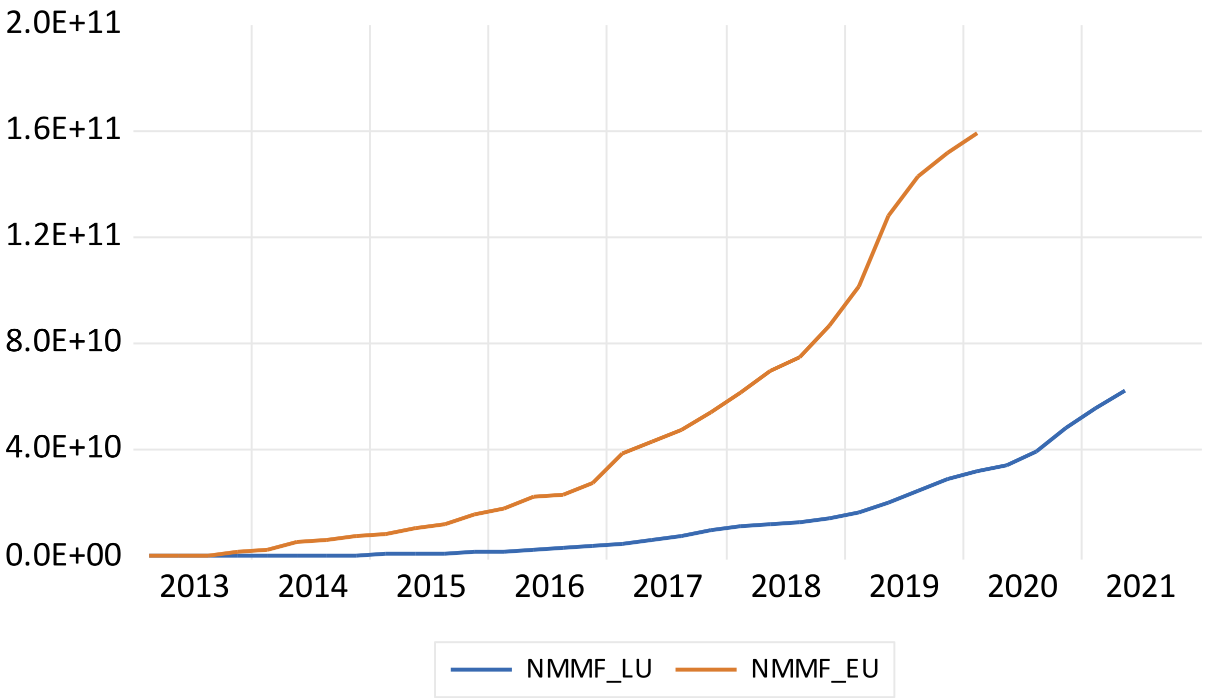
[38] https://www.isin.org/isin/

(CSDB)[39]. Only the Luxembourgish holders are taken into consideration to start, we are aware that it is a limited scope and we will be compelled to enlarge it sooner or later; however it is a good starting point to explore and therefore have an acute idea of the feasibility and the main obstacles to overcome for larger scopes. There is no limitation for the size of the sample since we only consider the ISIN code that is not the case for some other European initiatives that consider only large size (>5 bln EUR). We reject this approach to avoid a size bias. We have tried to limit the overuse of the commercial providers such as Bloomberg given their informational opacity and their questionable classification; however we have decided based on the ISIN code to verify if the share appears in other databases. Moreover we have taken into consideration a strict definition of green finance, since we include entities with only sustainable projects (narrow definition) and exclude those managing both sustainable and non-sustainable projects (large definition). Finally, we recover 3 075 unique ISIN codes for the 2013-2021 period.

The provisory database for Luxembourg provides interesting results in line with the European Green Bonds database published by the ECB. The following graph displays the time series trajectories of the sustainable bonds.

Chart -2-

European (EU) and Luxembourg (LU) Sustainable bond holders time series (Quarterly frequency, Stocks, from 2013Q1 to 2021Q1, billion Euro)



Sources: BCL and ECB

[39] The CSDB is a database fed by several commercial data providers and institutional sources, including ESCB national central banks and the ECB. https://www.ecb.europa.eu/pub/pdf/other/centralisedsecuritiesdatabase201002en.pdf

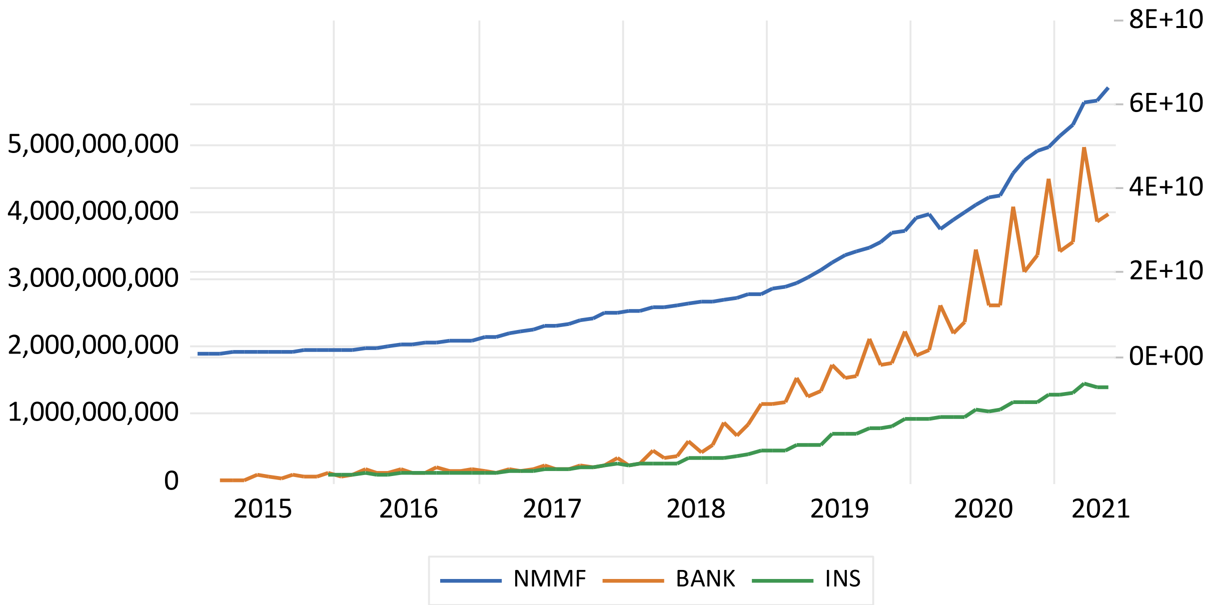
Both curves have an increasing trend, which confirms the development of sustainability concerns amongst the investors. They are now more sensitive to the ESG criteria for their investments that is satisfying. The sustainable bond stocks for Luxembourg and Europe for the period 2016Q1 to 2020Q1[40] had respectively been multiplied by about 16 and 9.

Given the time series trajectories, the regulators should promote the information disclosure and this information should be transparent, harmonized and verifiable. This is the most important challenge for the regulation authorities because the Green Bond Principles (GBP) are voluntary guidelines set out by the International Capital Markets Association (ICMA), first introduced in June 2018 to provide transparent accurate and honest information to investors. Two remarks deserved to be highlighted. First, there is no mandatory and until now the sustainability criterial are not harmonized and there is no consensual definition. Secondly, it is very important to have an accurate picture of the sustainable bonds evolution for regulation purposes.

By laying aside these remarks for a while, it is also interesting to note that there are some similitudes between the European bonds and the Luxembourg bonds. From the holders' side, according to the ECB database, the main holders are non-monetary market funds followed by the insurance and bank sectors. For Luxembourg, the ranking is quite similar since the holders are mainly from the non-money market funds (NMMF)[41], banks (BANK) and insurances (INS). For each sector, there is an amazing development as witnessed by the chart hereafter.

Chart -3 -

Time series trajectories for different holders sectors (Monthly frequency, from 2015M01 to 2021M05, Stocks, billion Euro)



Source: BCL

[40] We have chosen this period because there is for both bonds curves a take-off.

[41] https://www.ecb.europa.eu/pub/pdf/other/eb201604_article01.en.pdf

The banking sector, followed by the insurance sector, is an important holder of bonds regardless of the bond category. This ranking is not surprising since money non-market bonds (NMMF) in the ESG field are still important actors in the economic funding in Luxembourg. Moreover, banks (BANK) are heavily interconnected with other financial institutions such as money market funds. This interlinkage is not new and has been largely described by the financial literature (Jeffers and Baicu, 2013; Sengupta and Xue, 2020), whose the most common conclusion is that the development of non-banking activities is related to three principal factors, namely the regulation policy, the surge of fintech start ups and banking competition. Moreover, COVID-19 accelerates the development of non banking and fintech activities in all areas. This tendancy is not an ephemere change but a protracted transformation. The economic funding is essentially oriented towards markets, which is not a bad thing if they are monitored by legal authorities. However, sometimes financial services are sophisticated, not regulated and higly risky. The main limits of this kind of services are the dearth of tranparency and liquidity and they often escape from all surveillance and regulation processes. Indeed, some bond assets are funded by non-banking saving instruments. Consequently, there are tight linkages between the bond market and non-banking activity (Gabor and Ban, 2015; Ehlers and Zhu, 2018). In addition, according to the Financial Stability Board, the non-banking may take two principal forms that are securitization and the development of the high-yield bond market.

This point has raised the questions of financial stability and of stress testing, for instance. Indeed, the main threat is the non-money market funds'risk-taking decision trade-off between the benefits of the financial products inflows and the risk of causing negative spillovers to other parts of fund sponsors'business. This potential threat could occur in case of financial disruption because of the incertainty related to the recovery expectations and the sanitary crisis.

The building of green bonds database is therefore essential within the framework of stress tests, for instance. Indeed, they permit to test how the system is resilient to extreme events. These kinds of tools have been used by central banks after crisis to furnish essential information on the resilience of the financial and monetary system (bank, market, insurance). The evaluation of the system's resilience is fundamental for the regulation authorities since the systemic risk is omnipresent and its consequences on economies are dramatic. Stress tests require qualitative database and this stage it is currently impossible to implement them in an optimal manner.

By using this databases in a bivariate Midas-VAR model (GDP, Sustainable bonds), we find that the Green bonds impacts the GDP (Carreira and Gueddoudj, 2021). The relationship is long term and bidirectional (VAR Granger Causality/Block Exogeneity Wald Tests). This result has emphasized the interlinkage between the real sphere (GDP) and the financial sphere (sustainable bonds) and therefore the occurrence of a systemic crisis in case of endogenous or exogenous shocks. Even if the results are consistent (since several robustness test have been run) and encouraging, unfortunately the length of the database is too short (about 36 observations)[42]. The provisory solution linked to the length problem is to develop models dedicated to short database since the algorithm aiming at increasing the length introduces biases.

As already underlined previously, there are several initiatives to fill the gap in terms of data, and more particularly in the green bonds fields and these initiatives are welcome and the efforts should be pursued since despite all these efforts, the data gap is still paramount. Nevertheless, to tackle the data gap challenge several recommendations are required.

[42] We should note the definitions of large sample (>30 or >50) and small sample are still under debates.

4. Recommendations for CB database users

One of the most important challenges is to deal with the database public availability and their disclosures. The production of qualitative database concerns diverse levels (sector, geographic, granular and aggregated). Several reports from European and international institutions (BIS, ECB, IMF, NGFS, World Bank, etc.) claim more qualitative database whatever the costs since there is no issue without reliable and harmonized data. Our future is shaped by the development of database since data are the engine of our empirical models assumed to orient the policy strategies of today and tomorrow. The aim of this last section is to provide some exploratory recommendations related to the data user's challenges. These latter are related to the methodologies and the tools to reduce the data gap and upgrade the disclosures and the content. The next steps should be a rational, orderly and international cooperation. This section is a kind of specific conclusion (based on the previous developed paragraphs) exposing how the central banks as data users and producers may act for the improving of the climate change approach. Three points are explored: bottom-up and up-down methodologies for a better regulation, the store tools (dashboard, catalogue or in a global manner repository) and general provisory recommendations.

4.1. Needs of sustainable data for a better regulation: Bottom-up and top-down approaches

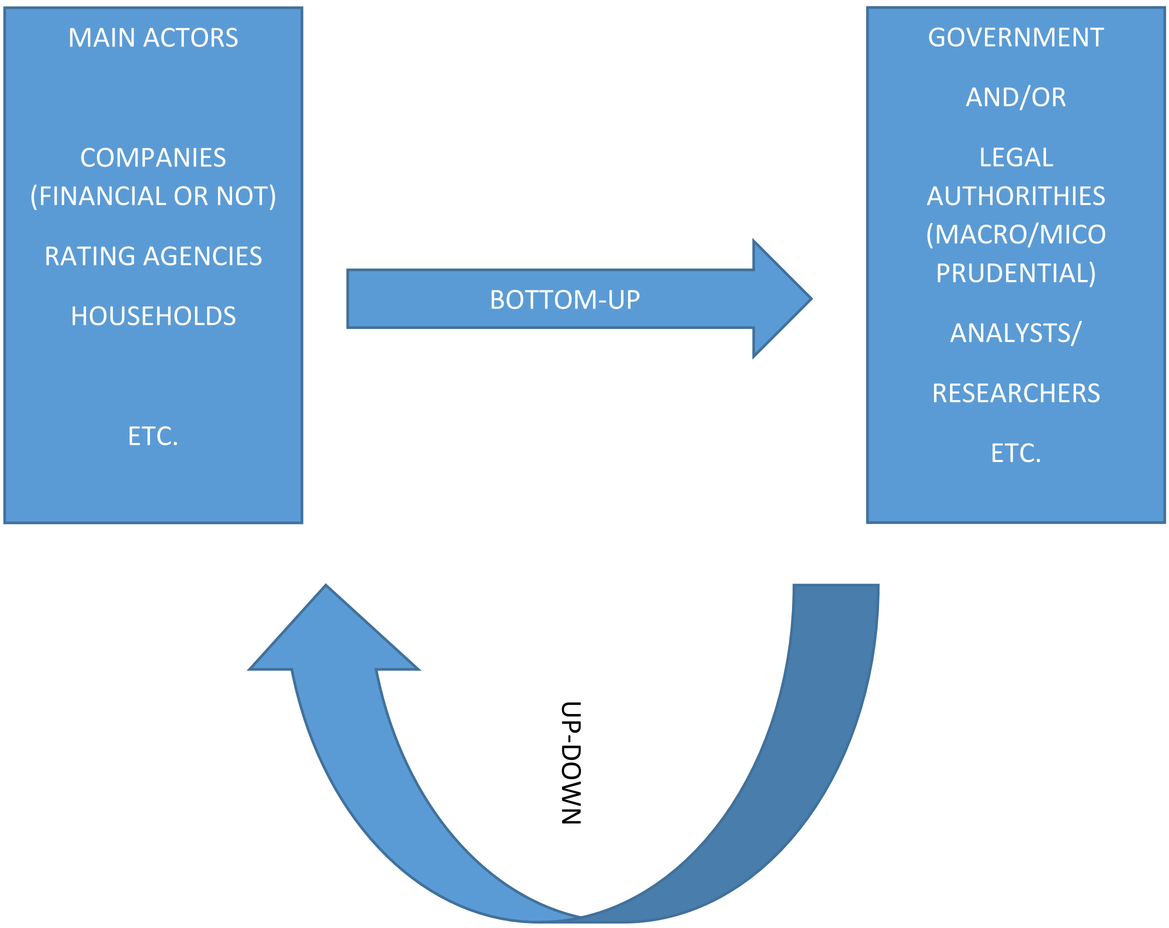
This sub-section is dedicated to regulation methodologies and recommendations for the short term perspectives to achieve an optimal sustainable transition. As admitted, today the data gap challenge is the most important challenges for central banks during the short term and the cornerstone of many sustainable issues.

Regulation is a corollary of any monetary and financial policies to reduce risk of significant costs to taxpayers and the financial system (i.e. limit the systemic risk). It also provides benefits to reach sustainable goals. The regulation tools require qualitative database and harmonized concepts to reach their goals. There are several sustainable information flows but they suffer from a lack of quality, therefore (bottom-up/top-down) approaches seems to be a good alternative to ameliorate the data gap and the regulation tools.

There are several methodologies and the aim of this section is not to describe all of them but the most common used or proposed by the principal actors of the climate change. As already known, the most used methods are the bottom-up and the top-down (or need to do) methodologies that have been largely described by the literature (Sabatier, 1986; Yohannes, 2001; Suntharasaj, 2013; Ljungström et al. 2020).

Regarding the top-down methodology, we start by defining and modelling the top level concepts that are refined during the process and this kind of approach is most of the time run by highly qualified experts in the domain such as engineers, for instance. Whereas the bottom-up approach is close to a macro vision since it starts from assumption already defined the scope framework through concepts and architecture, as well as the technical terminologies and the conceptual knowledge used for the architecture building. Of course both methods are useful however, they have advantages and drawbacks. For the top-down approach, it is a friendly method, reused and multi-usage .Therefore it is possible to define new research path for instance. Moreover, the flexibility of the methodology of a cost such as the degree of expertise, the cost, the time consuming and the important effort to run this king of approach. Given all these limits, it is obvious that sooner or later, the size will be a constraint and it depends on the current knowledge including legal one that is highly evolving and dynamic. For the bottom-up approach, there are several advantages such as the larger scale and more rapid since all the scope and the technical framework is already defined and relatively difficult to change in case of rapid evolution and may be costly. Figure-1- represents the interlinkage between both methodologies.

Bottom-up and up-down scheme Figure-2-



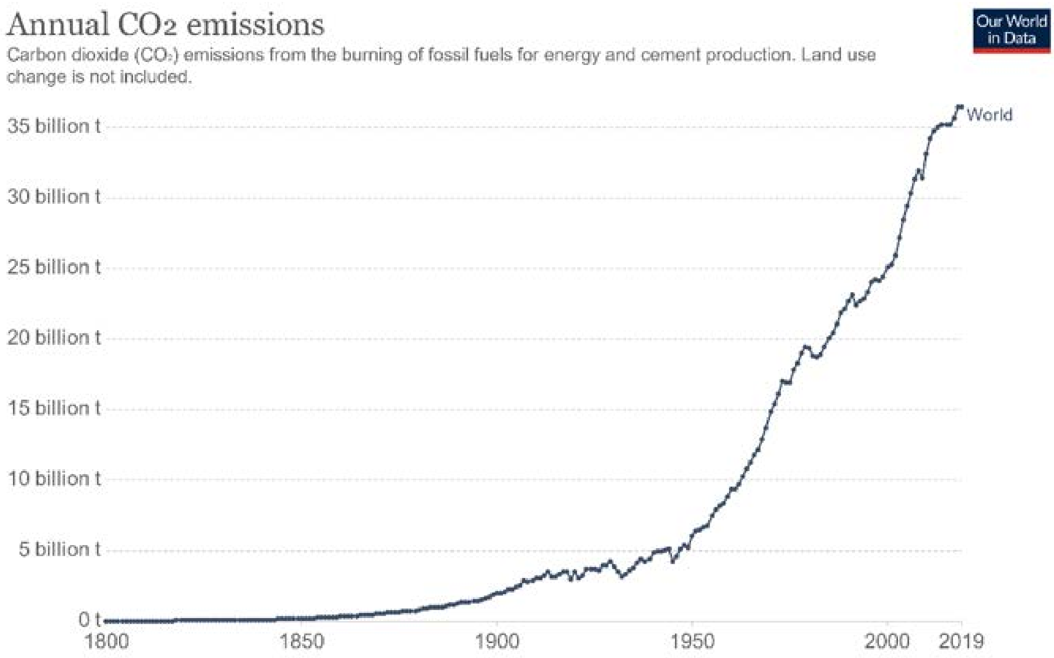
Source: Author

This simple scheme can be easily applied to the CO2 emissions taxes, that should be a short term priority, in order to evaluate them rationally since according to the IPPC, despite the current taxes, CO2 emissions do not collapse but increase (with a lower growth rate). This conclusion leads to rethink the mechanism of the CO2 taxes. In theory, a carbon price is assumed to share the pollution damages and induce a change in behaviours by promoting cleaner technologies and financial innovations to tend toward the ecological transition and *in fine* renew the economic growth restrained by pollution. To price the CO2 emissions there are two well-known methods: ETS[43] and the carbon price. The following

[43] Cf. sub-section 3. 2.

paragraphs is dedicated to the second method. According to the High-Level Commission on Carbon Prices report co-organized by Joseph Stiglitz and Nicholas Stern in 2017[44], the taxes should be around at $40-80 per tonnes by 2020 and $50-100 per tonnes by 2030. The carbon taxes could be an efficient tool to curtain the evolution of the CO2 emissions if the price is dissuasive. In May 2021, the EU carbon price hits 50 euros per tonnes, which reaches the target defined by the High-Level Commission on Carbon Prices report (Reuters, May, 4, 2021). However, this target seems to be not sufficient to drastically reduce the CO2 emissions, as demonstrated by the CO2 time series trajectory (Chart-4-).

Annual world CO2 emissions from 1800 to 2019	Chart-4-



Note: CO2 emissions are measured on a production basis, meaning they do not correct for emissions embedded in trade goods.

Source: Global Carbon Project: Carbon Dioxide Information Analysis Centre (CDIAC)

For the pricing exercises, it is delicate since a granular approach should be highly recommended to propose differentiated taxation system related to the level of pollution of each entity. Before, using such a tool, numerous efforts should be done to reinforce the data quality and analysis scope (i.e. increase the size scope, scope 3 mandatory etc.).

The taxation tools should be fair and in line with the famous "polluter pays principle".

To conclude this sub-section, the interlinkage between the both methods (bottom-up and up-down) is suitable and it may be a good approach to improve the data gap for a better understanding of the climate change challenges.

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44 https://static1.squarespace.com/static/54ff9c5ce4b0a53decccfb4c/t/59b7f2409f8dce5316811916/1505227332748/CarbonPricing_FullReport.pdf

The next section proposes potential recommendations to store all sustainable information collected given the current patchy visibility.

4.2. Statistical store tools: Dashboard and Repository/catalogue

To increase the use and the visibility of the sustainable variables, several storage tools are required. The tendency is to propose dashboard or a repository/catalogue.

According to the Statistics Committee's Expert Group Climate Change and Statistics (STC-EG CCS) consultation carried out last year with the involvement of the ESCB and SSM users' committees[45], there is a huge demand for qualitative and quantitative databases for analytical purposes (at macro, micro and meso-economics levels). From the same consultation, several interesting and specific conclusions have emerged. Indeed, the shares of commercial and non-commercial database are respectively 47% and 53%. This means that private database providers are not negligible given their weights in the studies surveyed by the Expert Group. It is well known that for commercial database, there is no transparency and therefore the data quality is questionable. Nevertheless, we cannot exclude the fact that private providers are an alternative solution for the user's analytical reports and/or research works, Besides, the database scopes are emissions statistics (about 49%), transition related indicators (36%), physical risk statistics (7%), and forward looking tools (around 8%). It is obvious that the climate change question has occupied an important place in the economic and political scene; however, the sustainability scope cannot be reduced to the climate change scope. It should be welcome to enlarge the scope in order to deal with sustainability problematics that include climate change, and then fully understand the future analytical challenges. Remind that the user's empirical models/works are conditioned by the database availability and the data quality/availability.

Moreover, the absence of an overview of existing indicators and data sources, as well as of structured and user-friendly access procedures to the data sources, is considered an important obstacle to be overcome in order to facilitate sustainable data search/knowledge. In addition, the users have also underlined the urgency of the climate change databases. To answer to this urgent request, it is suitable at a first stage to provide information on the database availability thanks to a synthetic and/or friendly user interface. Several solutions exist but only two instruments are taken into account to limit the scope: data repository/catalogue and dashboard.

The present paragraph is dedicated to the presentation of these two approaches. The aim is twofold. The first goal is to shed light on the advantages and the drawbacks of each of these two tools. Of course, as the methodological scope is different it is not possible to conclude that the repository/catalogue is superior to the dashboard or the opposite. The conclusion is that these two approaches are not substitutable but complementary.

The second goal is to demonstrate the necessity to set up on the very short term a repository/catalogue rather than a dashboard, since the first tool provide more general information needed by users.

This orientation (to build the data repository/catalogue) is based on the several European and international initiatives to provide information on the climate change related risks (or on the sustainability).

[45] https://unece.org/sites/default/files/2021-03/S4_5_CC_and_financial_Fortanier.pdf

We start by defining these different tools and expose the main advantages and drawbacks for each approach (see Table -6-).

A dashboard is a set of few selected variables/indicators aiming to provide information on specific topics, climate change for instance. Hence, it is a data visualization instrument, which permits to users to have a synthetic picture of the selected theme. Even non-experts can easily understand the content and the future trends in case there are forecasting exercises. Given the few numbers of variables and of data and graphs, the phases of implementation, automation for the calculation/building process and updating are quite easy to realize. However, this smart and dynamic tool may be not enough flexible in case of rapid changes. Each new variable introduced in the dashboard requires discussions or debates, the same occurs in case of variables withdrawals. Besides, the first step of building the dashboard, which is the selection of the indicators or metrics etc. to measure a phenomena, takes time and the selection may be rapidly obsolete in case of rapid state of change. In addition, some dashboards have not changed since years. This denotes a kind of lack of flexibility. Moreover, it is a very difficult exercise since with few variables/indicators the dashboard is assumed to offer consistent information on specific problematics. The risk of such approach is also the lack of realism given its simplicity.

As shortly exposed in the former sections, for the climate change, there are several European and international initiatives, particularly in the information collection. We present only 4 dashboards without entering into details since it is outside the section's scope; however, it is interesting to briefly expose them in order to deduce some lessons and current trends.

We can cite as a first example the IMF dashboard that takes into account 11 key experimental indicators related to 4 topics (Economic Activity and Climate, Cross-Border, Financial, Physical and Transition Risks, and Government Policy). The principal target of the IMF dashboard is to measure the impact of climate change on the economies[46].

The NGFS dashboard considers several key indicators for 21 jurisdictions reported in 6 items (Real economy, Reporting, Risk, Mobilization, Regulation, and Global initiatives). The goal of the dashboard "on scaling up green finance" is to collect a group of optimal variables to monitor, measure and better understand the conclusions related to efforts to green economies/or the financial system. The next step is to develop a repository[47]. All these store exercises have emphasized on the financial aspect of the climate change that is in line with the NGFS mandate.

The OECD has also published specific dashboards on the green growth[48] or on the carbon pricing[49], which are outstanding and fruitful.

Amongst non-European countries dashboard initiatives, we can cite the US version dashboard[50] given its advance in this field. However, it is largely oriented towards the physical[51] and transition[52] risks. Like the US dashboard, the UK version[53] deals with the physical and transaction risks.

Given the relative novelty of the climate change problematics, the current dashboards (i.e. IMF and NGFS) aimed to capture the impact of climate change on economies are in a preliminary phase. We welcome these interesting initiatives; however, they are all oriented towards the climate change impacts.

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[46] https://climatedata.imf.org/
[47] https://www.ngfs.net/node/365521
[48] https://www.oecd.org/greengrowth/48224574.pdf
[49] https://carbonpricingdashboard.worldbank.org/what-carbon-pricing
[50] https://www.climate.gov/
[51] Acute and Chronic risks
[52] CO2 emissions
[53] https://www.metoffice.gov.uk/hadobs/monitoring/dashboard.html

Unfortunately, the climate change partly materialized by the global warming does not permit us to see the wood for the trees. In a general manner, the dashboards are goal oriented tools, they all take into account specific topic (CO2 emissions or green finance or biodiversity loss etc.).

The solution to tackle the limits of the dashboard's exercises is likely to complete and integrate them with a data repository/catalogue tool that enlarges the scope and the informational content, for instance.

A data repository/catalogue is a neatly optimal inventory of available datasets across all sources (e.g. both private and public data providers). It is very useful for the users since it gathers main relevant information about the databases associated to their sources, via a structured layer for information. The data repository/catalogue is ordered and accessible for all users; it also provides information about the access identification codes, the units, the definitions, the frequencies, the start and end dates etc. The main advantages of this instrument are its potential "exhaustiveness", its flexibility and its friendly user interface. The main drawbacks are its time consuming nature, especially during the first implementation steps and the necessity to avoid the overabundance of information. The data repository/catalogue should be optimally calibrated since too much information kills information.

There are several data repositories/catalogues from different data providers; however, they do not take into account all the sources of the sustainable databases, as described in Section 3. This kind of tools is crucial for the users. Table -6- summarizes the pros and cons of each tool.

Dashboard and Repository/catalogue: Pros and Cons Table-6-

Tools	Pros	Cons
Dashboard	• Time saving approach for the producer • Smart and customisable presentation • Data and Graphs easily implemented and automated • Synthetic approach (Presentation of key indicators for specific topics) • Drill rapidly into details • Real time approach • For all users	• Limited information • Lack of realism • Limited objective • Not flexible in case of information volatility (ex. Short term exogenous shocks)
Repository/Catalogue	• "Exhaustive" approach • Real time approach • Easily automated for the update step • For all users	• Time consuming approach (short-term implementation step) • Overabundance of information /Too much information kills information

Source: Author

To conclude this section, data Repository/catalogue and dashboard are not substitutable but complementary. They are two different approaches aimed at corresponding to the users' needs. According to our knowledge, there is no data repository/catalogue which integrates all different types of data sources and the limits of all data introduced. Moreover, very few information on the quality of the data. The repository/catalogue should precise the quality of all data and particularly of the commercial data that are opaque and therefore questionable.

All world database included in the public catalogue should be cautiously verified and information on the scope, the definition, the frequency etc. should be integrated to provide the most exhaustive information and permit to the users to know exactly what they are measuring in their empirical works. In case of no information or insufficient information for the database reported in the catalogue, an informative notification should be available or introduce green orange and red flags to rank the data quality.

After having briefly justify the necessity to build a data repository/catalogue very soon, we describe in the next section, in a practical manner, some recommendations reflecting short term priorities.

4.3. General recommendations

The recommendations are related to the database availability. The methodologies, metrics and tools require a deep understanding of sustainability concepts, which is not easy but not impossible given the nature of the challenges. The first challenge is to find common basis for the concepts and define the EU harmonised taxonomy that is not ready today but will be available in 2022 according to the EC (European Commission). This step is the cornerstone of the sustainable finance and growth since the two variables are interlinked, there is no growth with finance and *vice versa*. In the meantime, the authorities should start defining common labels list of the companies that are in line or not with the Paris Agreement on climate change and in the case of non-alignment, they should define several thresholds that are characterised the firms climate change goals. This list of companies will be a tool for the investors that are aware of the ESG benefits for the sustainable development and orient their investment towards climate change project, for instance. However, the main obstacle to such recommendation is the companies 'behaviour that refused to be classified because of the fear of the famous 'blame and shame' and the loss of their reputation. The legal authorities should also provide information to explain the necessity of the transition companies list that also reports deadlines from today to 2050 (date for being clean or sustainable) with intermediate goals. The approach will also be fruitful for banks, insurances or any institutional investors and of course, for the authorities that can measure the efforts realized by firms and evaluate the progress made to converge towards the Paris Agreement requirements and adjust timely their policy tools aiming to tackle the climate change risks. However, we have to bear in mind that the lack of database is also a huge challenge for authorities and particularly for the central banks who are in charge of the financial stability and stability prices and *in fine* economic growth rate.

As already underlined, it might be interesting to build a repository/catalogue characterized by its exhaustiveness and its flexibility. However, it may be useful to develop a set of recommendations classified by priorities for is building that means we should define short term medium term and long term perspectives and/or targets.

In this sub-section, we will explore three sets of coordinated recommendations. We must bear in mind that it is a provisory/proposal frame and it may be modified at any time and improved in the very short term. It is not an exhaustive list of recommendations for the short term.

1/ The first set of recommendations is a potential world cooperation between the main actors of the statistics production.

We can for instance imagine a collaboration between all statistics authorities IMF, World Bank, BIS, OECD, Eurostat, the Eurosystem statistical Directorates and National ESS during the first phase and extend this collaboration to other actors such as academics institutions, Governmental and non-governmental organizations etc. (phase 2). The third phase is to extent to commercial providers since their data quality is questionable and they are utilized by an important share of users.

A central authority experienced on the data centralization and disclosure (such as IMF, OECD or G20) could be the main statistics actor in setting up and maintaining the catalogue for transaction cost reasons. In this case, an analysis of organizational settings would welcome. By organizational settings, we mean resources and responsibilities. The goals are to create sustainable statistics debates on a regular basis on methodologies and commonly develop economic and financial indicators in line with the ESG concerns. Reliable and harmonized database disclosures is essential to bring up more detailed information about the ESG issues and more particularly the climate change given its priority nature,

This first set of recommendations is justified by the economies of scale, the creation of synergies, complementarity developments by combining human and financial resources and inconsistency removals.

2/ The second set of recommendations is a classification of risks data according to priorities. As previously exposed, currently there are several granular and aggregated information assumed to measure the physical risks and it may be easier to start the catalogue with such databases and rapidly extend it to transition risks and other risks. Since the building of the catalogue is very heavy in terms of resources; so the setting up activities may be last between several periods (that we have to roughly precise). However, the EG STC CCS survey has shown that the transition risks issues where omnipresent in the NCBs works, it may be then more suitable to start by this risk to answer to the users' needs. As the two risks are interconnected it is possible to collect simultaneously the two risks, but the task is complex. Remind that the transition risk takes into account several items surrounded by uncertainties (i.e. Policy change and reputational impacts, consumer preferences, new technologies etc.), which are not easy to capture with accuracy. Granular collection should be the priority to fully understand the ESG challenges and essentially the climate change challenges.

3/ The third set of recommendations is related to the quality of the database and the harmonization. As already underlined the weight of commercial data in user's works and especially in the supervisors and regulators works is relatively important. There is a kind of asymmetrical information between the users and the providers this significates we have not enough information about the quality of the content and the scores or definition used to classify the firms as sustainable or not for instance. To set the idea on a simple example, we make use of the carbon firm's classifications. For instance, the identification of the low/high carbon firms is still puzzling that is not normal given the climate change emergency. At this stage, we should also note the key necessity of harmonization between the ESG criteria, definitions, and classifications, etc. since "the devil is in the details". Indeed, according to the Intergovernmental Panel on Climate Change (IPCC) report, there are 5 major industry sectors assumed to be highly polluting. More precisely, with the IPCC classification, the Toyota Motor Corporation is listed as a high carbon emissions firm whereas the MSCI ESG Ratings classify the same firm as a low emission company (Choi et al., 2020). These divergences should be avoided at the very short term because they are not consistent. Moreover, they raise again the question of the reliability of private/commercial data providers, which are largely used by academic papers and the central bank's researchers/and or analysts.

We need experts (biologists, mathematicians, physicians, economists, financial auditors etc.) dedicated to verify the content of commercial data and other databases (i.e. NGOs). In case we have no information the users will be informed by the label no information on the content for instance. The following table resumes the content of our provisory recommendations.

Recommendations for the short term — Table -7-

Recommendations	**Phase 1**	**Phase 2**	**Phase 3**
R1 Collaboration	Mandate an International Authority to endorse the role of leader Main actors for the collaboration: BIS,IMF, OECD, WB, Eurostat, Eurosystem statistical Directorates and National ESS etc.	academics institutions, Governmental and non-governmental organizations	Commercial providers
R2 Risks data priority	Transition risks	Physical risks	Other risks
R3 Data quality control and harmonization	Collect information data (granular and aggregated)	Involve experts in the informational content analysis	Provide labels of quality to users.

Source: Author

The three phases are flexible, interchangeable and interactive, the time length of each phase is random. It depends on several factors such as the negotiation periods, the acceptation/ refusal of each actor and of course exogenous events. Moreover, some risks are interlinked; the physical risks and the transition risks are totally nested. For instance, it is suitable to collect simultaneously CO2 information (financial and not financial) since their emissions are interconnected to the financial system. As already underlined, the banks report CO2 assets (from firms) in their balance sheet. The target of Table -7- is to propose an orderly and efficient road map/picture and more clarifications of the steps sequences.

After this indispensable step of database, regulation and adjustment policies should be more efficient, since better calibrated and easier to apply given the future common standards.

5. Conclusion

In summary, it is obvious that regulation authorities as central banks have to participate actively to the promotion of the sustainable finance (Volz 2017; Dikau et Volz 2019; Jeffers and Plihon, 2020; Coeuré, 2021) and the disclosure of database available for all users (central banks, universities, private or public research institutes, NGOs, etc.). However, they should not be alone to find pro-climate solutions.

Then, from a database scope, there are several lacuna and the urgency is to provide qualitative and harmonized data that will permit to develop stress tests that are indispensable to measure the resilience of the financial system, heart of productive system. Central banks and other public or private actors need robust and reliable statistics to preserve the common goods, particularly the planet, which currently is not the case. Some relevant sustainable database (at different level granular, sector, countries) exist that deserve to be optimally corrected, disclosed and used. The spread and the sharing of the database are the key of better understanding of the impact of the climate change on the countries, for instance. Indeed, the identification of imbalances are essential and their corrections via calibrated tools/instruments are indispensable.

World financial regulators should extend the sustainable or climate reporting to all listed companied as well as asset managers to be in line with the increasing demand of investors for disclosure and with the need of users to understand fully the sustainability.

The sanitary crisis has reinforced the need of data disclosure and it should be the first step to increase our needs to collect timely reliable information.

In addition finance and informatics, combined with artificial intelligence, technologic innovations cannot be separated from the energy consumption that raises the question of the conciliation of the increase of the energy utilization and the digitalization, for instance. For the digitalization sector, the database are totally incomplete and there are lacuna in terms of indicators. This point should be treated simultaneously with the sustainability data collection. Besides, the role of AI coupled with big data should not be neglected to increase our knowledge on sustainable issues; however, as pointed AI is energy consuming and currently there is no sustainable energy at a large scale that could limit the carbon footprint.

From the policy side, budget policies, particularly fiscal measures should also sustain the monetary supervisors' actions. Both monetary and budget policies should be coordinated to limit or annihilate totally the planet's damages related to anthropocene and capitalocene (Moore, 2017).

Moreover, the scope is global and success in international cooperation in climate change actions depends on various determinants because numerous and different players are involved and they have different goals and perspectives. Central banks intervene to meet their policy targets, governments participate to define national policies and reach their goals, firms want to be in line with the public ESG concerns, academic researchers pursue their academic interests etc. To match all these interests, an optimal use of top-down and bottom-up approaches should be rapidly efficient.

Nowadays, transition risks cannot be analyzed without taking into account the uncertainty, accented by new environments (technology, ecology transition, etc.); economies are plunged into a new environment where the "unknown unknowns" theory (Logan, 2009) is omnipresent and this assertion is reinforced by the recent ongoing sanitary crisis. A U-theory (Scharmer, 2016 and Scharmer and Kaufer 2018) may be useful to solve partly the issue of environmental finance. Concisely, the U-theory enables the possibility to find the best solution for a group or an organization. All agents have to participate actively to the project. There is no leader to impose solutions or discussions. The interactions between agents create common solutions thanks to an interactive process. The solution prototype are evolving and therefore be can be continuously improved by all participants. The U- theory is a method that considers the uncertainty as new possibilities reservoirs to solve thorny and theoretically unsolvable questions. The climate changes create risks and the solutions bring opportunities. We should act in a timely manner; propose fiscal and monetary stimulus packages to boost resources and sustainable growth; to prevent risks and utilize opportunities. All environment actors have to adapt optimally to this new paradigm. Accordingly, the economic policy responses to the environmental emergency need to match this specific environment, posing a challenge to both economists and decision makers.

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Appendices

Table 1.A. Sources, incentives, objectives and sectors in sustainable finance definitions and taxonomies in EU

	LU Definitions	EU Taxonomy	France Definitions	Netherlands Definitions
Sources				
Sovereign Green Bond	X		X	X
Green loans definitions in legislation[54]	X	X	X	X
Incentives				
Interest rate incentives	X		X	X
Tax incentives or subsidies	X		X	X
Monetary policy/collateral incentives				
Objectives				
Social objectives included	X	X	X	
Climate change adaptation	X	X	X	X
Climate change mitigation	X	X	X	X
Water and marine protection	X	X	X	X
Pollution prevention and control	X	X	X	X
Waste and recycling	X	X	X	X
Ecosystems/Biodiversity	X	X	X	X
Sectors covered				
Nuclear[55]	X	?		
Gas with emissions threshold[56]	X	X		
Clean fuel	X			
Clean Coal (supercritical)	X			
Hydro	X	X	X	X
Solar	X	X	X	X
Wind	X	X	X	X
Biofuels (biogas, biomass)	X	X		X
Power Transmission and distribution	X	X	X	X
Energy efficiency	X	X	X	X

[54] http://legilux.public.lu/eli/etat/leg/loi/2018/06/22/a521/jo

[55] There is no nuclear power plant in LU, however, the nuclear consumption represented 10,7% of the total energy consumption in 2019 . For the period 2009-2019, there is a great decrease in nuclear consumption (about -54%). This trend is in line with the government will to eliminate this source of energy at term.

[56] https://www.oecd.org/tax/tax-policy/taxing-energy-use-luxembourg.pdf

Green buildings/energy efficiency in buildings	X	X	X	X
Private passenger transport	X	X	X	X
Public passenger transport	X	X	X	X
Freight rail	X	X	X	X
Waterborne transport	X	X	X	
Water infrastructure	X	X	X	X
Clean water supply	X	X	X	
Forestry	X	X	X	X
Fisheries and aquaculture	No data in this field	X	X	
Preparation, re use, recycling	X	X	X	X
Waste to energy	X	X	X	X
Clean steel	X	X		
Clean aluminium	X	X		
Clean cement	X	X		
Low carbon technologies	X	X		
Hydrogen[57]	X	X		
Information and Communication Technology		X		

Source: OECD (https://www.oecd-ilibrary.org/sites/cdb1fb77-en/index.html?itemId=/content/component/cdb1fb77-en#section-d1e134

Table- 1.A- demonstrates that there are several variables assumed to evaluate the greenness degree of economies. It is obvious that common elements are available, which is a good news. However, the main tasks are to verify the content of each sub-items and ensure the database reliability, which is very difficult because of the data gap. This point reinforces the idea of the role of national banks to collect from several reporting outstanding information related to the greenness, which are compiled by the ECB. The advantage of the ECB compilation is that all variables are in line with the European guidelines and definitions.

[57] https://fedil-echo.lu/focus/hydrogen-to-decarbonise-luxembourgs-industrial-sector/

Table –A.2- Climate change risks and prudential tools activations

				Synthetic risks (Combination of physical transition and liabilities risks)		
Financial cycle and other key macro-economic variables (GDP, inflation, unemployment, etc.)	expanding phase of the financial cycle	Healthy economy		Preventive green policies.	Partial implementation of green policies.	Extensive implementation of green policies.
		Unhealthy economy		Policies to support sustainable growth and jobs.	Partial implementation of green policies.	Extensive implementation of green policies.
	Recession phase of the financial cycle	Healthy economy	without crisis	Preventive green policies.	Partial implementation of green policies.	Extensive implementation of green policies
		Unhealthy economy		Policies to support sustainable growth and jobs.	Partial implementation of green policies + Policies to support sustainable growth and jobs.	Extensive implementation of green policies.
		Healthy economy	with crisis	Preventive green policies.	Partial implementation of green policies.	Extensive implementation of green policies.
		Unhealthy economy		Policies to support sustainable growth and jobs.	Partial implementation of green policies + Policies to support sustainable growth and jobs.	Extensive implementation of green policies + Policies to support growth and jobs.

Notes: Shaded boxes indicate that these situations no longer exist. The green orange and red rectangles represent low, medium and high risk, respectively.

Potential decision tree of probabilities related to climate change risks

					Risks thresholds
		TR	vert	$(p_{TR/E1})$	V R
	(p_{E1}) E1	PR	vert	$(p_{PR/E1})$	
		LR	vert	$(p_{LR/E1})$	
		TR		$(p_{TR/E2})$	
Risks [58]	(p_{E2}) E2	PR	vert	$(p_{PR/E2})$	
		LR	vert	$(p_{LR/E2})$	
		TR		$(p_{TR/E3})$	
	(p_{E3}) E3	PR		$(p_{PR/E3})$	
		LR		$(p_{LR/E3})$	

With Ei is the states of nature (i=1, 2 and 3).

$(p_{JR/Ei})$ is the conditional probability (probability of a JR occurrence given Ei with J=transition (T), physical (P) and liability (L) risks).

TR, PR and LR are respectively the transition risk, the physical risk and the liability risk.

For the colour of the thresholds, we use a basic rule. For each branch of the decision tree, we select the worse situation for the aggregated risks.

This simple representation can easily be generalised to n states of nature and develop more scenarios.

[58] By risks we mean risks that are purely ecological and are evaluated and prioritized by the scientific community. The evaluations of the risks require reliable data.

BANQUE CENTRALE DU LUXEMBOURG
EUROSYSTEM

Statistical data needs on sustainable finance for central banks

International Conference on «Statistics for Sustainable Finance»

14-15 September 2021, Paris.

Sabbah Gueddoudj

Statistics Department

Introduction

- How to apprehend the sustainability notion: definition vs taxonomy.
  LU taxonomy version (Section 1)

- Sustainable database needs and the role of central banks (CB):
  Some European experiences.
  LU sustainable bonds (Section 2)

- Recommendations for CB database users
  Repository and international cooperation (Section 3)

BANQUE CENTRALE DU LUXEMBOURG
EUROSYSTÈME

Section 1 Definition vs Taxonomy (1/2)

- Definitions

a- Pricewaterhouse Coopers Consultant (2013)

b- Höhne et al.(2012)

c- United Nations Environment Programme (UNEP)

etc.

Why should we condense the complexity of a variable into a unique definition (Lindenberg, 2014)?

BANQUE CENTRALE DU LUXEMBOURG
EUROSYSTÈME

Section 1 Definition vs Taxonomy (2/2)

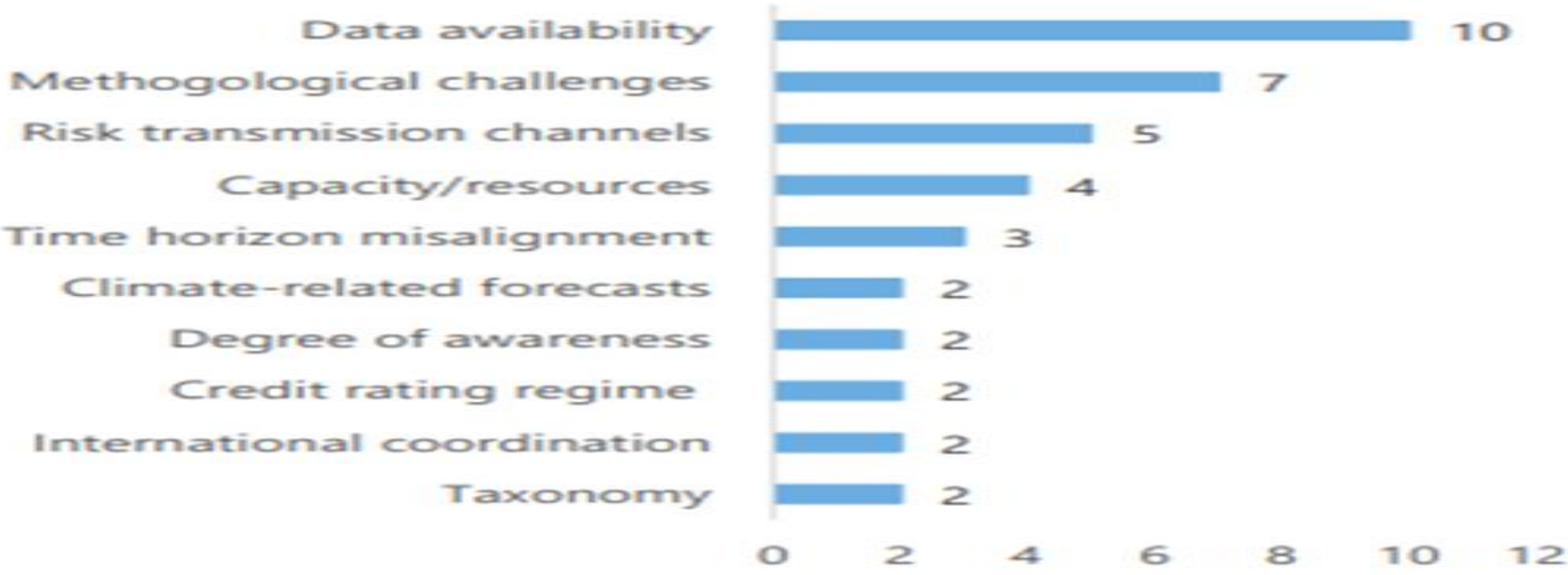
- Taxonomy sample for EU, FR, LU and NL (based on OECD works)

	LU Definitions	EU Taxonomy	France Definitions	Netherlands Definitions
Sources				
Sovereign Green Bond	X		X	X
Green loans definitions in legislation[48]	X	X	X	X
Incentives				
Interest rate incentives	X		X	X
Tax incentives or subsidies	X		X	X
Monetary policy/collateral incentives				
Objectives				
Social objectives included	X	X	X	
Climate change adaptation	X	X	X	X
Climate change mitigation	X	X	X	X
Water and marine protection	X	X	X	X
Pollution prevention and control	X	X	X	X
Waste and recycling	X	X	X	X
Ecosystems/Biodiversity	X	X	X	X
Sectors covered				
Nuclear*	X	?		
Gas with emissions threshold	X	X		
Clean fuel	X			
Clean Coal (supercritical)	X			
Hydro	X	X	X	X
Solar	X	X	X	X
Wind	X	X	X	X
Biofuels (biogas, biomass)	X	X		X
Power Transmission and distribution	X	X	X	X
Energy efficiency	X	X	X	X
Green buildings/energy efficiency in buildings	X	X	X	X
Private passenger transport	X	X	X	X
Public passenger transport	X	X	X	X
Freight rail	X	X	X	X
Waterborne transport	X	X	X	
Water infrastructure	X	X	X	X
Clean water supply	X	X	X	

BANQUE CENTRALE DU LUXEMBOURG
EUROSYSTÈME

Section 2- Sustainable database needs and the role of central banks: European initiatives (1/2)

- EU Surveys

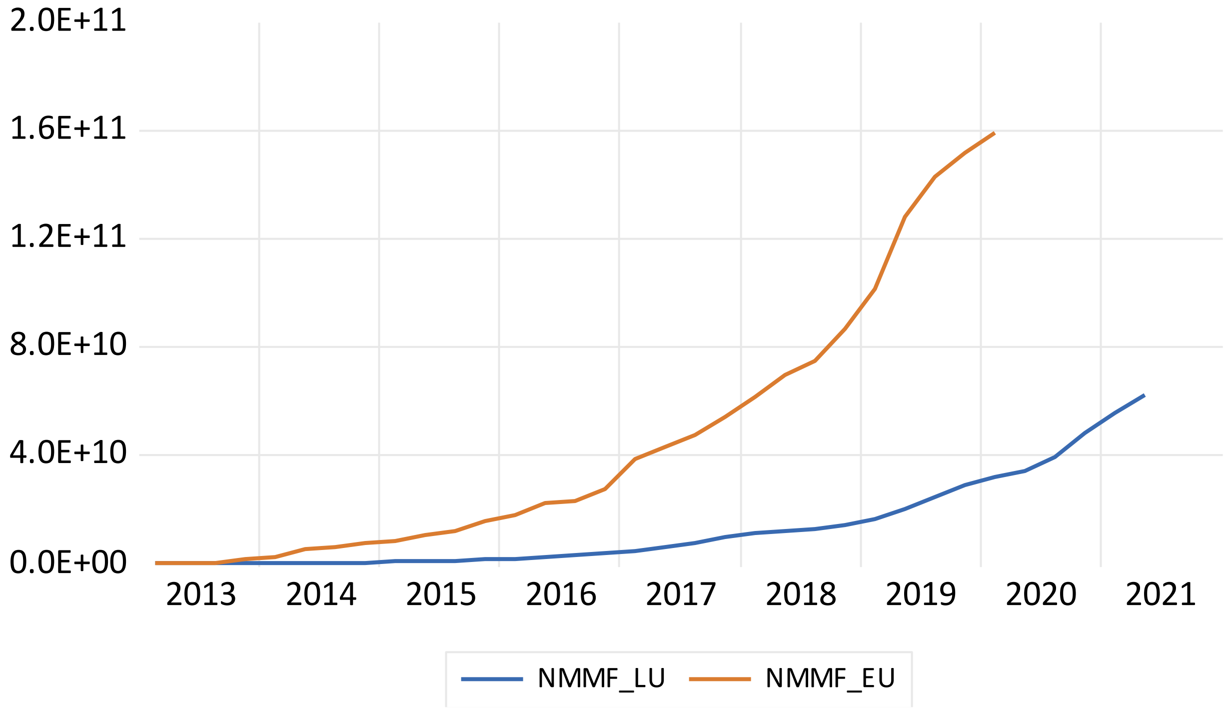


Source: Basel Committee

BANQUE CENTRALE DU LUXEMBOURG
EUROSYSTÈME

Section-2- Sustainable database needs and the role of central banks: European initiatives (2/2)

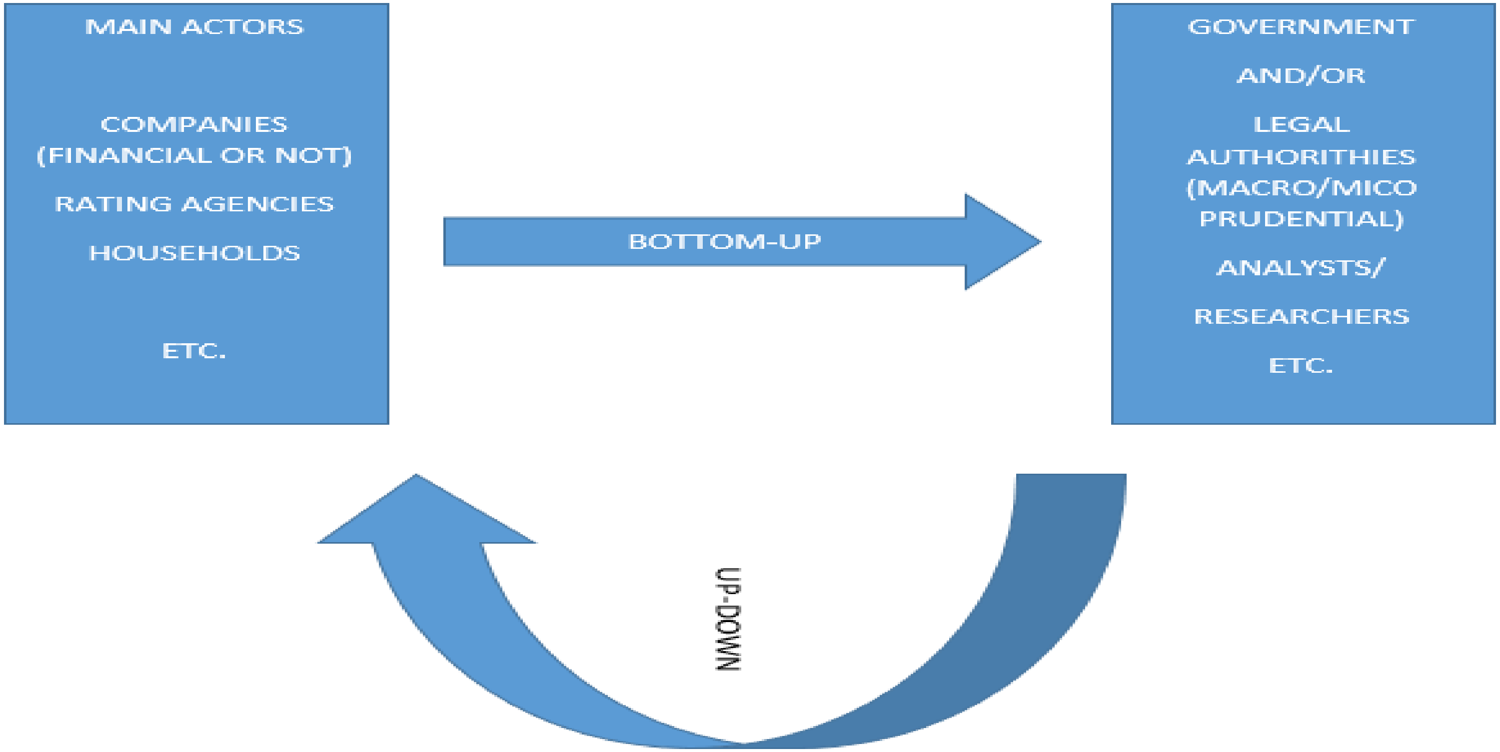
- European and Luxembourg Sustainable bond holdings time series (Quarterly frequency, from 2013Q1 to 2021Q1, billion Euro)



BANQUE CENTRALE DU LUXEMBOURG
EUROSYSTÈME

Section-3- Recommendations for CB database users (1/3)

- Bottom-up and top-down approaches



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Section-3- Recommendations for CB database users (2/3)

- Dashboard vs Repository (i.e. Catalogue)

Tools	Pros	Cons
Dashboard	• Time saving approach for the producer • Smart and customisable presentation • Data and Graphs easily implemented and automated • Synthetic approach (Presentation of key indicators for specific topics) • Drill rapidly into details • Real time approach • For all users	• Limited information • Lack of realism • Limited objective • Not flexible in case of information volatility (ex. Short term exogenous shocks)
Repository/Catalogue	• "Exhaustive" approach • Real time approach • Easily automated for the update step • For all users	• Time consuming approach (short-term implementation step) • Overabundance of information /Too much information kills information

Section-3- Recommendations for CB database users (3/3)

- Orderly roadmap for a comprehensive and reliable data catalogue

Recommendations	Phase 1	Phase 2	Phase 3
R1 Collaboration	Mandate an International Authority to endorse the role of leader Main actors for the collaboration: BIS,IMF, OECD, WB, Eurostat, Eurosystem statistical Directorates and National ESS etc.	academics institutions, Governmental and non-governmental organizations	Commercial providers
R2 Risks data priority	Transition risks	Physical risks	Other risks
R3 Data quality control and harmonization	Collect information data (granular and aggregated)	Involve experts in the informational content analysis	Provide labels of quality to users.

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Conclusions

- The role of CB is crucial as data producers and data users given their missions and their historical backgrounds.

- Data lacuna, lack of quality and long term/historical time series unavailability are obstacles to the CB missions.

- Climate change is global therefore international cooperation is required.
  ''If you want to go fast, go alone; if you want to go far, go together'' (African proverb).

- Inclusion in the data collection of the digitalisation and the artificial intelligence (IA) sectors since 1/ they are energy consuming and 2/ they play (and will play) an important role for the data collection today (and tomorrow).

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Thanks for your attention. For any questions and/or suggestions, do not hesitate to contact us at

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International Conference on "Statistics for Sustainable Finance", co-organised with the Banque de France and the Deutsche Bundesbank

14-15 September 2021, Paris, France, hybrid format

The Bundesbank's Sustainable Finance Data Hub[1]

Maurice Fehr, Christine Schlitzer and Elena Triebskorn,
Deutsche Bundesbank

[1] This presentation was prepared for the conference. The views expressed are those of the authors and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

The Bundesbank's Sustainable Finance Data Hub

Maurice Fehr, Christine Schlitzer and Elena Triebskorn
Deutsche Bundesbank, DG Statistics

1. Motivation

The lack of good quality and readily accessible climate-related data has posed a challenge for central banks, supervisors and financial sector participants alike. Global progress on improving climate data is under way, but in the short and medium-term, leveraging of already available data sources and approaches is essential. This paper describes the steps taken by the Bundesbank to overcome the shortage of data, the lessons learned, first empirical results, and ways on how to increase data availability through cooperation initiatives.

2. Idea of a Data Hub

To enable climate related analytical work within the Bundesbank, a central data hub to collect climate related data was set up in early 2020. It collects user needs within the bank and provides a central access point for data and data related questions. The Sustainable Finance Data Hub is tasked with examining market data that serve inter-divisional and permanent needs within the Bundesbank. The Data Hub is a specialized unit within the statistics directorate, serving varying user needs within the central bank. Data is provided through a central data base and access to this data can be requested at the data hub. It is also the first contact point for any methodological questions.

In-house data availability

Currently, we are in a market exploration phase for climate related data. Since December 2020, data from two private data providers are available bank-wide. We acquired a variety of climate-related indicators, most notably greenhouse gas emissions, ESG ratings and their underlying sub ratings. Other indicators include carbon risk, temperature alignment, screening criteria etc. A market exploration for geospatial tools on physical risk indicators is currently under way.

Given the different user needs within the institution, measurement uncertainty and differences in coverage of 3rd party providers, one data source is not enough. Even rather established climate related metrics, such as reported scope 1 and 2 emissions can show vastly different results across providers. In addition, two different data sources can complement each other in terms of the type of metrics provides, as well as in terms of the coverage of company level data. For this reason, the Bundesbank has adopted a multi-indicator approach.

We recently conducted a small in-house survey on the currently used providers and found out, that over 70 percent of respondents do in fact work with data from both providers. Satisfaction with the data provider is related to how transparent the data compilation is and the methodological guidance provided. Almost all users work with climate-related data, such as emissions, followed by carbon risk ratings. We want to continue the exchange with our users on their data needs and experiences through workshops and bilateral exchanges.

Being transparent to the public

Given the often scattered data sources of publicly available climate data, making macro-data available to the general public through dashboards und underlying data can facilitate access to existing data sources. The Bundesbank dashboard focuses on comparison of Germany vs. rest of the EU and includes financial, real economic and climate-related indicators. Graphs and underlying data are available on the Bundesbank statistics website for download in an easily accessible format.[1]

In addition, we reached an agreement with a 3rd data provider to publish certain aggregates on green and social bonds on our website. This work with a non-traditional stakeholder forms part of the Networks on Greening the Financial System Dashboard on scaling up green finance, which we update annually.

3. Cooperation efforts to increase data availability

Given the highly dynamic nature of climate-related data and data needs, cooperation with other stakeholders is key. This may include regional central bank cooperation to explore the possibilities to increase data sharing as well as working with non-traditional stakeholders and thinking about how to use digitalisation.

Regional central bank cooperation

The Bundesbank is the lead central bank in the joint Eurosystem procurement for up to two climate-related data providers. All participating central banks will have the right but not the obligation to participate in the Framework Agreements resulting from the public tender procedure. Given that many central banks face similar data challenges such cooperation minimises duplication of efforts and achieves synergies (e.g. in terms of describing relevant business requirements, the contract management or regarding the process for selecting the most suitable data providers itself). In addition, it ensures consistency of analysis and improves comparability across central banks by the broad use of the same data providers.

Working with non-traditional stakeholders

To promote using digitalization to bridge climate related data gaps, the Bundesbank submitted, together with Banco de España, a proposal on "Information extraction applied to sustainability-related disclosures" to the recent G20 TechSprint on Green Finance as well as a project proposal for the envisaged BIS Eurosystem Innovation Hub.

In addition, we are at the beginning of joint projects with TU Darmstadt, a technical university, working with international experts on natural language processing where we want to examine issues related to sustainability disclosure

[1] Green finance dashboard | Deutsche Bundesbank

reports and physical risk indicators. Such initiatives will become even more impactful, the more voluntary and mandatory climate related disclosure initiatives are under way, pathing the way for a long-term statistical response.

4. Conclusion

Given the growing importance of climate-related data for policy making working has to continue to increase availability and quality of data. Fulfilling UN's Fundamental Principles of Official Statistics shall be an important aim for statistical work and provide guidance on the steps we shall take – worldwide. We are looking forward of the follow up of the G20 Data Gaps Initiative and concrete steps to be taken.

While those and other important initiatives are under way, it is important for central banks to find short and medium term solutions to close data gaps. Given that sustainable finance data is still a new field for statisticians and users alike, it is important to bring together demand and supply for climate data using an appropriate intra-institutional organizational setting, such as a data hub. Different user needs and measurement uncertainty explain the necessity for a multi-source approach to climate data. And while in-house data needs have to be met, central banks should keep in mind the necessity to communicate with the general public.

In the medium term, central banks need to work together with traditional and non-traditional stakeholders and use comparative advantages. This will enable the best possible use of existing data. Finally, promoting digitalization to bridge climate related data gaps is pathing the way for a long-term statistical response, the more voluntary and mandatory climate related disclosure initiatives are under way.

The Bundesbank's Sustainable Finance Data Hub

Elena Triebskorn, Sustainable Finance Data Hub, Directorate General Statistics

Introduction
Short and medium-term approaches to closing data gaps

- Global progress on improving climate data is under way, but in the short and medium-term, **leveraging of already available data sources** and approaches is essential.

- This presentation describes **steps taken by the Bundesbank** to overcome the shortage of data, first empirical results, and ways on how to increase data availability through cooperation initiatives.

- **Five short and medium-term responses** to closing data gaps:

Bringing together demand and supply: Using an appropriate intra-institutional organizational setting

- To enable climate related analytical work within the Bundesbank, a **central data hub** to collect climate related data was set up in early 2020. The Sustainable Finance Data Hub is tasked with examining market data that serve **inter-divisional and permanent needs** within the Bundesbank.

- The Data Hub is a **specialized unit** within the statistics directorate, serving varying user needs within the central bank.

- Data is provided through a **central data base** and access to this data can be requested at the data hub. It is also the **first contact point** for any methodological questions.

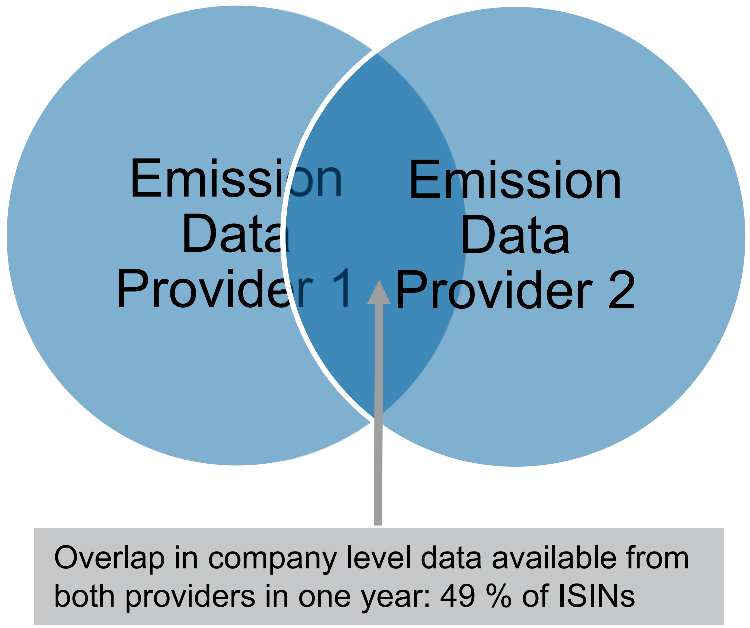
- In addition, we **contribute to international climate-related data discussions** through participation in the Network on Greening the Financial System WS Bridging Data Gaps, the Irving Fisher Committee sustainable finance work as well as the Committee on Monetary, Financial and Balance of Payment Statistics TF on sustainable finance.

Different user needs and measurement uncertainty: The necessity for a multi-source approach

- Various data providers measuring the same or closely related phenomena reveal **measurement uncertainty.**

- **Diverse user needs** call for a comprehensive set of indicators and data source to analyse climate risk.

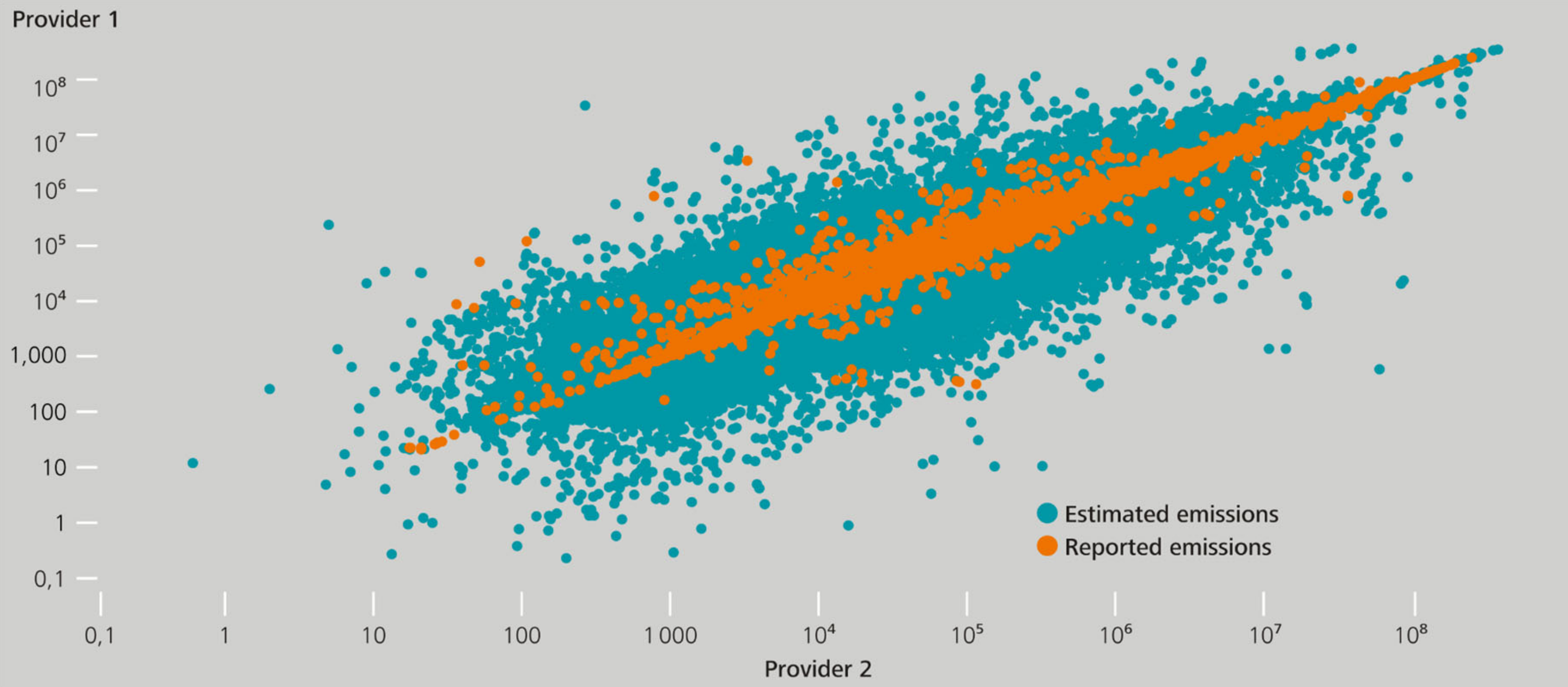
- In addition, two different data sources can **complement** each other in terms of the type of metrics provides, as well as coverage of company level data.



Multi-source approach: Allows for robustness checks

Comparison of greenhouse gas emissions (scope 1 + 2) from two providers

Tonnes of CO_2 equivalents, log scale



Deutsche Bundesbank

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Multi-source approach: Results from recent in-house survey

- In September 2021 we organized an **in-house workshop, including a small survey**, with users to receive feedback on the two data providers currently available.

- Results show that **70 % of respondents use data from both providers**, mainly for robustness checks and because of a specific data package, only available from one of the vendors.

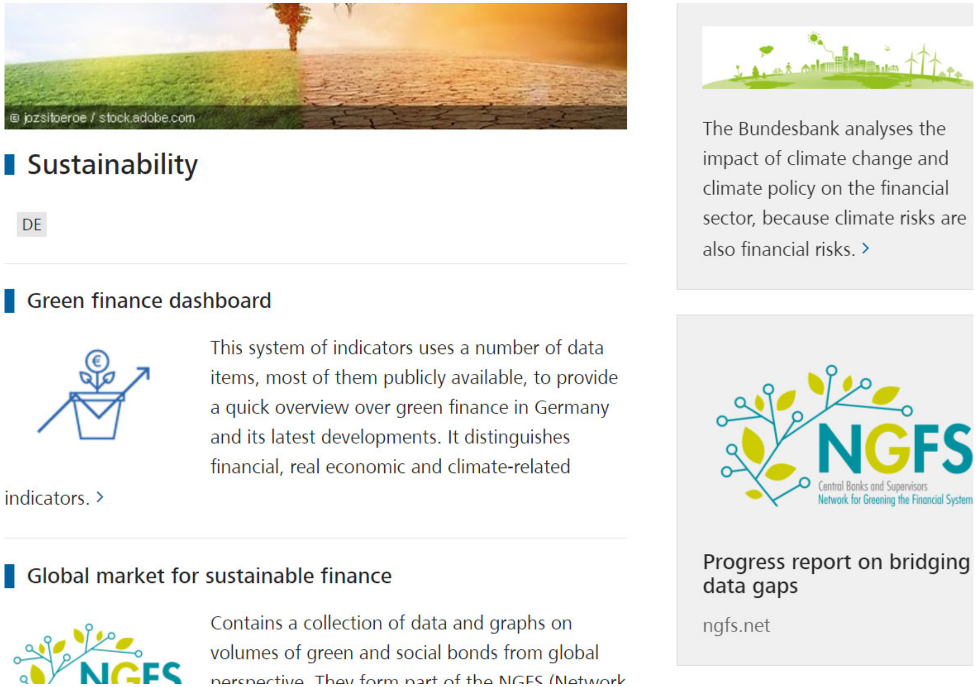
- Users value having **both access** to:

    1. A data **providers plattform** to get an overview of available data and receive methodological information
    2. The **in-house database** for larger data sets as well as other services we provide, such as combined data sets and additional identifiers

Being transparent to the public: Sustainability Statistics website including green finance dashboard

- Given the often scattered data sources of publicly available climate data, making data available to the general public through dashboards and underlying data can **facilitate access to existing data sources**.

- We reached an agreement with a 3rd party data provider to publish certain **aggregates on green and social bonds** on our website. This work with a non-traditional stakeholder forms part of the NGFS Dashboard on scaling up green finance, which we update annually.



Enhancing (regional) central bank cooperation: Joint Eurosystem procurement for up to two climate data providers

All participating central banks will have the right but not the obligation to participate in the Framework Agreements resulting from the public tender procedure.

Given that many central banks face similar data challenges such cooperation minimises duplication of efforts and achieves synergies.

In addition, it ensures consistency of analysis and improves comparability across central banks by the broad use of the same data providers.

Work with non-traditional stakeholders: Promoting digitalization

- To **promote using digitalization** to bridge climate related data gaps we submitted, together with Banco de España, a project proposal on "Information extraction applied to sustainability-related disclosures" to for the envisaged **BIS Eurosystem Innovation Hub**.

- We are at the beginning of **joint projects with TU Darmstadt**, a technical university, working with international experts on natural language processing where we want to examine issues related to sustainability disclosure reports and physical risk indicators.

⇨ Such initiatives will become even more impactful, the more voluntary and mandatory climate related disclosure initiatives are under way, **pathing the way for a long-term statistical response**.

⇨ In the meantime, we support efforts to **build international hubs of already available data sources**, such as the NGFS bridging data gaps repository and CMFB work on data catalogues.

Thank you for your attention!

Questions?

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Tracking sustainable investment: who is financing who?[1]

Francisco Conceição, Rafael Figueira and Pedro Silva,
Banco de Portugal

[1] This presentation was prepared for the conference. The views expressed are those of the authors and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

Tracking sustainable investment: who is financing who?[1]

Francisco Conceição, Rafael Figueira and Pedro Silva[2]

Abstract

Transitioning to a more sustainable economy will undoubtedly require substantial amounts of investment from governments and corporations. Since the last decade, environmental concerns have become a leading trend in the financial world. From the various financial instruments available, climate-linked securities – green bonds – are emerging as one of the leading options to finance this transition. This paper analyses the issuance and holdings of green bonds, with a particular focus in the Portuguese market. Based on market information, we identify the green bonds that have been issued to assess the market size and its characteristics. We find that the majority of green bonds are denominated in euros and dollars, present long maturities, and are awarded investment-grade ratings. In the Portuguese market, from the holders perspective, insurance corporations and pension funds are the main investors in these type of securities, which are mainly issued by non-resident entities. Our analysis focuses on the institutional and economic sectors of both issuers and holders, to assess and track the size and direction of the financial flows.

Keywords: Green bonds, Sustainability, Sustainable finance, Financial markets, Credit rating, Holdings, Euro Area, Portugal

JEL classification: G10, G24, M14, Q56

[1] The views expressed in this article are those of the authors and not necessarily those of the Bank of Portugal

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Contents

Introduction

Transitioning to a more sustainable and climate-friendly society has become a worldwide priority. Countries see reducing greenhouse gas emissions as an imperative and have committed to adopt the necessary changes. The Paris agreement marked a very important step, by defining clearly the goals that have to be achieved, and how they can be achieved.

The size of investment necessary to finance the transition is one of the major challenges faced, but it has also presented itself as an opportunity for the financial system to reinvent itself and start considering the risks and benefits associated with the transition.

This paper builds on the idea that, to monitor the financial performance of the climate transition, financial regulators and statistical authorities must monitor the investment trends associated with the climate transition in order to mitigate the financial and transition risks, to evaluate if the financial system is being able to match the projected financing needs, and to see who is financing whom.

We focus our analysis on green bonds, since they have rapidly become one of the leading financing instruments for the transition. The first green bond emission occurred in 2007, and in the first half of 2021 the amount outstanding already reached 875 billion euros.

The analysis was performed both on the issuers perspective (who is being financed), and on the holders perspective (who is financing). Europe is currently the leading market in green bonds, with thirteen of the twenty countries with the most amount outstanding. The most relevant economic sectors issuing green bonds have been the financial and insurance sector, public administration, and utilities.

In the end of 2020, Euro area investors held 272 billion euros worth of green bonds (more than 30% of the world total), with the financial system, especially investment funds, being the most representative sector investing in these bonds. Of the green bonds held, around 75% had also been issued by euro area entities.

In Portugal, the first green bond emission occurred in 2019. In the end of the first half of 2021, the amount outstanding was 3.6 billion euros, a small fraction (1.3%) of the total securities market. As for the holdings of Portuguese residents, whereas monetary financial institutions are the largest investor in the overall debt securities market, insurance corporations and pension funds are the largest investor in green bonds.

This paper starts by presenting the motivation to track sustainable financing. Then it presents a worldwide overview of the evolution of the green bond market. The section after looks into the characteristics of Euro area investors. The final section focuses on the Portuguese case, namely its issuances and its investors, comparing overall portfolios of debt securities with the green bond portfolios of resident investors.

The Paris Agreement – a task for central banks

In 2015, nearly every nation in the world came together in Paris to agree on a pathway that would limit the increase in the global average temperature to 2 degrees Celsius above pre-industrial levels, while also pursuing further efforts to limit this increase to 1.5 degrees. Reducing greenhouse gas (GHG) emissions stands out as the main policy to achieve this objective, with countries having to compromise on specific goals for these reductions.

Reducing GHG emissions without compromising economic development is one of the major challenges faced by countries – in a comprehensive sense: governments, industries, financial corporations, citizens, and so on – especially considering the investments necessary and the rapid pace of change that is demanded. It is generally believed that, despite the considerable amount of investment necessary, not undertaking it (frequently called the "business as usual" scenario) would have major costs that greatly surpass the investment needs. This means that the net benefits of transitioning to a low carbon society make this investment, not only necessary, but also rational.

With that said, one of the objectives also laid out on the Paris agreement was "Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development[3]". This objective acknowledges the costs associated with the transition, and the necessity of guaranteeing that those costs have a sustainable and viable way of being financed. This calls out for dynamic and resilient financial systems that are, on the one hand, capable of financing the transition, and on the other hand, able to mitigate transition risks and guarantee financial stability.

This goal can be seen as a call for action for central banks and supervisors, as several of their functions (depending on the legal framework of each country) can be impacted by climate change and the foreseen economic and social transition:

- as monetary authority, they must be aware of the implications of this transition for interest rates and inflation, and even consider adopting climate considerations when conducting monetary policy operations;
- as policy advisors, and particularly when they are also statistical authorities, central banks are responsible for collecting the necessary data to support decision-makers, and inform the public;
- as supervisors, central banks have to guarantee financial stability by making sure that financial institutions are aware and integrate, in their analysis, the risks associated with climate transition.

The new monetary policy strategy of the European Central Bank (ECB), for instance, lays out an action plan to include climate considerations in its strategy. According to the ECB, "Climate change and the transition towards a more sustainable economy affect the outlook for price stability through their impact on macroeconomic indicators such as inflation, output, employment, interest rates, investment and productivity; financial stability; and the transmission of monetary policy"[4]. Also, regarding supervision, the ECB has published a guide on climate-related and environmental risks for banks, and plans to introduce climate-related risks as part of the stress tests regularly conducted.

The Network of Central Banks and Supervisors for Greening the Financial System (NGFS) is also a clear example of the importance of Central Banks and Supervisors for meeting the goals of the Paris agreement. Set up in 2017, and with a growing list of

[3] https://unfccc.int/sites/default/files/english_paris_agreement.pdf

[4] https://www.ecb.europa.eu/press/pr/date/2021/html/ecb.pr210708_1~f104919225.en.html

members, the NGFS aims to "enhance the role of the financial system to manage risks and to mobilize capital for green and low-carbon investments"[5].

Financing the transition

According to the Organisation for Economic Co-operation and Development (OECD), for infrastructure to be consistent with the two-degree Celsius scenario, investment needs will reach 6.9 trillion dollars (equivalent to 8% of 2019 GDP) per year between 2015 and 2030. The large investment needs in question will require different forms of financing. In addition, transitioning to a more sustainable society will require changes in all economic sectors, across all countries, which means that the financing options will depend greatly on the type of investment and the ability to obtain financing.

One of the key differences between the Kyoto protocol and the Paris agreement is that the former required only developed nations to reduce emissions, with no targets for emerging countries. The Paris agreement, on the other hand, was signed by nearly every country in the world, which poses even more demanding efforts for developing nations: these countries not only have a more limited access to the technologies necessary, but they also typically have less developed financial markets, and less ability to obtain favourable terms for financing.

The two most typical forms of financing are through loans and debt securities. Whereas loans are typically an agreement between a bank and the entity requesting the loan, debt securities are sold in the market, meaning that they can be bought by companies, private individuals, financial institutions and governments. Although these types of instruments are not new, there is a growing trend to earmark them with how the amount raised will be used. Especially for debt securities, since these are accessible to all investors, debt-issuers are growingly disclosing how the proceeds will be invested, hoping to appeal to investors that may share their concerns and priorities. Considering the importance given to tackling climate change, more and more investors are looking to commit their resources to projects they feel will contribute to that end. This has led to the appearance of green bonds, whose importance is growing rapidly, and who are playing a leading role in financing the transition.

Green bonds are debt securities whose proceeds will be used for projects with environmental benefits. They serve, essentially, as a commitment from the green bond issuers to their potential investors. The idea is that investors will not only see these bonds as a personal revenue opportunity, but will also take into account the positive impact of the project being financed.

Green bonds can be issued directly by the entity that will undertake the investment, or can be issued by organisations who will then loan the amounts raised to green-aligned projects. For instance, financial institutions or governments can raise funds by issuing green bonds, and use the proceeds to finance green loans to various different projects and entities.

In order to assure that the climate targets are met, while maintaining financial stability and economic development, it is very important to understand who is requesting financing, and who is providing that financing (who is financing whom?). One of the reasons for this is to see whether all sectors are undertaking the necessary changes,

[5] https://www.ngfs.net/en/about-us/governance/origin-and-purpose

especially those that are most exposed to transition risks. For those that have to undertake the investments, it is essential that they have access to favourable financing conditions that will not put in jeopardy their financial sustainability.

The financing side also has to consider its financial sustainability. On the one hand, to reduce its risks, it has to reduce its exposure to GHG-intensive sectors, but, on the other hand, it must also provide financing for these sectors to transition away from GHG.

Finally, decision-makers such as governments, who have made the compromise of making the necessary transformations in their economies, must support their decisions with the relevant data. They must monitor if the pace of transformation is adequate, the risks for their economies, and their economic development.

Data

There is currently no official statistical classification that identifies which securities are considered green bonds. Therefore, for the purpose of this paper, we used a classification from a commercial provider of market data, from which we extracted a list of ISINs (International security identification number). In total, we identified 4050 debt securities classified as green bonds.

For the section Green bond market, we used information from the ECB's Centralised Securities Database (CSDB).

For the section Euro Area investment in green bonds, we used data from the ECB's Securities Holdings Statistics Database (SHSDB), as of December 2020. This database contains holdings data on a security-by-security level, broken down by diverse classifications. The data used excludes holdings of Central Banks.

Regarding the section The Portuguese case, we used information from the integrated securities database of Bank of Portugal (SIET).

All the analyses, except those that say otherwise, use the amount outstanding (nominal value) in euros for stocks at the end of June, 2021.

The Green Bond Market

The first green bond issuance is considered to have occurred in 2007, when the European Investment Bank (EIB) issued a Climate Awareness Bond (CAB), amounting to 600 million euros, with a 5 year maturity. The amount raised was used by the EIB to finance green projects, mainly related with renewable energy. Since then, the EIB has become a major player in the green bonds market, having raised more than 30 billion euros, in several currencies.

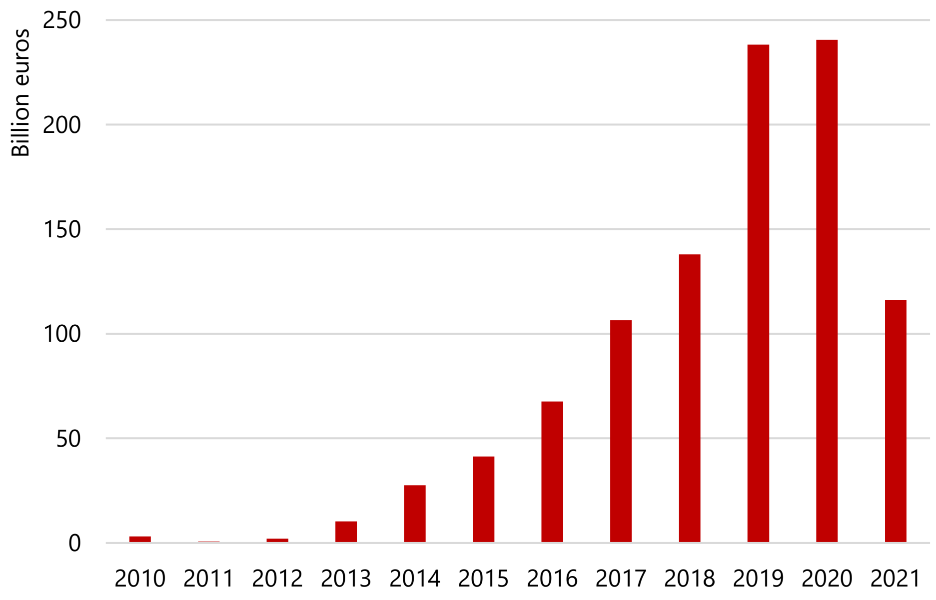
Since 2007, the amount issued per year has been increasing considerably. The amount issued in 2020 is 390 times higher than that of 2007, and almost twice the amount issued in 2018.

In the end of 2020, there had been 850 billion euros worth of green bond issued in the world, with an outstanding amount, at that point, of more than 750 billion euros. As of June 2021, the amount outstanding (AO) was close to 875 billion euros.

Graph 1 shows the amounts issued each year:

Amount issued

Graph 1



Sources: CSDB, IMF Climate Data

Maturity

Since 2016, the amount outstanding for each year is very close to the amount issued on that year, which means that the majority of these bonds has not reached its maturity. In fact, the majority (in terms of amount outstanding) of green bond securities alive as of June 2021 had an original maturity higher than 5 years.

The average original maturity for each bond (average weighted by amount outstanding) is slightly higher than 10 years. Table 1 shows the number of bonds and the total amount outstanding for different intervals of maturity.

In table 2, we split the bonds into four intervals, according to each bond's amount outstanding. This means that, for instance, the first interval contains all bonds whose amount outstanding is between zero and the first quartile of amount outstanding. The second interval contains all bonds whose amount outstanding is between the first quartile and the median, and so on. We then calculated the average (original) maturity for each of the intervals. We can see that the average maturity for the first three intervals is between 8 and 9 years, while previously we saw that the overall average was 10.2. In the fourth interval, however, the average maturity is 10.8 years, which is closer to the overall maturity. This seems to point that the highest value bonds have bigger maturities than the smaller ones.

Amount outstanding by maturity

Table 1

Maturity Range (years)	Amount outstanding (Billion euros)	Number
<=5	280.25	2,049
]5,10]	370.54	1,321
]10,30]	175.87	563
]30,50]	20.61	49
>50	28.05	68

Sources: CSDB

Weighted average maturity by amount outstanding[1]

Table 2

Statistic	Amount outstanding (Million euros)	Weighted average maturity
Weighted average by AO	NA	10.2
AO 1st quartile	25.764	8.9 (0-1st quartile)
AO 2nd quartile	87.209	8.1 (1st-2nd quartile)
AO 3th quartile	391.645	8.3 (2nd-3rd quartile)
AO Maximum	28 874.000	10.8 (3rd quartile-max)

[1] This analysis excluded five bonds with a maturity higher than 100 years

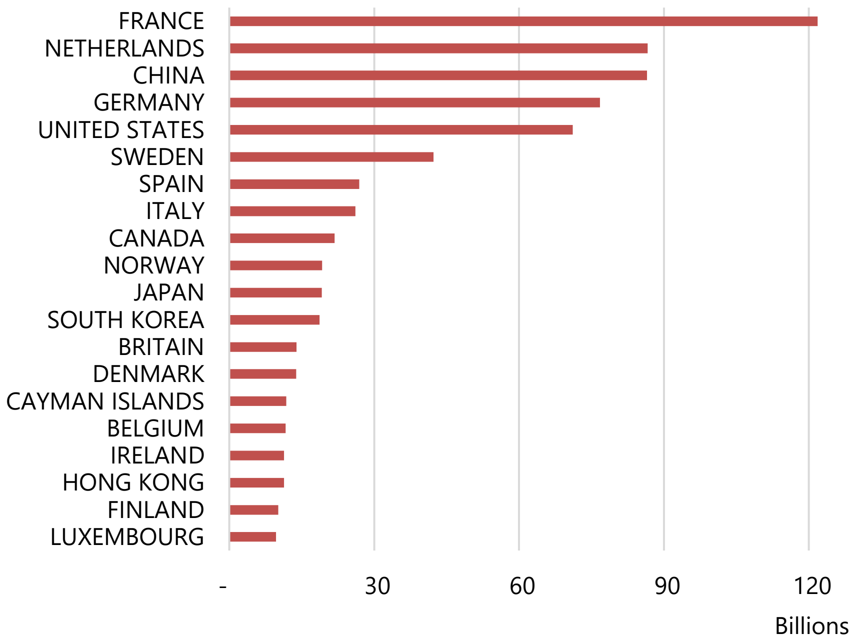
Sources: CSDB

Country

By country of the issuer, France currently holds the lead in terms of amount outstanding: there are more than 120 billion euros worth of bonds that were issued by French entities, almost 14% of the total. In second place is the Netherlands, followed very closely by China, with around 86 billion euros outstanding. Of the top 20 countries, 13 are located in Europe, 4 in Asia, and 3 in North America. These account for more than 80% of total amount outstanding worldwide.

Amount outstanding per country

Graph 2

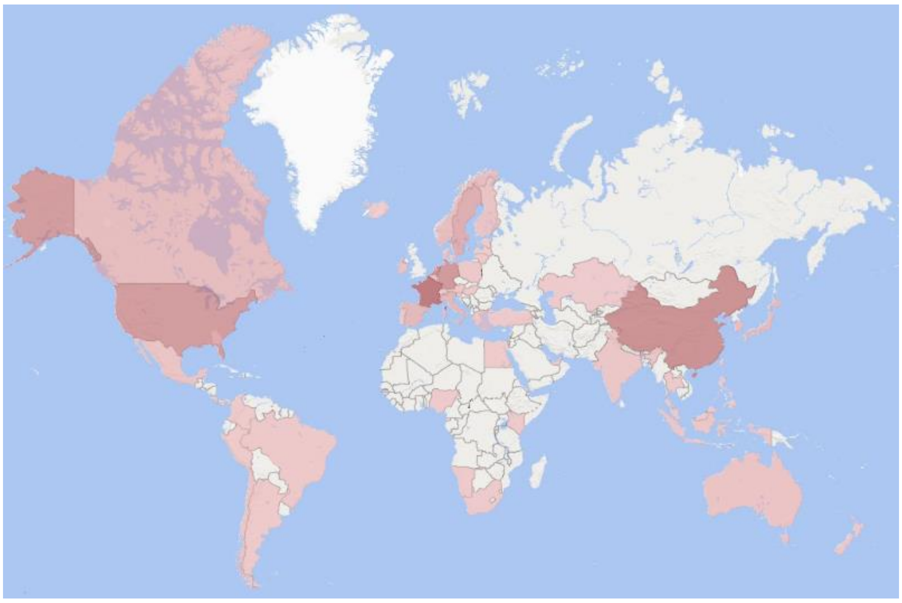


Sources: CSDB

The map below (image 1) represents all the amounts outstanding for every country. The darker the colour is, the bigger the amount outstanding for that country.

Amount outstanding per country

Image 1



Sources: CSDB

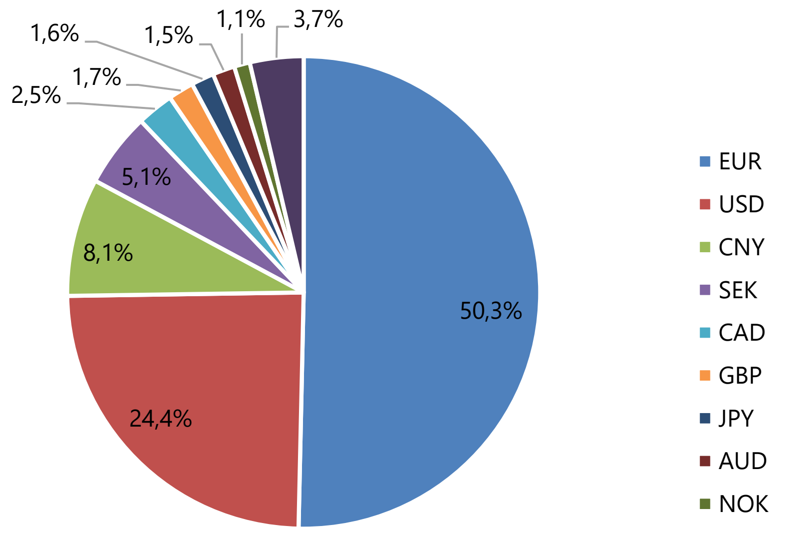
This country analysis excludes supranational organisations, which are very important players in this market. These organisations represent more than 70 billion euros of the total amount outstanding (7.6%). These organisations are comprised mostly of development banks, which use the proceeds from the green bonds issued to finance environmental or sustainable projects. Although the European Investment Bank stands out (since 2017 it has raised more than 30 billion euros in green bonds), there have been green bond issuances from development banks in the various continents. If you were to include this category in the country ranking by amount outstanding, it would be in sixth place.

Currency

Taking into account which countries (and supranationals) have issued the most, one would expect a large proportion of the issuances to be denominated in Euros and US Dollars. In fact, around 50.3% of the outstanding amount is denominated in Euros, followed by the US Dollar (24.4%) and the Chinese yuan renminbi (8.1%). Green bonds have been issued in 37 different currencies.

Amount outstanding by currency denomination

Graph 3



Sources: CSDB

Economic sector

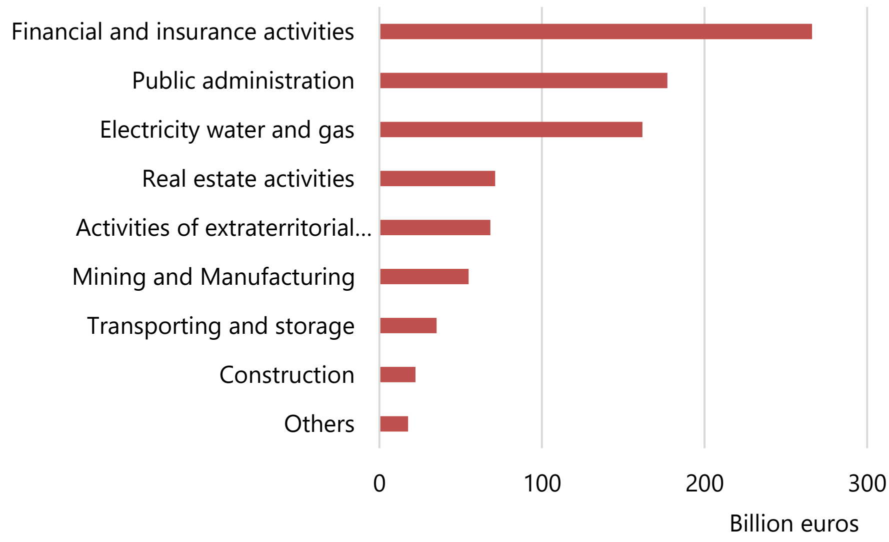
According to the NACE[6] classification, the majority of the issuers belong to the financial and insurance activities, public administration and electricity, water and gas sectors. These make up around 69% of the total amount outstanding (AO). However,

[6] Statistical classification of economic activities in the European Community

this information can only tell us the NACE classification of the issuer, but not how the proceeds are used. As mentioned before, financial corporations and public administration often issue green bonds, and then use the proceeds to loan to other entities who will undertake green-aligned projects. This means that the proceeds from a green bond issued by a development bank can be used, for instance, in the manufacturing or industrial sectors.

Green bonds AO by NACE

Graph 4



Sources: CSDB

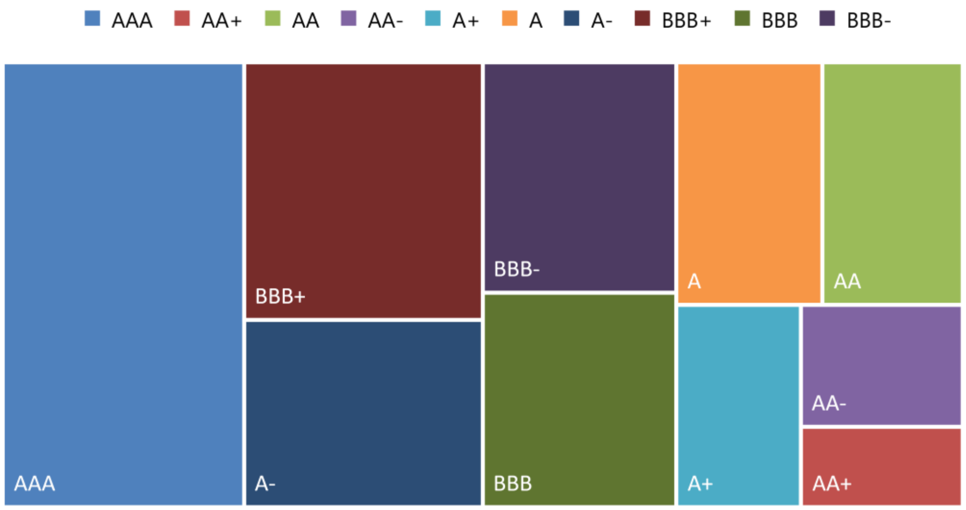
Credit rating

Considering credit ratings, we find that 62% of the amount outstanding (AO) of the green bonds has a rating attributed (equivalent to 26% of the number of bonds). Of those, 89% were attributed a rating considered investment grade[7], and 25% of bonds received the highest ranking – AAA. The green bonds with a rating considered non-investment grade, account for 60 billion euros of the amount outstanding.

[7] See table in Annex

Investment grade green bonds AO by Rating

Graph 5



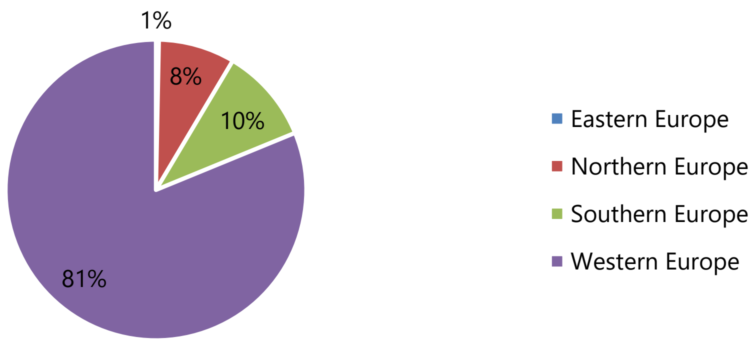
Sources: CSDB

Euro area investment in green bonds

This section presents a characterization of the euro area (EA) portfolios in green bonds. At the end of 2020, euro area investor's portfolios contained 272 billion euros worth of green bonds. This amount is just a small parcel comparing with the more than 15 trillion euros from all the long-term debt held by euro area investors.

AO of Green Bonds by EA holding's region | Dec 2020

Graph 6

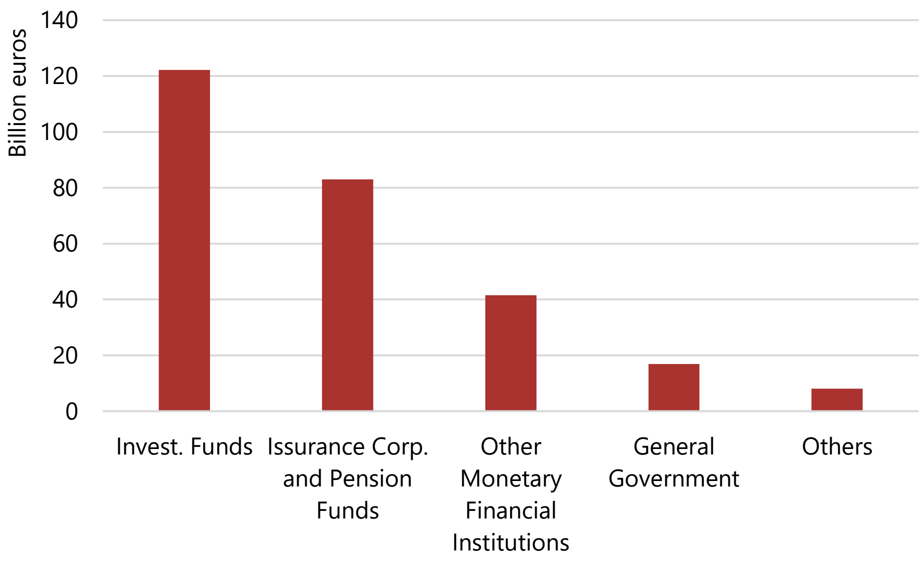


Sources: SHSDB

The major part of green bonds are held by Western Europe investors, representing 81% of the total amount outstanding (AO) held by euro area investors. Southern and Northern Europe presents a similar share of the total of EA holders, with 10% and 8% respectively, while Eastern Europe only represents 1% of EA investment in green bonds.[8]

EA investers in green Bonds AO by holder sector | Dec 2020

Graph 7



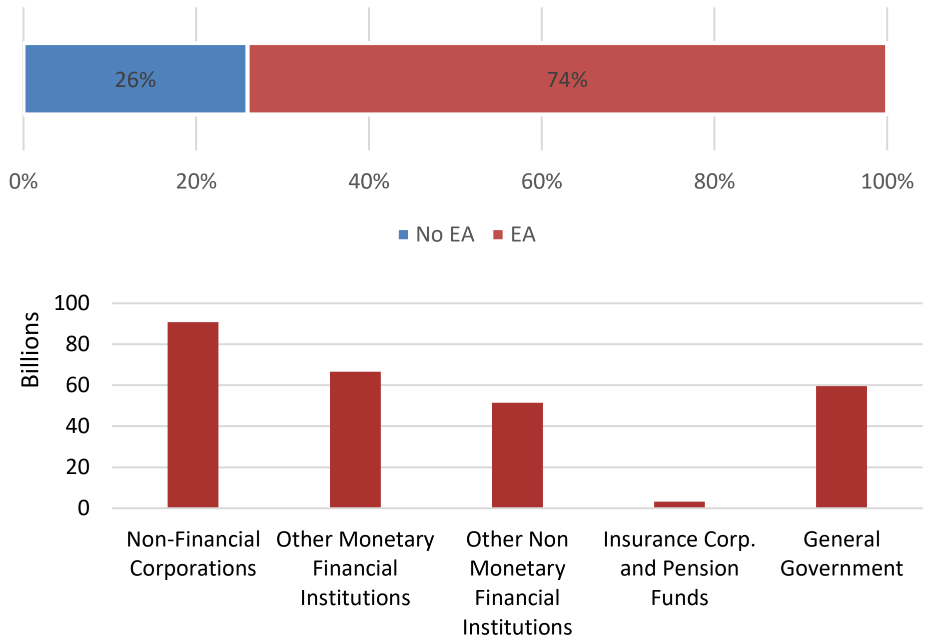
Sources: SHSDB

In terms of the euro area holder's institutional sector, financial corporations hold 92% of the amount outstanding of green bonds, while the non-financial sector (general government, non-financial corporations and private individuals) represented only 8% of the total AO in the end of 2020. Investment funds are the main EA investors in green bonds, holding a stock worth around 122 billion euros, followed by Insurance corporations and pension funds with 83 billion euros. The monetary institutions, excluding central banks, hold 42 billion euros worth of green bonds.

[8] Euro area countries division based on the statistic standard M49 (United Nations, 1999): Western Europe is composed by France, Germany, Luxembourg, Netherlands, Austria and Belgium; Eastern Europe by Slovenia and Slovakia; Northern Europe by Ireland, Finland, Latvia, Estonia and Lithuania; and Southern Europe by Italy, Spain, Portugal, Greece, Malta and Cyprus.

EA investment in Green Bonds by issuer sector and currency area | Dec 2020

Graph 8



Sources: SHSDB

Almost three quarters of Euro Area investors' holdings of green bonds is intra-EA, more precisely, 74%. Unlike what we saw for the holding sector, it is the non-financial sectors that have issued the most of the amount outstanding (Non-financial corporations and general government, together, represented 55% of the amount outstanding at the end of 2020). The main issuer are the non-financial corporations, with a stock of 91 billion euros, followed by the monetary financial institutions, general government and non-monetary financial institutions (excluding insurance corporations and pension funds) with 67, 60 and 51 billion euros respectively. Regarding green bonds issued by insurance corporations and pension funds, they only represent 1% of the stocks held by EA investors.

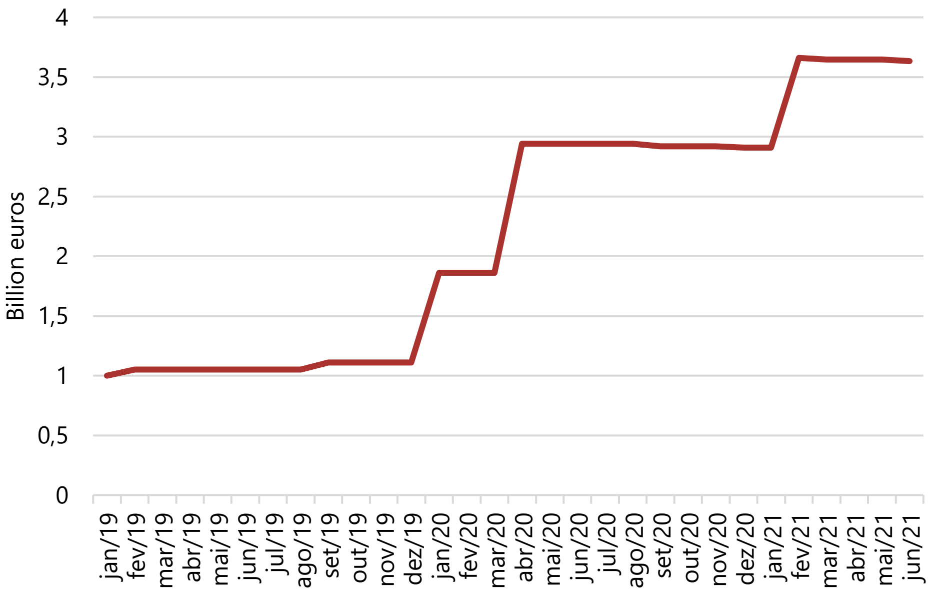
The Portuguese case

Green bonds issuance

The first Portuguese green bond issuance occurred in January 2019, 12 years after the first green bond was issued in the world. In June 2021, the green bonds issued by Portuguese entities amount to approximately 3.6 billion euros, corresponding to 1.3% of the total debt securities amount outstanding (AO).

AO of Portuguese Green Bond Issues

Graph 9



Sources: SIET

The Portuguese issues are mainly from the electricity, water and gas sector (88%), and seem to be linked mainly with long-term projects, since the weighted average maturity is 47 years.

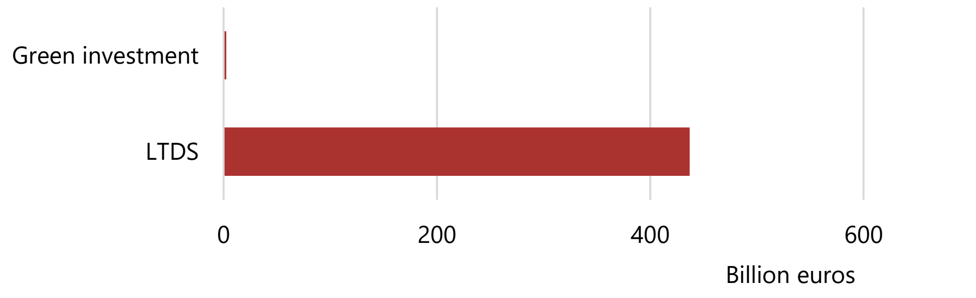
Of the total amount outstanding, 95% is held by non-residents (Since the first issuance, non-residents have always held more than 90% of the amount outstanding). Regarding the resident holders, these are mainly monetary financial institutions (57%) and insurance corporations and pension funds (30%).

Portfolios of green bonds and long term debt securities

In order to compare the Portuguese green bonds investment with the regular investment, we will compare the total holdings of *LTDS* (long-term debt securities), which include the amounts outstanding of all long-term debt securities held by Portuguese residents, and *Green investment* which contains only the outstanding amount of green bonds held by Portuguese resident.

Portuguese resident holdings | Dec 2020

Graph 10



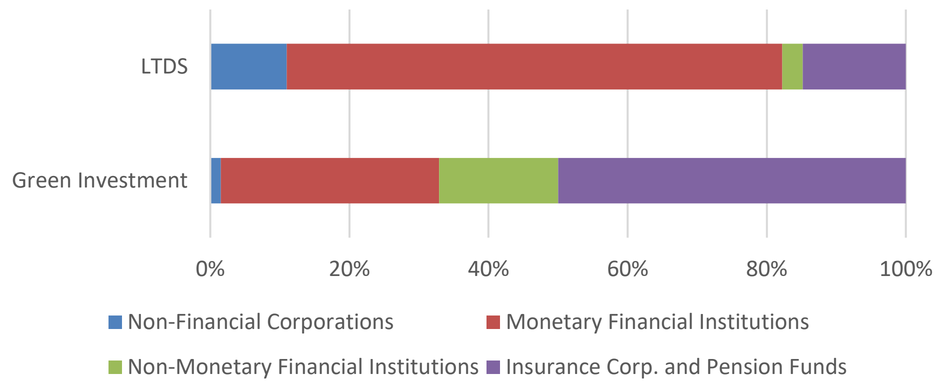
Sources: SIET

Green bonds account for only 2.5 billion euros of the total holdings of 434 billion euros of Portuguese investors, meaning that green bonds only represent 0.6% of the LTDS Portuguese portfolio.

However, the total amount held by investors that have, at least, one green bond in their portfolio is relatively close to the total holdings value (370 billion euros), which means that a large proportion of investors (in terms of size of the portfolio) have invested in green bonds – investors accounting for 85% of total holdings have invested in green bonds.

Portuguese resident holdings by holder sector | Dec 2020

Graph 11

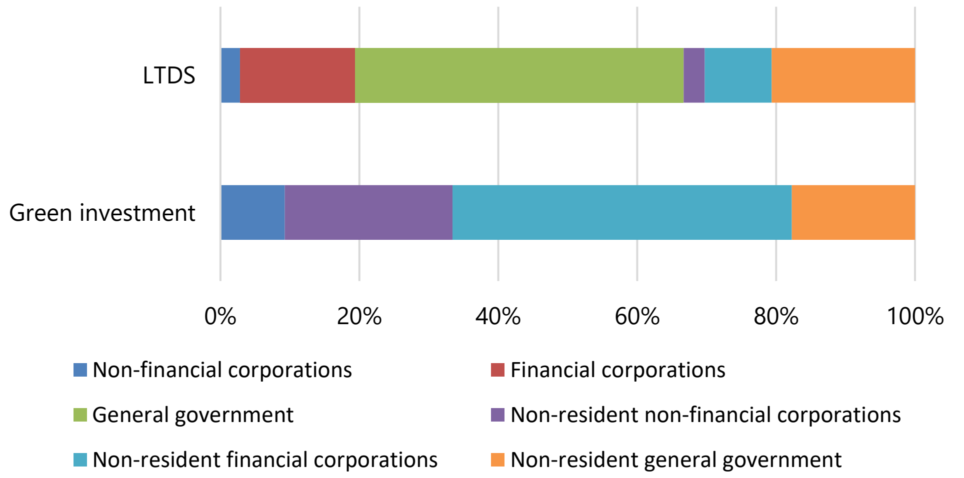


Sources: SIET

Graph 11 details the sectors of resident investors, in terms of portfolio size. The investment in green bonds follows a very different pattern than the overall investment. Overall investment is clearly dominated by monetary financial institutions (71%), followed by insurance corporations and pension funds, and non-financial corporations. On the other hand, the insurance corporations and pension funds sector is the biggest investor in green bonds (50% of holdings), followed by monetary financial institutions (31%) and non-monetary financial institutions (17%).

Portuguese resident holdings by issuer sector | Dec 2020

Graph 12



Sources: SIET

In terms of the institutional sector of the bond issuers, clear differences are also visible (graph 12): in overall terms, investment is focused mainly on bonds issued by the resident general government, followed by non-resident general government bonds, and resident financial corporations. Green investment, on the other hand, is mostly aimed towards bonds issued by non-resident financial corporations, followed by non-resident non-financial corporations and non-resident general government. Comparing the division between financial and non-financial sectors the difference is evident. In the LTDS portfolio, 73% is issued by non-financial sectors while green bonds portfolios are more balanced, with 51% issued by non-financial sectors.

Focusing solely on residence, 67% of total investment corresponds to bonds issued by resident entities, however, when it comes to green bonds, only 9% of this investment corresponds to green bonds issued by residents. These differences can be explained by the low amounts of green bonds issued by resident entities. For instance, while 47% of overall investment is in bonds issued by the resident general government, there have been no sovereign green bonds issued in Portugal.

Portuguese resident holdings by issuer NACE | Dec 2020

Table 3

	NACE of the issuer	
NACE	LTDS	Green investment
Electricity, water and gas	1%	35%
Public administration	62%	18%
Financial and insurance activities	22%	23%
Mining and Manufacturing	3%	5%
Real estate activities	0%	3%
Transporting and storage	0%	3%
Others	10%	13%

Sources: SIET

A similar analysis, can be conducted considering the NACE classification of the issuer, instead of the institutional sector. The results are expected to be similar to the previous ones, although there are some conceptual differences between institutional sector and NACE.

According to table 3, the predominance of securities issued by Public Administration in the green bonds portfolios are significantly lower than in the LTDS portfolios, 18% against 62% respectively. Another highlight is that 35% of the green bonds portfolio are issued by entities belonging to the electricity, water and gas sector, comparing with only 1% from the LTDS portfolios. Financial and insurance activities present an important share in both portfolios, with 23% in the green investment portfolio and 22% in the LTDS portfolio.

Regarding the maturity of debt securities held by Portuguese investors, the weighted average contractual maturity of green bonds is 11 years, two years less than the average maturity for all LTDS.

Conclusion

Our society has committed to transition towards a more sustainable and green environment, setting out ambitious goals, especially to reduce GHG emissions. The task ahead will require large amounts of investment, which presents a challenge for the financial system in particular. For this reason, central banks and supervisors have a particular role in guaranteeing the necessary financing, while preventing the risks associated.

We argue that, to guarantee that the transition goals are met, it is detrimental to know who is financing whom. This allows: to monitor if the financing needs are being met, and at what conditions; to guarantee that debt-issuers and investors are aware of the risks; and to support decision-makers and the public with the relevant data.

This paper focuses on green bonds, which have become a leading source of financing, and intends to demonstrate the need to keep track of this investment. With the first issuance in 2007, the green bond market is increasing rapidly and has spread worldwide. In June of 2021, the green bonds amount outstanding reached 875 billion euros, with Europe as one of the leading markets. Regarding the issuer sector, the biggest players are the financial sector, public administration and companies engaged in the electricity, water or gas sector, with a combined market share of 69%.

Within the Euro Area (EA), Western Europeans have been the largest investors in this type of bonds (81%), holding 272 billion euros of green bonds. Investment funds have a prominent role, representing almost 50% of the total investment. In fact, the financial sector as a whole is responsible for 92% of investment in EA bonds. Additionally, EA investment is mainly directed towards bonds that were also issued in the EA.

In terms of the Portuguese debt securities market, green bonds represent only 1.3% of the total debt securities amount outstanding. Portuguese green bonds were mainly issued by electricity water and gas sector companies (88%) and present a big weighted average maturity – 47 years. Regarding the Portuguese investors, contrary to what happens in Euro Area, Insurance Corporations and Pension Funds are the main investors in green bonds, mainly issued by non-resident entities (50%).

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Annex

	Rating	
Investment grade	AAA	Highest Quality
	AA+	High Quality
	AA	High Quality
	AA-	High Quality
	A+	Strong payment capacity
	A	Strong payment capacity
	A-	Strong payment capacity
	BBB+	Adequate payment capacity
	BBB	Adequate payment capacity
	BBB-	Adequate payment capacity
Non-investment grade	BB+	Likely to fulfil obligations, ongoing uncertainty
	BB	Likely to fulfil obligations, ongoing uncertainty
	BB-	Likely to fulfil obligations, ongoing uncertainty
	B+	High Credit Risk
	B	High Credit Risk
	B-	High Credit Risk
	CCC+	Very High Credit Risk
	CCC	Very High Credit Risk
	CCC-	Very High Credit Risk
	CC	Near Default
	D	Default

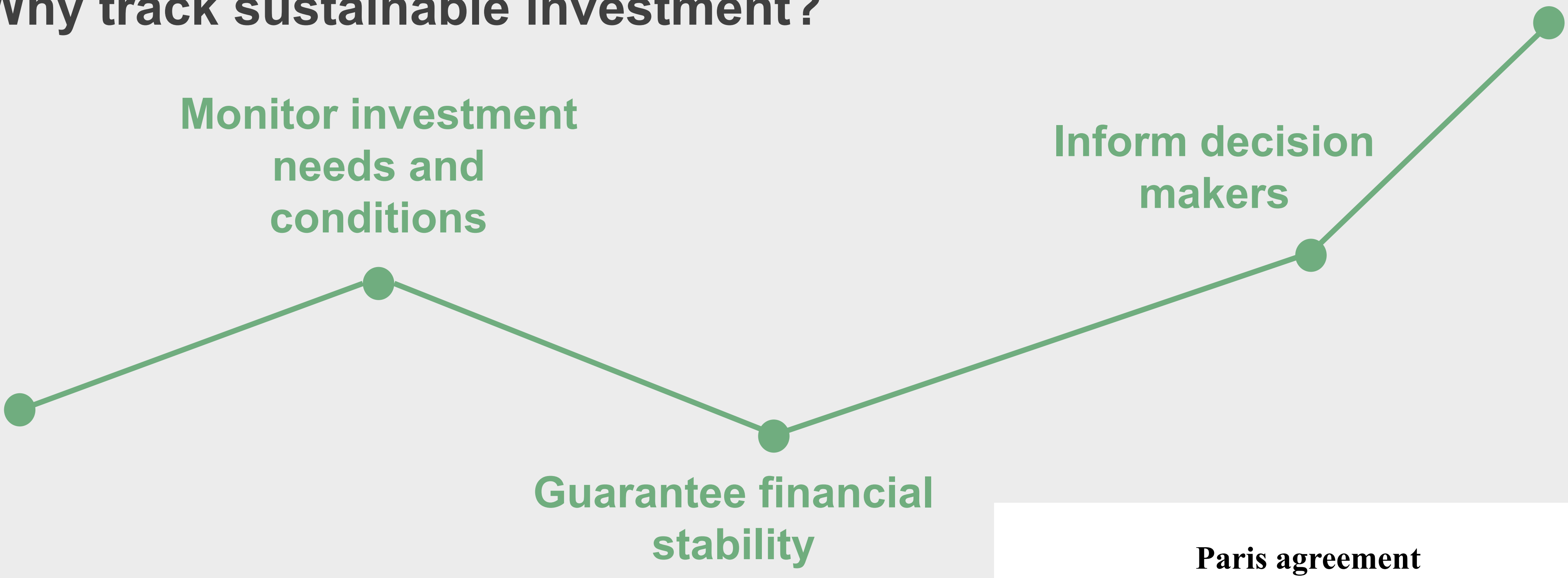
Tracking sustainable investment: Who is financing whom?

Francisco Conceição, Rafael Figueira, Pedro Silva

BANCO DE PORTUGAL

International Conference on Statistics for Sustainable Finance
14-15 September 2021, Paris

Why track sustainable investment?



ECB climate-change action plan

…develop new experimental indicators, covering relevant green financial instruments…

Paris agreement

Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development.

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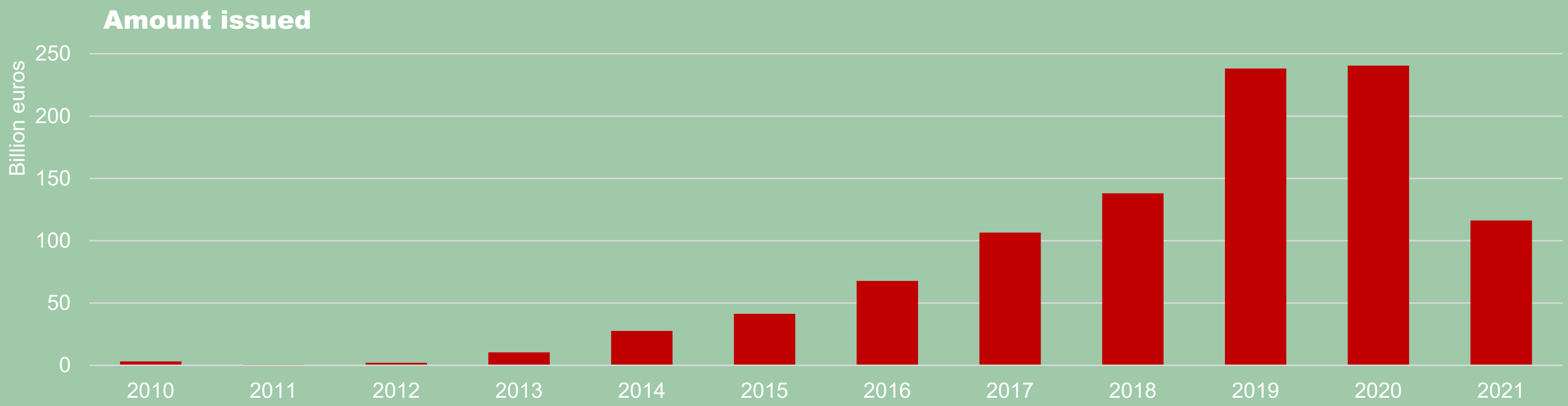
Green bonds are debt securities whose proceeds will be used for projects with environmental benefits.

First green bond issued: EIB (2007) – €600 million



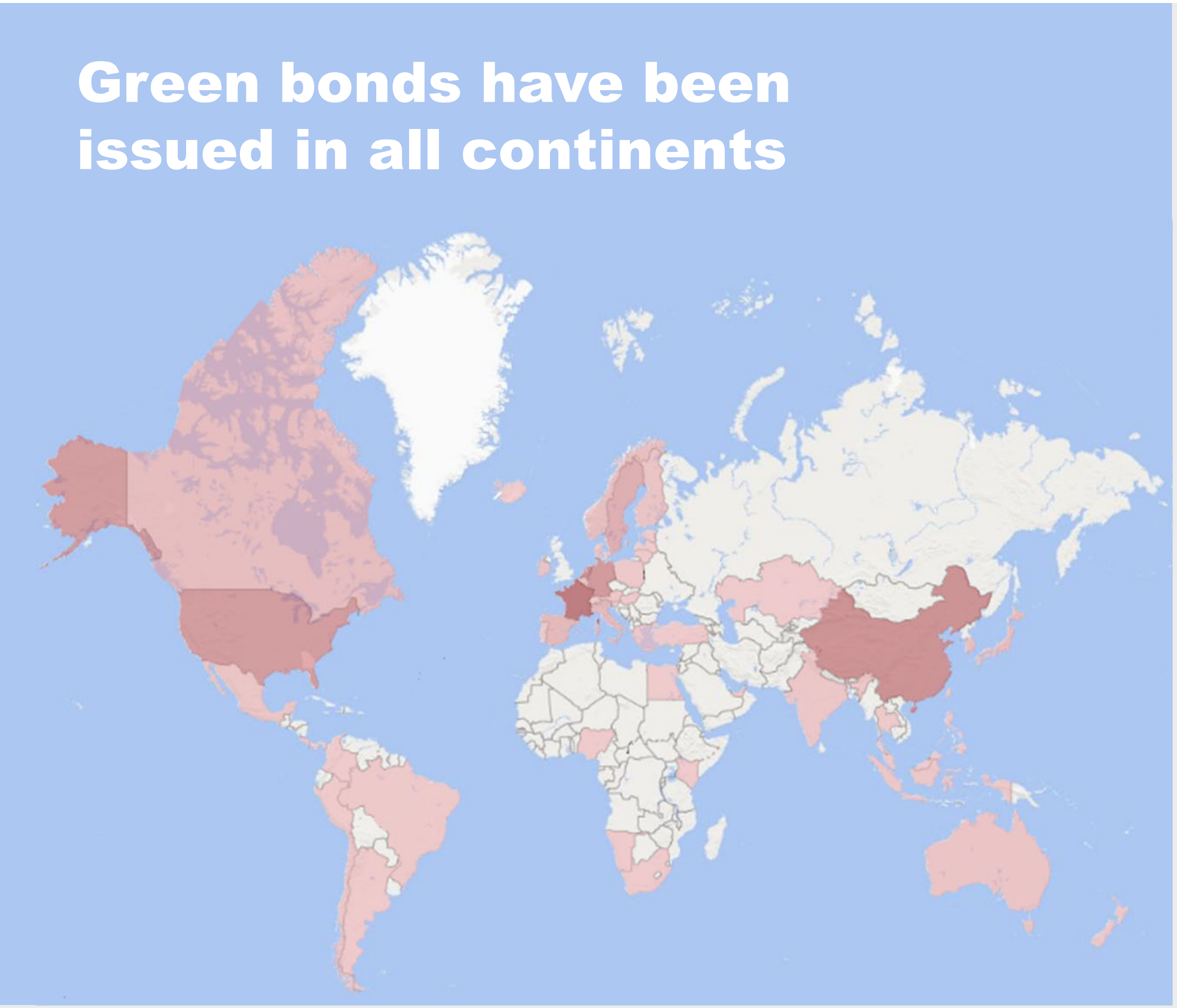
Amount outstanding

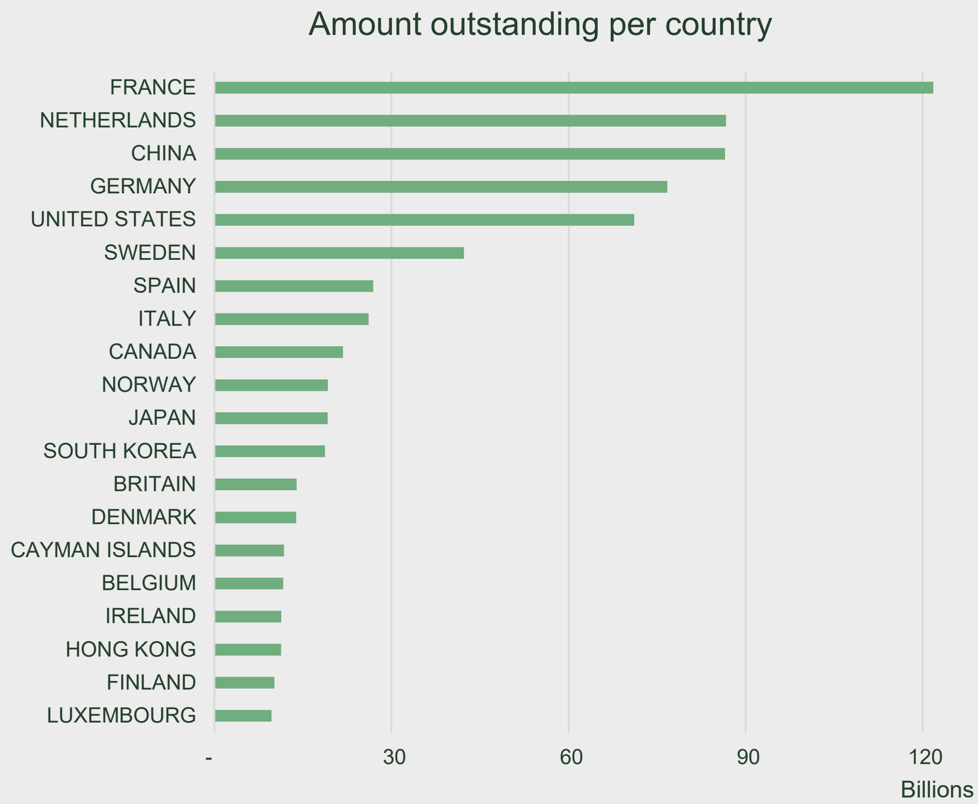
€875

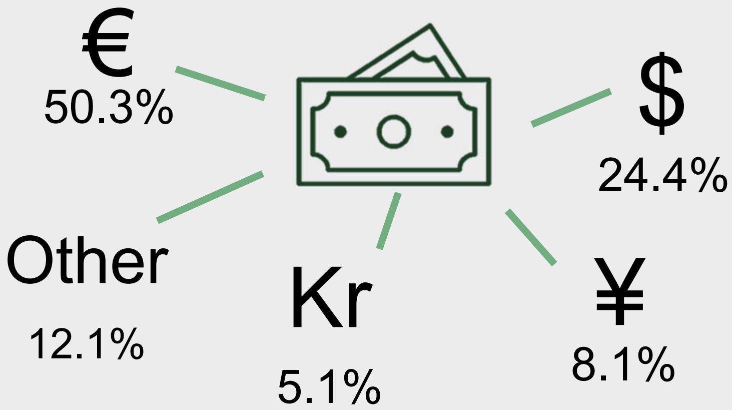
billion

June 2021

Green bonds have been issued in all continents







Supranational organisations represent €70 billion of total amount outstanding

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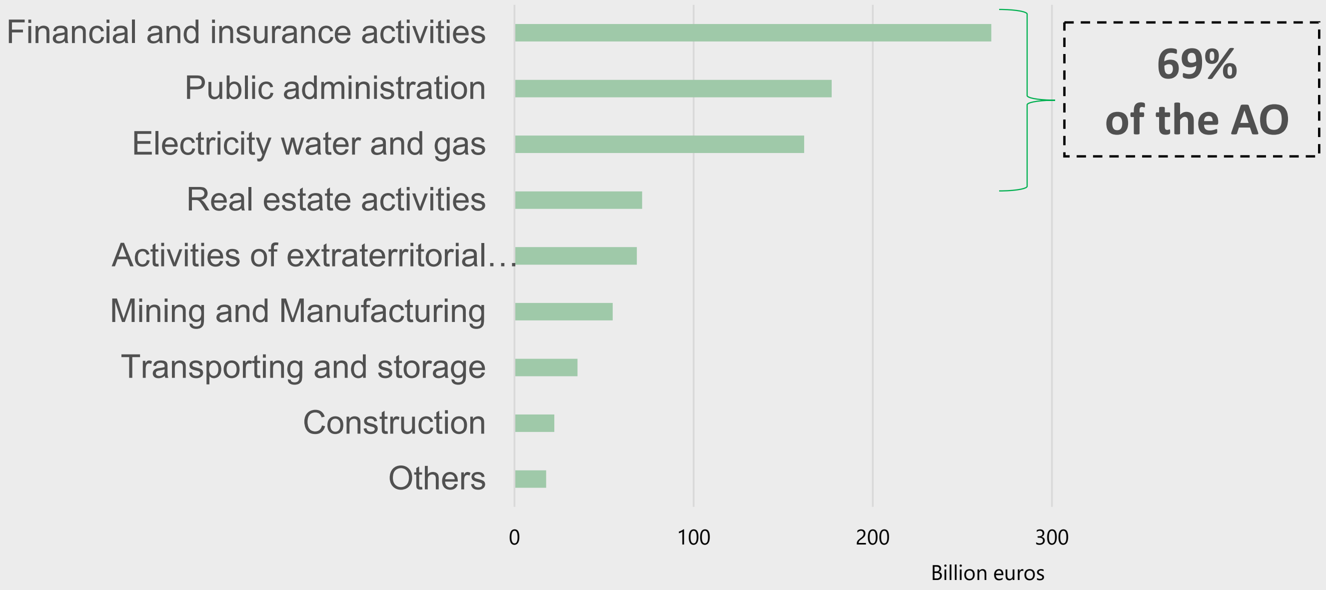
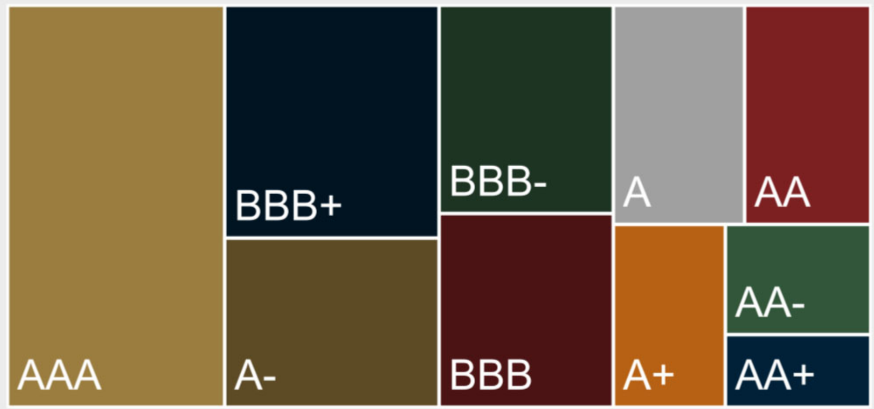
Amount outstanding by NACE

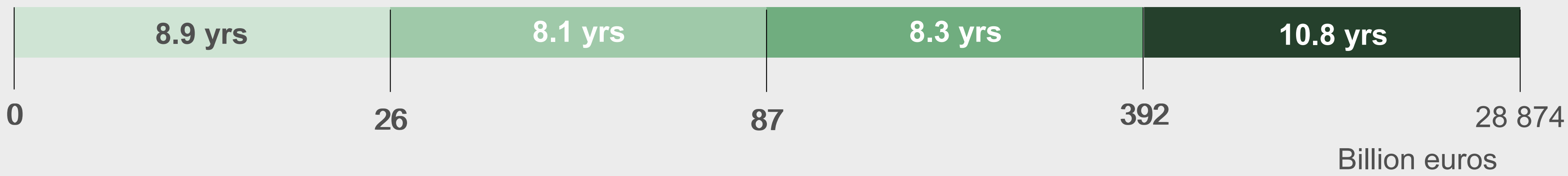


Rating attributed to 62% of AO

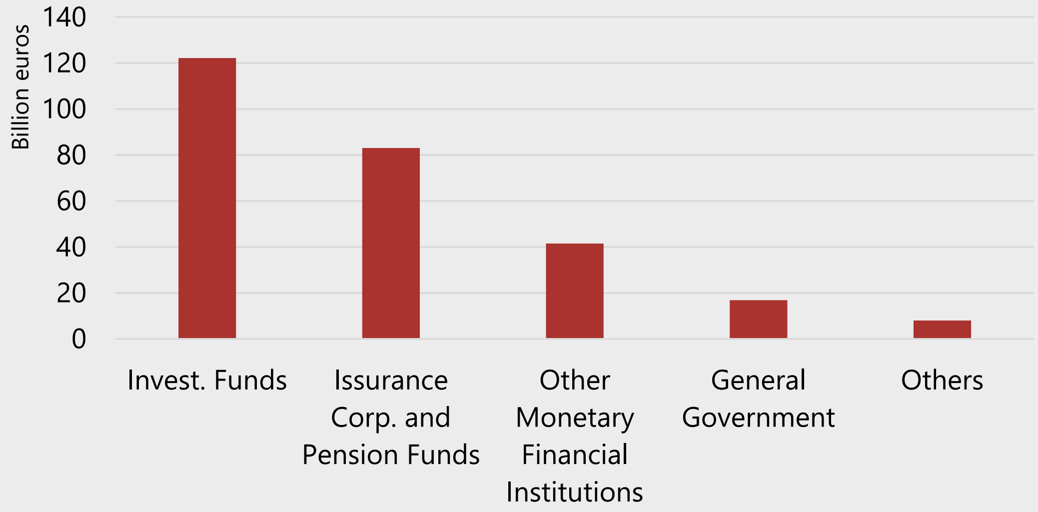
89% investment grade



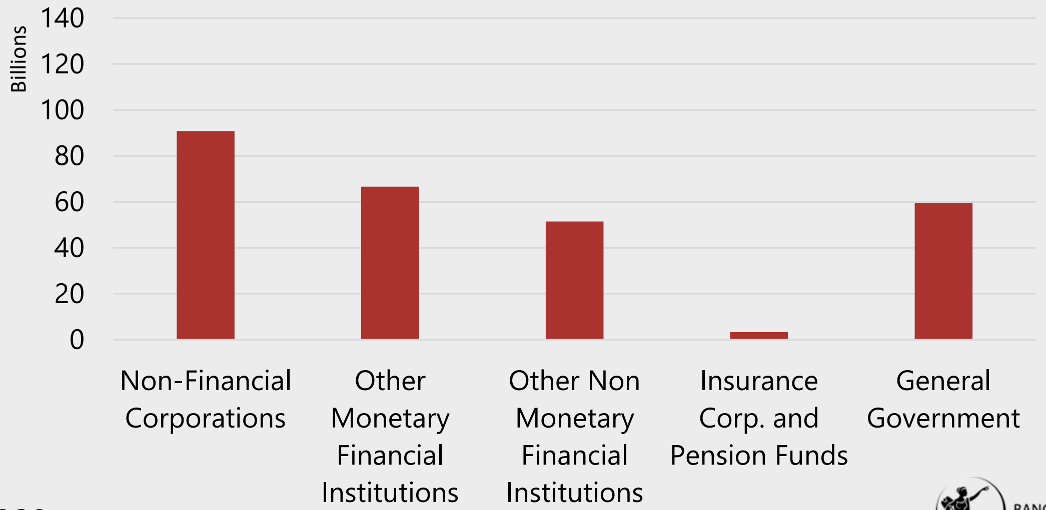
Weighted average maturity by amount outstanding – 10.2 years

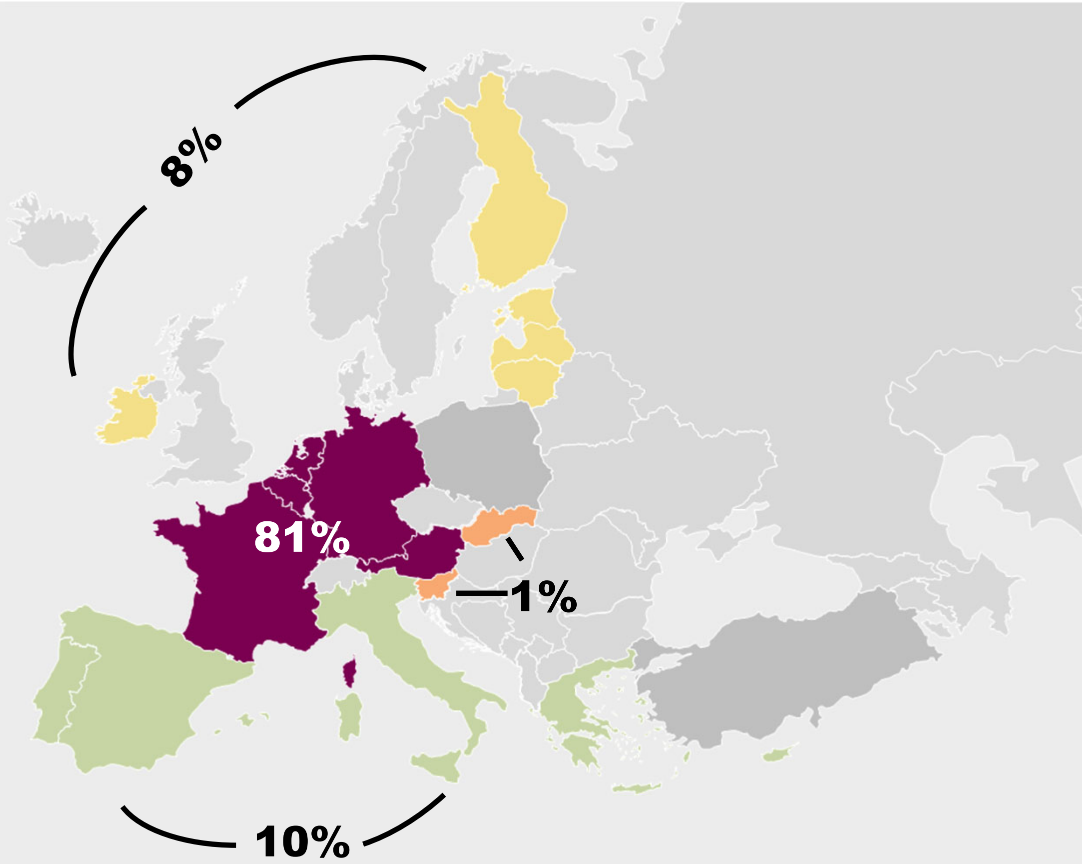


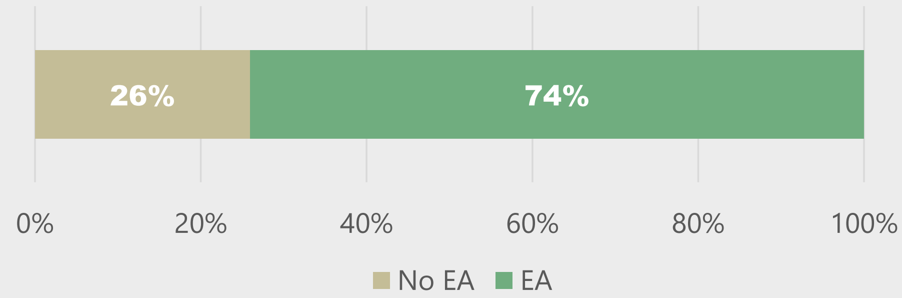
Holder sector



Issuer sector







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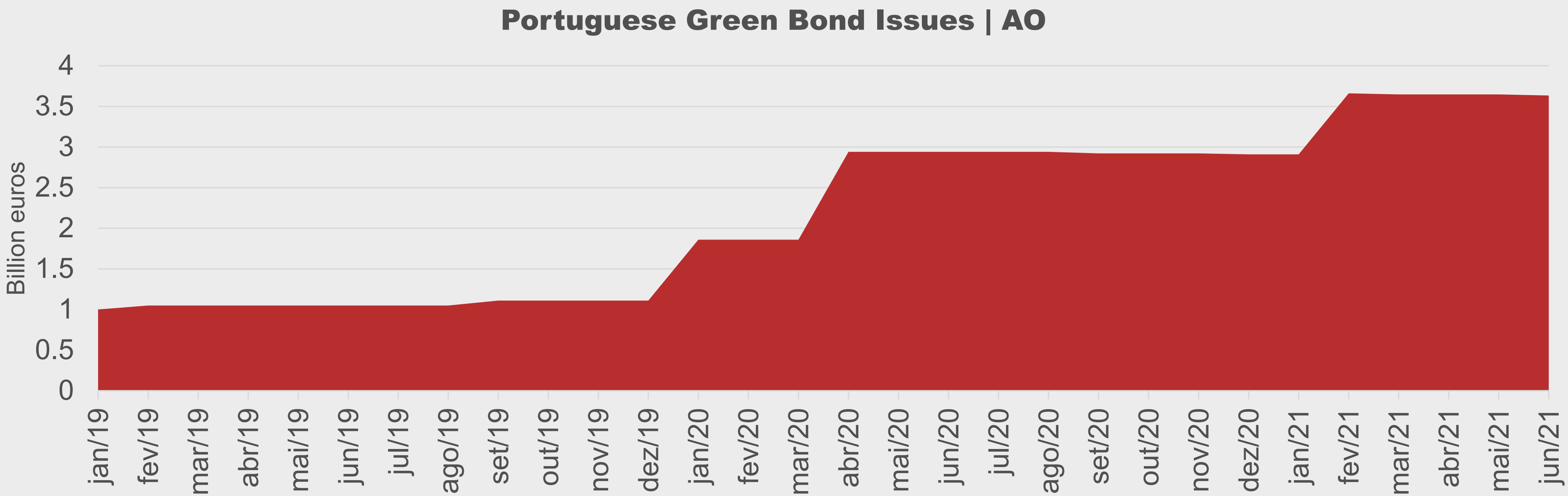
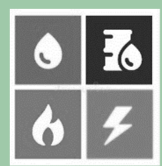


First issue in January 2019

First bond in the hotel sector

47 years



88%

95%

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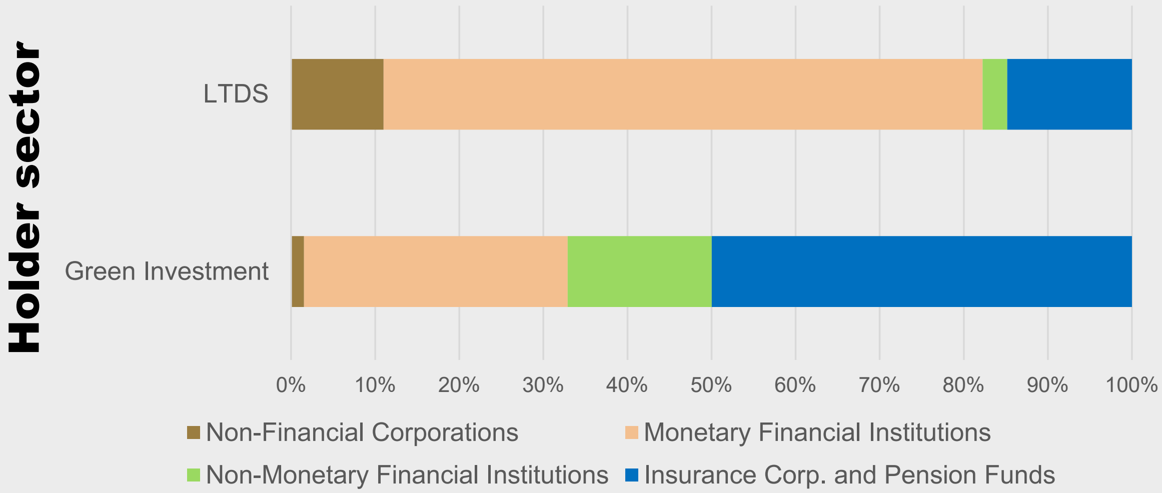

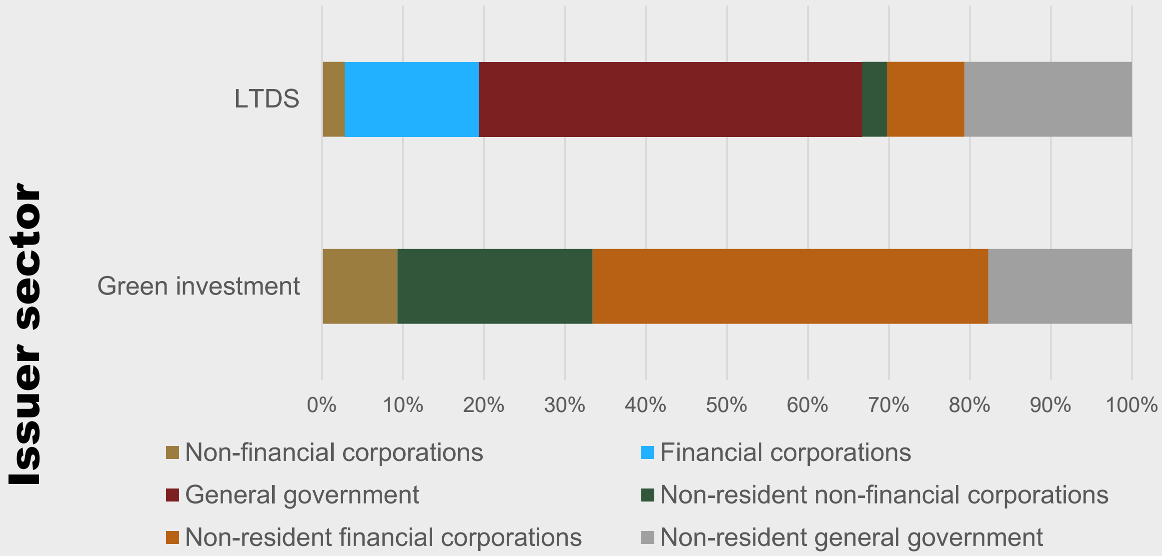

Resident (PT) Holdings of green bonds

Amount outstanding

€246 billion

December 2020

% of LTDS portfolio

0.6%

December 2020

NACE	LTDS	Green investment
Electricity, water and gas	1%	**35%**
Public administration	**62%**	18%
Financial and insurance activities	**22%**	**23%**
Mining and Manufacturing	3%	5%
Real estate activities	0%	3%
Transporting and storage	0%	3%
Others	10%	13%

Dec 2020

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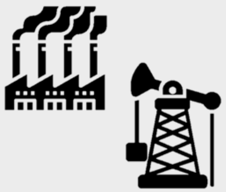
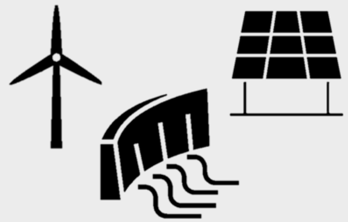
Tracking sustainable investment

We have a clear role to play in supporting the transition towards a more sustainable society





- **Monitor investment needs and conditions**
- **Guarantee financial stability**
- **Inform decision makers**
- **(…)**

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14-15 September 2021, Paris, France, hybrid format

Are ethical and green investment funds more resilient?[1]

Laura Capota, Margherita Giuzio, Sujit Kapadia and Dilyara Salakhova,
European Central Bank

[1] This presentation was prepared for the conference. The views expressed are those of the authors and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

Are ethical and green investment funds more resilient?

*

Laura-Dona Capotă, Margherita Giuzio, Sujit Kapadia, Dilyara Salakhova

May 10, 2022

Abstract

In this paper we look at how investors in investment funds with an environmental, social and corporate governance mandate (ESG) react to past negative performance. Such analysis is motivated by an increasing investors' interest in this market as well as seemingly more limited outflows from ESG funds during the market turmoil in March 2020. In the absence of an ESG-label, we define an investment fund to be ESG- or Environmentally-focused if its name contains relevant words. The econometric analysis shows that ESG/E equity and corporate bond funds exhibit a weaker flow-performance relationship compared to traditional funds in 2016-2020. This finding may reflect the longer-term investment horizon of ESG investors and their expectation of better risk-adjusted performance from ESG funds in the future. Furthermore, we explore how the results vary across institutional and retail investors and how they depend on the liquidity of funds' assets and wider market conditions. A weaker flow-performance relationship allows funds to provide a stable source of financing to the green transition and may reduce risks for financial stability, particularly during turmoil episodes.

JEL classification: G11, G23, Q56, C58

Key words: investment funds; sustainable investments; green finance; climate risk

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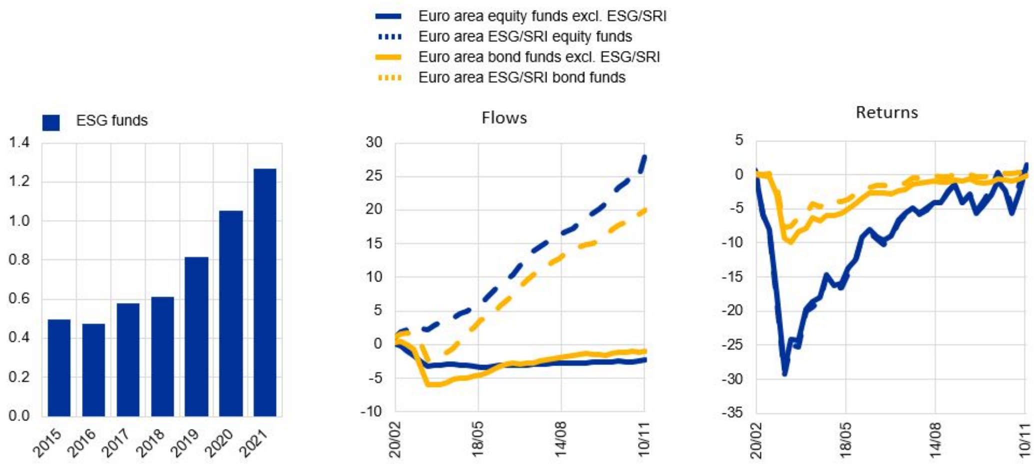
1 Introduction

Assets under management of global ESG funds have soared in the last years, reaching almost €1.3 trillion in June 2021, from €0.5 trillion in 2015 (Figure 1, left panel). This trend is expected to continue thanks to the gradual wealth transfer to millennials and rising investor awareness of climate change and related policies, also driven by the increased frequency and severity of natural catastrophes.

In March 2020, during the worst market turmoil since 2008, ESG equity and bond funds experienced between 3% and 4% lower outflows than their non-ESG peers. Also, ESG equity (ESG bond) funds recovered much faster, showing an overall c.25% (c.20%) growth of assets under management (AuM) in 2020, while non-ESG funds barely returned to the levels of AuM at the beginning of 2020 (Figure 1, middle panel). The higher resilience of ESG fund flows to the market shock may be explained only partially by their higher returns, as ESG and non-ESG funds exhibit similar monthly performance. The return of ESG bond funds in March 2020 was -7% vs. -9% of their non-ESG peers, while ESG and non-ESG equity funds displayed a return of -29% (Figure 1, right panel).

Figure 1: Growth of ESG funds and performance during the Covid-19 turmoil



Source: Bloomberg Finance L.P., EPFR Global and ECB calculations

In this paper, we test the hypothesis that investors in ESG and Environmental-focused funds (E-funds)[1] are less sensitive to negative performance than non-ESG fund investors,

[1]In the remainder of the paper we use Environmental-focused funds, E-funds and green (or green ESG) funds interchangeably.

as suggested by stylised facts of the flows in the market turmoil in March 2020. We estimate this sensitivity on an extended sample of 4 900 funds between 2016 and 2020. Such an extended period of time includes various periods of market development including market distress, comparable to the 2007-2009 financial crisis. To the best of our knowledge, we are the first to test the flow-performance relationship of ESG in a comrehensive manner: first, separately for ESG and Environmental funds; second, for both bond and equity funds; third, for a long time period, 2016-2020; finally, for retail and institutional investors.

The literature provides several theoretical justifications to this hypothesis. First, ESG investors have been shown to be willing to forgo short-term returns and volatility to pursue their ethical and environmental goals. Hartzmark and Sussman (2019) and Dottling and Kim (2020) argue that investors may value sustainability more than performance and therefore they are more committed to funds that share these values in their mandates. In addition, Krueger et al. (2020) show, based on survey results, that institutional investors may account for climate risks in their decisions also because of considerations related to investors' reputation, investors' moral/ethical concerns, and legal/fiduciary duties. Riedl and Smeets (2017) also suggest that ESG investors are more committed to long-term investment horizons and therefore pose lower risks in terms of demand volatility. Finally, investors may expect higher risk-adjusted returns from sustainable investments in the future, as a result of carbon policies. Kuang and Liang (2021) support this hypothesis by showing that investors are more sensitive to poor performance of funds with a higher carbon risk portfolio.

We construct a unique dataset by combining a number of data sources and classifying funds as ESG or non-ESG. We obtain flows, returns and portfolios of euro area funds from Lipper Refinitiv. We identify retail and institutional fund shares using ECB Securities Holdings Statistics by Sector (SHSS), and we assess funds' portfolio liquidity using the ECB Centralised Securities Database (CSDB). We classify ESG- and E-focused funds as those that market themselves as such via the use of certain words in their names, e.g. "Climate", "Environment", "Sustainable", "Green", "ESG" etc. We use this approach as there is no regulatory standard or label to identify ESG/E-funds. Data providers, such as Morningstar and Bloomberg, provide information if a fund is classified as ESG by looking at the names and prospectuses or by analysing their assets. However, these classifications provided by different providers correlate only partially, raising concerns about greenwashing (Boffo and Patalano (2021), Berg et al. (2020)). We argue that looking at fund names is the easiest way in which investors can identify ESG funds. IMF (2021) confirms that labels are an important driver of fund flows. In our analysis, we focus purely on investors' perception of a fund being ESG/Environmental and not if a fund truly pursues ESG/Environmental investment strategy, in contrast for example to Kuang and Liang (2021), who study the flow-performance relationship of funds, according to the exposure of their portfolio to carbon risk.

We run an econometric analysis to estimate the flow-performance relationship of ESG- and E-focused equity and bond funds, compared to their non-ESG peers, adapting the state-of-art specification by Goldstein et al. (2017). In addition, we explore how the results vary across institutional and retail investors and according to the liquidity of funds' assets and wider market conditions. Our results suggest that both retail and institutional investors in ESG and E-funds are less sensitive to past negative performance, even in periods of market distress and funds' illiquidity, suggesting a higher resilience of these funds. The results are robust to alternative specifications and inclusions of controls. In particular, the lower sensitivity of ESG fund flows to negative returns is not explained by the rapid growth of the ESG fund sector. At the same time, we find that the difference between the sensitivities of ESG and non-ESG funds is statistically different only for ESG equity funds.

These results suggest that financial markets can help support the transition to a more sustainable economy by channeling capital from investors to sustainable projects, particularly, if investors turn out less sensitive to low(er) performance. The continuing shift towards ESG and E-funds can help foster the green transition, especially because it is mostly focused in the equity markets, which have been shown to be effective in financing green projects (see De Haas and Popov (2019)). However, for these investments having a positive impact on the transition, greenwashing risk should be addressed. Greenwashing represents a risk both for the green transition and for financial stability and, in the absence of clear standards of ESG/E-labels, investors' confidence in the market may be undermined, leading to significant outflows. A consistent, harmonized and verified ESG/E-label would help reduce such uncertainty and greenwashing risk.

Our paper contributes to several strands of literature. First, it complements existing research on investor behaviour and their sensitivity to past returns. The flow-performance relationship has been extensively studied for conventional funds (see Sirri and Tufano (1998), Chevalier and Ellison (1997), Chen et al. (2010) for equity funds or Goldstein et al. (2017), Chen and Qin (2017), Falato et al. (2021) for bond funds). Several studies have added to this literature by analysing whether ESG or Socially-Responsible Investment (SRI) funds display a different flow-performance relationship than conventional funds (see Renneboog et al. (2011), El Ghoul and Karoui (2017), Benson and Humphrey (2008), Bollen (2007)). They reach the conclusion that investors in socially responsible funds display a weaker flow-performance relationship (at least on the segment of poor returns) compared to their traditional peers. However, Bialkowski and Starks (2016) show that in contrast to the aforementioned studies, SRI investors do not display resilience to poor performance, a finding they explain by the growing number of socially responsible funds in the market.

We add to this literature by using a more recent sample of ESG and conventional funds (covering January 2016 until December 2020), which allows us to study the impact of the Covid-19 crisis. Also, as ESG indicators incorporate three factors (namely the E, S and G factor respectively), we further distinguish funds having an environmental focus. Moreover, we study the presence of a potential different flow-performance relationship between ESG funds and conventional funds for both equity and bond samples. Although equity funds manage most of the assets of funds classified as ESG, bond funds play an increasing role in the sustainable industry. Also, for bond funds, the sensitivity of investors to poor performances (which has been demonstrated by Goldstein et al. (2017), Chen and Qin (2017)) might have financial stability implications. The illiquidity of the assets that bond funds might hold may lead to a stronger first-mover advantage in this type of funds, potentially leading managers to fire-sale their assets in order to reimburse investors wishing to redeem in response to poor performance. Our results suggest that for both equity and bond funds samples, investors in ESG or in environmental-focused funds show resilience to past poor returns, which would allow sustainable funds to provide a more stable source of financing for the green transition. This result is in line with the findings by IMF (2021) that use a quantile regression specification for a sample of sustainable investment funds worldwide.

Second, our paper contributes to the literature studying whether investors react differently to sustainability indicators depending on their type (namely retail or institutional). Our findings suggest that both types of clientele show greater resilience to poor returns in ESG funds. Our results complement the ones of Dottling and Kim (2020) which show that retail investors redeemed during the Covid-19 shock even from the high-sustainability funds, which they interpret as retail investors perceiving sustainability as being a luxury good during periods of economic distress. Our results are in line with those of Hartzmark and Sussman (2019), Pastor and Vorsatz (2020), which also find that retail, as well as institutional investors favour investments in high-sustainability funds. However, we add to this literature by specifically testing whether the different types of clientele display a distinct sensitivity to past returns. Our results are complementary to those of Kuang and Liang (2021), who find that institutional investors are more responsive to the carbon risk exposures of investment funds' portfolios, unlike retail investors. This, indeed, is plausible, as institutional investors have a larger capacity to access and analyse investment funds' asset holdings.

Finally, a rich literature on the characteristics of ESG investors has emerged recently. Different studies may provide explanations for the resilience of ESG investors that our results show. First, Dottling and Kim (2020), Hartzmark and Sussman (2019), Pastor and Vorsatz (2020), Bauer et al. (2018) argue that investors in sustainable funds are committed to their mandates and that they might value sustainability more than performance. Also, according to Krueger et al. (2020), survey results indicate that the protection of the investors' reputations, their moral/ethical considerations, as well as their legal/fiduciary duties incentivize institutional investors to include climate risks considerations into their decisions. Second, the absence of sensitivity to past 1-month performance in ESG funds might be driven by a longer-term investment horizon displayed by investors in this type of funds (see Riedl and Smeets (2017), Dottling and Kim (2020)). Finally, another plausible explanation for our findings consists of the existence of a belief that sustainable investments will generate higher future returns. The literature provides mixed evidence on whether sustainable investments help achieve higher returns or lower the portfolio risk. Hartzmark and Sussman (2019) do not find evidence that high-sustainability funds outperform low-sustainability ones. In the same vein, Gibson Brandon et al. (2019) demonstrate that returns are not higher in responsible investing. On the other hand, Pastor and Vorsatz (2020), Ferriani and Natoli (2020), Ammann et al. (2019) show that low-ESG risk funds outperform high-ESG risk funds. Nofsinger and Varma (2014) demonstrate that market stress plays a role in the performance of SRI investments: they outperform during periods of market distress, but they underperform during normal periods. However, the shift towards more assets invested in sustainable products may cause a potentially higher risk-adjusted investment performance. Gibson Brandon and Kruger (2018) prove that a higher performance is achieved if more investments are made into assets with higher environmental characteristics by institutional investors.

The rest of the paper is structured as follows. Section 2 presents the data and the descriptive statistics of our sample. Section 3 describes the empirical specifications and the main results. Section 4 presents robustness tests. Finally, section 5 concludes and discusses the policy implications of our results.

2 Data

2.1 Sample construction

We obtain our two variables of interest (namely the monthly values of assets under management and the raw monthly return) from Lipper Refinitv database. Our sample consists of bond and equity funds domiciled in the Euro Area (only mutual funds are comprised in our sample). In September 2020, the initial sample covers 57% of the assets managed by Euro Area bond funds and approximately 60% of the assets managed by Euro Area domiciled equity funds respectively. The sample covers the period from January 2016 until December 2020 at a monthly frequency, and the analysis is pursued at a share level. A fund typically issues multiple shares targeted to different investors: a larger minimum initial investment and smaller fees attract institutional investors. As our analysis also aims to differentiate investors' reaction to past returns depending on their type, we choose fund shares as our unit of observation. ESG/E shares are defined as such if their name contains specific words. To identify ESG funds, we look at such words in funds' names as "ESG","SRI","Social","Environment", "Climate", "Sustainable", "Green","Governance","Carbon", "Transition", "Ecology", "Responsible", "Durable", "Ethical". The E funds are a subset of ESG funds, and their names contain a sub-range of words specifically linked to environmental concerns, such as "Environment", "Climate", "Sustainable", "Green", "Carbon", "Ecology"[2]. To define retail and institutional shares, we use ECB internal database on securities holdings statistics at a sector level (SHSS). According to the ECB SDW, the SHSS provide information on holdings of securities by euro area resident sectors at a quarterly frequency. Retail (institutional) shares are identified as those where retail (institutional) investors hold more than 50% of funds' total net assets. Finally, we employ Lipper Refinitiv fund portfolio level data and ECB consolidated securities database (CSDB) to compute the share of a fund's portfolio invested liquid assets. This allows us to create a variable accounting for the fund's liquidity. However, we use the fund's liquidity measure only on the bond fund sample, as stocks in which equity funds invest are liquid instruments. The fund's liquidity measure displays the percentage of the portfolio invested in high quality assets, namely cash and cash equivalents, bonds from euro area governments, supranationals, central banks as well as non-Euro Area government bonds that have an AA/AAA rating.

We follow several steps in order to arrive at the final sample. First, we use the Lipper schemes variable (indicator of the type of assets that asset managers invest in) in order to keep only corporate bond funds from the sample of overall bond funds. Second, for both equity and corporate bond samples, we keep funds with a global, European or emerging markets investment focus. We follow this strategy in order to keep only a homogeneous group of funds for our analysis and therefore eliminate funds investing only in a single country. Third, in order to avoid incubation bias, we eliminate shares with less than 5

[2] In the dictionary of search words, we include all these words in different European languages.

million Euros of assets under management and an age of less than one year. Finally, in order to ensure a certain history of flows for our analysis, we keep only shares displaying at least 12 consecutive non-missing observations of flows. The analysis covers only UCITS funds. Our sample covers 1,803 and 9,437 non-ESG shares, and 206 and 1,274 ESG shares, of active corporate bond and equity funds domiciled in the Euro Area.

2.2 Descriptive statistics

Figure 2 and 3 present the summary statistics for equity and bond funds respectively. Flows are defined in relative terms over the previous month assets. Over the sample period, non-ESG equity funds record an average outflow of -0.11%, while ESG equity funds record an average inflow of 0.66%. The average inflow is also bigger for ESG funds in the bond funds sample (0.84% average monthly inflow for ESG funds compared to 0.34% for conventional counterparts). Excess returns are defined as the share's raw return in excess of the risk-free rate (monthly yield of 10-year AAA-rated government bonds issued by Euro Area countries). The median monthly excess return for non-ESG equity funds is slightly lower than the one reported by ESG or green ESG counterparts (0.98% compared to 1.19% and 1.31% respectively). On the contrary, for bond funds, the median monthly return is positive and slightly higher for non-ESG funds than for the ESG or green ESG counterparts (0.34% compared to 0.29% and 0.23% respectively). The median age of a conventional equity fund is around 6.5 years, while the one of a green ESG fund is approximately 6 years. Bond green ESG funds are only slightly younger than their traditional counterparts. On average, bond non-ESG funds hold more liquid assets in their portfolio compared to the ESG counterparts (on average, 4.45% of their portfolio is invested in high quality assets compared to 2.91% reported by ESG bond funds).

Figure 4 displays the evolution of assets managed by bond and equity funds from January 2016 until December 2020. This evolution is further split between conventional funds and ESG funds. We can observe that over the sample period, the assets managed by the overall system increased (by approximately 50% for bond funds and by 55% for equity funds respectively). The assets managed by ESG funds account for an increasing part of the total assets managed by mutual funds. ESG bond funds managed around 5%

Figure 2: Summary statistics (equity funds)

		Mean	Std Dev	P5	P50	P95	N
Non-ESG	Flows(%)	-0.11	3.72	-8.37	-0.04	9.08	380 909
	Return(%)	0.69	4.33	-6.74	0.98	6.77	380 909
	Ln(TNA)	17.67	1.38	15.73	17.51	20.17	380 909
	Ln(age)	1.86	0.83	0.4	1.89	3.08	380 909
All ESG	Flows(%)	0.66	3.89	-7.27	0	9.46	42 856
	Return(%)	0.86	4.37	-6.92	1.19	7.15	42 856
	Ln(TNA)	17.71	1.33	15.74	17.61	20.02	42 856
	Ln(age)	1.71	0.89	0.25	1.73	3.04	42 856
Green ESG	Flows(%)	0.88	4.05	-6.9	0.02	9.46	21 647
	Return(%)	0.98	4.38	-6.91	1.31	7.62	21 647
	Ln(TNA)	17.57	1.31	15.69	17.43	19.93	21 647
	Ln(age)	1.72	0.88	0.25	1.79	3.02	21 647

Figure 3: Summary statistics (bond funds)

		Mean	Std Dev	P5	P50	P95	N
Non-ESG	Flows(%)	0.34	4.79	-9.69	0	12.56	54 522
	Return(%)	0.3	2.18	-2.37	0.34	3.19	54 522
	Ln(TNA)	17.69	1.41	15.72	17.56	20.23	54 522
	Ln(age)	1.74	0.69	0.46	1.79	2.85	54 522
	HQLA	4.45	8.09	-0.68	3.15	14.59	54 522
All ESG	Flows(%)	0.84	5.08	-9.69	0	12.56	4 442
	Return(%)	0.28	1.85	-1.73	0.29	2.74	4 442
	Ln(TNA)	17.67	1.16	15.96	17.52	19.87	4 442
	Ln(age)	1.49	0.79	0.24	1.49	2.75	4 442
	HQLA	2.91	3.98	-1.59	2.49	9.03	4 442
Green ESG	Flows(%)	0.89	4.9	-8.46	0.01	12.56	2 117
	Return(%)	0.25	1.7	-1.69	0.23	2.49	2 117
	Ln(TNA)	17.93	1.3	15.95	17.8	20.05	2 117
	Ln(age)	1.67	0.89	0.25	1.66	3.4	2 117
	HQLA	3.38	3.98	-0.62	2.62	9.62	2 117

of the total assets in 2016 and around 10.5% in December 2020. The same evolution is reported by equity ESG funds: beginning 2016 they managed 6.4% of the total assets compared to 13.8% in December 2020.

Figure 5 shows the effect of the Covid-19 crisis on the assets managed by bond and equity funds as well as on their returns. We generally observe strong outflows in March 2020, although less massive in ESG funds compared to non-ESG counterparts (traditional bond funds suffered outflows of 13% in March 2020 compared to 9% recorded by ESG peers). The difference between the two samples gets slightly smaller in the equity funds sample (22% of outflows recorded by conventional equity funds compared to approximately 19.6% reported by ESG peers). ESG funds recovered faster than their non-ESG counterparts in the months following the crisis. In 2020, ESG bond funds increased their assets under management by approximately 22.6%, while non-ESG peers saw a slight increase in the assets under management (1.6%). In the equity sample, ESG funds managed 22% more assets in December 2020 compared to January 2020. On the contrary, non-ESG funds did not completely recover during the same time period: end 2020 they managed 1% less assets than in January 2020.

Figure 4: Evolution of TNA and share of ESG funds by type

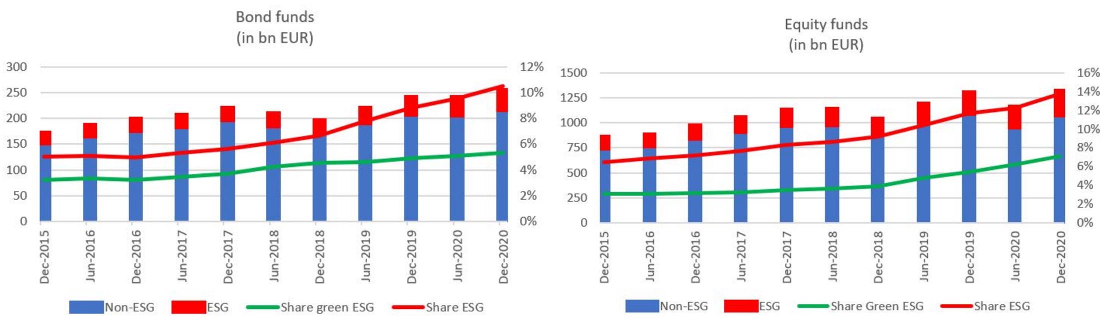


Figure 5: Cumulative flows and returns in 2020 by type

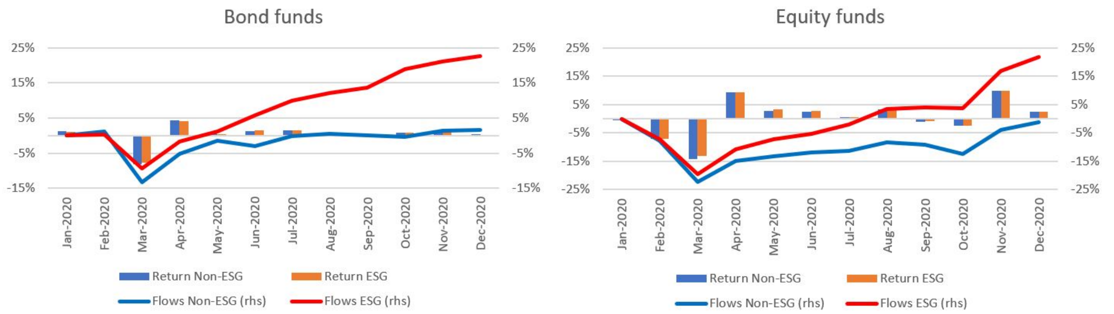
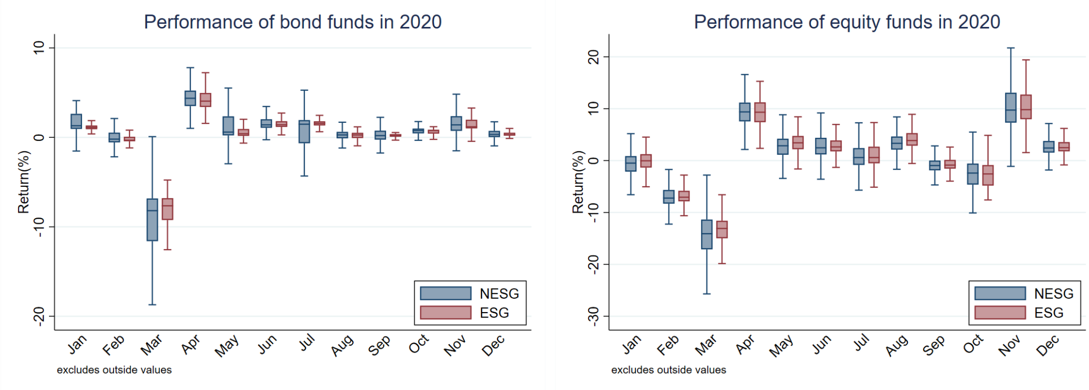


Figure 5 also displays the median monthly excess return by fund type. We can observe that the ESG and non-ESG counterparts were displaying a similar return. The interquartile range of performance is shown in figure 6. On average, ESG funds (both bond and equity) show higher returns than the non-ESG peers, but the difference between the two samples is small. Bond ESG funds show less volatile returns compared to their non-ESG counterparts (however, this may be due to a smaller sample of ESG bond funds).

Figure 6: Monthly interquartile range of excess returns in 2020



3 Results

3.1 Baseline regression

We employ a model as in Goldstein et al. (2017). The model allows us to test the existence of a potential non-linearity in the flow-performance relationship. Indeed, investors may react differently to positive and negative returns. A difference in investors' response between positive and negative returns might have financial stability consequences especially during crisis periods. If it is demonstrated that investors withdraw in response to past negative returns, their behaviour may have a detrimental effect if managers need to fire-sell assets in order to respond to outflows.

In this section we report the results on the sensitivity of flows into E-focused, ESG and non-ESG funds following past performance. We expect investors to be less sensitive to past performance of ESG/E-focused funds for several reasons: first, ESG/E-focused funds may attract more ethical and socially responsible investors as suggested by Dottling and Kim (2020), Hartzmark and Sussman (2019). Second, investors may perceive these funds as less exposed to ESG and climate-related risks or managing these risks better due to better awareness and thus expect better returns in the future. The last argument is in line with Pastor and Vorsatz (2020) who find that high-sustainability funds performed better during the Covid turmoil. We employ a baseline regression of the following form to test the flow-performance relationship for ESG and non-ESG funds:

$$
\begin{aligned}
Flows_{i,t} \;=\;& \alpha + \beta_1 RetPosESG_{i,t-1} + \beta_2 RetPosNESG_{i,t-1} + \beta_3 RetNegESG_{i,t-1} + \\
+\;& \beta_4 RetNegNESG_{i,t-1} + \beta_5 I(LaggedReturn < 0)_{i,t-1} + \\
+\;& \beta_6 I(LaggedReturn < 0)_{i,t-1} \times ESG + \beta_7 ESG + \\
+\;& \gamma Controls_{i,t} + \delta_i + \lambda_{ESG,t} + \epsilon_{i,t}, \qquad (1)
\end{aligned}
$$

where the dependent variable represents the share's relative net flows between month t and t-1. The four main independent variables account for non-linearities at the share's past excess return levels[34]: $RetPosESG$ is the past positive return of ESG share and 0 otherwise. $RetPosNESG$ is the past positive return of non-ESG share and 0 otherwise. $RetNegESG$ is the past negative return of ESG share and 0 otherwise. $RetNegNESG$ is the past negative return of non-ESG share and 0 otherwise. ESG is an indicator variable equal to one if the fund is marketing itself as taking into account ESG criteria in its investment decisions and zero otherwise. $I(LaggedReturn < 0)$ is an indicator variable equal to one if the share displays a negative past excess performance and zero otherwise. The baseline coefficients of interest are based on a triple-interaction term between the share's past return, the $I(LaggedReturn < 0)$ dummy and the ESG dummy. The reported results and t-statistics are based on selected sums of coefficients. Annex 1 (table 7) provides an explanation of how the four coefficients of interest are constructed. $Controls_{i,t}$ comprise a series of lagged control variables, such as the natural logarithm of age, size, past flows of the share, as well as the standard deviation of the past 12 monthly excess returns, which represents a proxy for the riskiness of the fund's portfolio. In order to account for unobserved time-fixed share-level effects, we introduce fixed effects at the share level. Moreover, month fixed effects need to be introduced to control for the growing assets under management of investment funds. However, as figure 4 shows, the positive

[3]Instead of using the past level of raw returns, one could also rank funds between themselves and construct a ranking variable, as in Sirri and Tufano (1998). However, we chose not to pursue this strategy in order to test the non-linearity of the relationship. While it can be true that investors compare a fund's performance to its peers, a ranking strategy would not be adapted to measure an investor's reaction to a common shock that affect funds similarly (as it was the case during the Covid turmoil).

[4]The excess performance is calculated as the difference between the raw return and the monthly yield of 10-year AAA-rated government bonds issued by Euro Area countries.

trend in assets is more pronounced for funds labeled as ESG compared to traditional peers. Therefore, in order to take into account this different trend we introduce crossed ESG and month fixed effects. Furthermore, we cluster errors by share class to allow for intertemporal dependence of regression residuals across shares.

Table 1: Flow-performance relation: ESG versus non-ESG peers
Specification using name classification and excess returns

	Equity funds		Bond funds	
	(1)	(2)	(3)	(4)
	All ESG	Green ESG	All ESG	Green ESG
	Flows	Flows	Flows	Flows
Ret Pos ESG	0.059***	0.097***	-0.172	-0.022
	(3.42)	(3.73)	(-1.11)	(-0.10)
Ret Pos NESG	0.051***	0.052***	0.021	0.021
	(10.12)	(10.16)	(0.75)	(0.73)
Ret Neg ESG	0.015	0.056	0.127	-0.123
	(0.56)	(1.48)	(0.79)	(-0.80)
Ret Neg NESG	0.069***	0.068***	0.077***	0.077***
	(10.69)	(10.66)	(2.83)	(2.84)
I(Lagged Return<0)	-0.001***	-0.001***	-0.001**	-0.001**
	(-4.60)	(-4.59)	(-2.05)	(-2.07)
I(ESG) x I(Lagged Return<0)	0.000	0.001	0.001	0.005
	(0.29)	(1.24)	(0.50)	(1.07)
Ln(age)	-0.009***	-0.009***	-0.007***	-0.007***
	(-12.50)	(-12.17)	(-3.42)	(-3.15)
Ln(size)	-0.009***	-0.010***	-0.014***	-0.013***
	(-29.84)	(-29.21)	(-14.61)	(-13.84)
Lagged Flows	0.170***	0.171***	0.153***	0.152***
	(50.12)	(49.13)	(21.89)	(20.99)
Std Dev Ret	-0.002***	-0.002***	-0.003***	-0.003***
	(-14.79)	(-14.72)	(-6.17)	(-6.12)
Constant	0.193***	0.194***	0.262***	0.257***
	(33.94)	(33.18)	(15.74)	(14.85)
Share FE	Yes	Yes	Yes	Yes
Month x ESG FE	Yes	Yes	Yes	Yes
Cluster	Share	Share	Share	Share
H0: Ret Neg ESG = Ret Neg NESG	0.046**	0.736	0.761	0.198
Adj. R^2	0.2	0.198	0.154	0.152
Observations	324 022	307 903	64 467	61 417
Sample	Name classification, Excess returns			

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

This table shows the flow-performance relationship for ESG and for non-ESG funds. We regress share's flows on share's past excess returns. An asymmetry in investor response is tested with respect to past negative and positive performance. Moreover, we also test an asymmetry in investor response to past returns with respect to a share being considered an ESG or a conventional fund share. The following control variables are introduced: Ln(age) indicates the past natural logarithm of share's age (expressed in years), Ln(size) indicates the past natural logarithm of share's size, share's lagged flows and the standard deviation of the past 12 monthly returns. The sample covers January 2016 - December 2020 and is at a monthly frequency. ESG/E-funds are defined according to the use of certain words in funds' names. The first 2 columns show the results for equity funds (the Green ESG are considered instead of All ESG in the second column), while the 2 last columns show the results for bond funds. Share fixed effects and crossed month and ESG fixed effects are introduced. Observations are clustered at a share level.

Columns 1 and 2 in Table 1 present the results for the baseline specification of the flow-performance relationship for ESG and Environmentally-focused equity funds respectively. All the control variables exhibit significant and expected effects, in particular, age, size and lower volatility of returns reduce the net flows, while flows also show certain persistence. Our main result is that investors in ESG and E-funds do not show statistically significant sensitivity to past negative performance, while investors in non-ESG equity funds respond to a 1 pp decrease in the negative returns by increasing their outflows of 0.069 pp. The difference in behaviour between investors in ESG and non-ESG equity funds is also statistically significant, at 5% . As pointed out by Goldstein et al. (2017), the positive flow-performance relationship in corporate bond funds may have negative implications for markets and financial stability due to a first-mover advantage and low liquidity of funds' assets. Columns 3 and 4 in Table 1 present the results for the same specification for ESG and green corporate bond funds respectively. We confirm the finding of Goldstein et al. (2017), namely that flows into corporate bond funds are sensitive to past negative performance with an 1 pp decrease in the negative returns leading to 0.077-0.082 pp higher outflows. In contrast, the sensitivity of flows into ESG and green bond funds appear to be negative but not statistically significant. However, the difference between the coefficients of ESG/green and non-ESG negative returns is not statistically significant. One reason behind this result can be a much smaller sample for ESG and environmental bond funds.

As previously mentioned, we define ESG/E- focused funds by using the name of the funds. However, it is important to test the robustness of our baseline result when using other classifications, such as the Morningstar globes (which would allow us to identify ESG funds as in Hartzmark and Sussman (2019) for example)

We first test the robustness of our results with respect to Morningstar globes in table 2. Columns 1 and 3 show the baseline results, where ESG funds are classified as such based on the name of the fund, while columns 2 and 4 show the results when using the Morningstar globes classification. However, as the Morningstar globes began to be consistently reported starting with 2019, table 2 presents the results of our baseline regression ran on a sample covering January 2019 until December 2020 (this also explains the difference in

Table 2: Flow-performance relation: ESG versus Non-ESG peers
Specification using name classification or Morningstar globes

	Equity funds		Bond funds	
	(1)	(2)	(3)	(4)
	Name	Globes	Name	Globes
	All ESG		All ESG	
	Flows	Flows	Flows	Flows
Ret Pos ESG	0.037*	-0.000	-0.229	0.157
	(1.91)	(-0.01)	(-1.36)	(0.89)
Ret Pos NESG	0.033***	0.039***	0.006	0.005
	(5.69)	(4.24)	(0.21)	(0.11)
Ret Neg ESG	-0.002	0.072***	0.045	-0.290
	(-0.07)	(4.07)	(0.27)	(-1.52)
Ret Neg NESG	0.057***	0.040***	0.094***	0.134***
	(7.63)	(3.37)	(2.89)	(3.43)
I(Lagged Return<0)	-0.001**	-0.001	-0.000	0.000
	(-2.39)	(-1.07)	(-0.29)	(0.15)
I(ESG) x I(Lagged Return<0)	-0.000	-0.000	-0.001	0.001
	(-0.40)	(-0.40)	(-0.25)	(0.18)
Ln(age)	-0.003**	-0.001	-0.001	0.003
	(-2.44)	(-0.55)	(-0.13)	(0.51)
Ln(size)	-0.015***	-0.015***	-0.024***	-0.024***
	(-24.00)	(-17.81)	(-16.67)	(-13.46)
Lagged Flows	0.115***	0.111***	0.117***	0.111***
	(29.23)	(21.09)	(14.07)	(10.53)
Std Dev Ret	-0.003***	-0.002***	-0.003***	-0.002***
	(-12.74)	(-7.87)	(-4.79)	(-3.14)
Constant	0.281***	0.275***	0.432***	0.436***
	(25.40)	(18.48)	(16.51)	(12.91)
Share FE	Yes	Yes	Yes	Yes
Month x ESG FE	Yes	Yes	Yes	Yes
Cluster	Share	Share	Share	Share
H0: Ret Neg ESG = Ret Neg NESG	0.063*	0.125	0.779	0.03**
Adj. R^2	0.23	0.22	0.18	0.17
Observations	176 292	97 695	35 015	21 939
Sample	Name or Morningstar globes classification, Excess returns			

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

This table shows the flow-performance relationship for ESG and for non-ESG funds. We regress share's flows on share's past excess returns. An asymmetry in investor response is tested with respect to past negative and positive performance. Moreover, we also test an asymmetry in investor response to past returns with respect to a share being considered an ESG or a conventional fund share. The following control variables are introduced: Ln(age) indicates the past natural logarithm of share's age (expressed in years), Ln(size) indicates the past natural logarithm of share's size, share's lagged flows and the standard deviation of the past 12 monthly returns. The sample covers January 2019 - December 2020 and is at a monthly frequency. In columns 1 and 3 ESG funds are defined according to the use of certain words in funds' names. In columns 2 and 4 ESG funds are defined as those having 4 or 5 globes assigned by Morningstar. The first 2 columns show the results for equity funds, while the 2 last columns show the results for bond funds. Share fixed effects and crossed month and ESG fixed effects are introduced. Observations are clustered at a share level.

the number of observations in columns 1 and 3 in table 2 compared to columns 1 and 3 in table 1). In columns 2 and 4, ESG funds are defined as those having 4 or 5 globes according to Morningstar. Non-ESG funds are defined as having 1, 2 or 3 globes accoring to Morningstar[5]. However, it may happen that a fund switches from being considered as ESG to non-ESG (for example if it switches from 3 to 4 globes). We choose to drop from the analysis these funds as we prefer analysing funds that consistently report being ESG or non-ESG[6]. This choice explains the different number of obseervations between columns 1 and 2 (3 and 4 respectively).

Columns 1 and 2 report the results for the equity sample. We observe that the effect of past positive returns (either in the case of ESG funds or non-ESG) is robust between the two classifications. However, higher past negative returns seem to lead to stronger outflows in the ESG funds classified as such by Morningstar globes. This finding is in contrast with the insignificant coefficient found for the ESG funds defined according to the name. This result may indicate that in equity funds, investors are naive and blindly trust the name of the fund[7]. However, in the bond fund space, we observe that results are robust when considering the two different classifications of funds. The analysis of the distribution of funds based on each classification also helps explaining the result. In the bond fund space, around 60% of the ESG funds classified accoring to the name are also classified as being ESG based on the Morningstar globes. However, this ratio falls to almost 30% in the equity fund space, which suggests a low overlap between the two classifications.

As we study a sample of funds domiciled in the Euro Area, one may argue that our results could also be driven by stronger environmental concerns in Europe compared to the US. In order to examine this question, the first two columns of the tables present in Annex 2 separate equity fund shares in table 10 (bond funds respectively in table 11) between Euro-Area based and non Euro-Area based shares. We define a share as

[5]Missing values of the globes are not taken into account, meaning that a fund will always be considered ESG if it always had 4 or 5 globes irrespective of the number of missing observations.

[6]The effect of losing or gaining globes on flows would be an interesting analysis in itself. However, this analysis is beyond the scope of this work.

[7]The sophistication of the underlying investors does not seem to play a role in explaining the results, as in unreported results we observe that both retail and institutional investors redeem more following a decrease of the negative performance in ESG funds defined by using the Morningstar globes

being based in the Euro-Area if the SHSS (which reports the shares detained by Euro-Area investors) explains more than 75% of the share's assets at least once during our sample history. Non Euro-Area shares are defined as such if the SHSS always explains less than 75% of the share's assets. If the findings were driven by our sample choice, we could expect that the coefficient $RetNegESG$ of Euro-Area based shares is insignificant, while the same coefficient would be statistically significant in the Non Euro-Area shares. We observe that this is never the case, either in the equity sample (table 10) or in the bond sample (table 11). In order to test the robustness of this result, we also separate shares according to their currency of denomination. Here we suppose that EUR/GBP-denominated shares have mostly European investors, while USD-denominated shares are mostly invested by Non-European investors. We observe that our previous results are robust to this specification as the coefficient of our variable of interest $RetNegESG$ does not display a statistical significance (however, in table 11 one column has a positive and significant coefficient for the $RetNegESG$ in the USD sample). Based on these results, we can therefore infer that our results are not driven by stronger environmental concerns displayed by European investors.

3.2 Difference in behavior between retail and institutional investors

Using the same baseline specification, we test if retail and institutional investors respond differently to past negative performance. A share is considered as being a retail (institutional) share if retails (institutionals) detain more than 50% of the assets [8]. Kuang and Liang (2021) find that institutional investors are sensitive to higher carbon risk in funds' portfolios while retail investors are not. The main rationale behind that finding is possibly a larger capacity of institutional investors to access and analyse investment funds' portfolios. In our case, we do not necessarily expect retail and institutional investors to behave differently as we focus on investors' perception of a fund being ESG/E-focused by looking at its name that is equally available for both types of investors. Using a sustainability fund classification based on the Morningstar globes, Hartzmark and Sussman (2019), Pastor and Vorsatz (2020) find that both retail and institutional investors prefer to invest into high-sustainability funds.

Tables 3 and 4 report the results for equity and bond funds respectively. For the equity funds, our results suggest that retail and institutional investors behave similarly, i.e. they are sensitive to past negative performance in non-ESG funds but not in ESG/E-funds. However, the difference in the coefficients displays a low significance or is not anymore significant. For bond funds, the main results are confirmed, however, the split of the sample into retail and institutional investors leads to loss in power with coefficients remaining significant but only at 10% for the retail sample. Also in the retail space, investors reward past good performers with inflows, as shown by the positive and significant coefficient of $RetPosNESG$.

[8] A 75% threshold has also been tested and results remain globally unchanged.

Table 3: The effect of share's clientele on the flow-performance relation of equity funds : ESG versus non-ESG peers
Specification using name classification and excess returns

	Equity funds			
	(1)	(2)	(3)	(4)
	Instit	Retail	Instit	Retail
	All ESG		Green ESG	
	Flows	Flows	Flows	Flows
Ret Pos ESG	0.075**	0.161***	0.101**	0.169***
	(2.35)	(3.74)	(2.05)	(3.33)
Ret Pos NESG	0.058***	0.067***	0.057***	0.067***
	(6.12)	(6.83)	(6.10)	(6.91)
Ret Neg ESG	0.017	0.015	0.076	0.074
	(0.33)	(0.28)	(1.05)	(1.11)
Ret Neg NESG	0.102***	0.067***	0.102***	0.066***
	(8.32)	(5.93)	(8.33)	(5.88)
I(Lagged Return<0)	-0.001**	-0.001***	-0.001**	-0.001***
	(-2.05)	(-2.85)	(-2.05)	(-2.83)
I(ESG) x I(Lagged Return<0)	-0.000	0.002	0.001	0.003*
	(-0.18)	(1.03)	(0.30)	(1.68)
Ln(age)	-0.008***	-0.016***	-0.008***	-0.016***
	(-6.80)	(-9.61)	(-6.52)	(-9.21)
Ln(size)	-0.010***	-0.009***	-0.010***	-0.009***
	(-19.11)	(-10.17)	(-18.72)	(-10.28)
Lagged Flows	0.143***	0.275***	0.144***	0.275***
	(28.77)	(27.77)	(28.04)	(27.30)
Std Dev Ret	-0.003***	-0.003***	-0.002***	-0.003***
	(-8.55)	(-10.06)	(-8.37)	(-10.14)
Constant	0.202***	0.195***	0.202***	0.197***
	(21.81)	(12.66)	(21.30)	(12.62)
Share FE	Yes	Yes	Yes	Yes
Month x ESG FE	Yes	Yes	Yes	Yes
Cluster	Share	Share	Share	Share
H0: Ret Neg ESG = Ret Neg NESG	0.092*	0.354	0.724	0.909
Adj. R^2	0.153	0.344	0.154	0.341
Observations	114 363	59 416	108 642	58 012
Sample	Name classification, Excess returns			

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

This table shows the flow-performance relationship for ESG and for non-ESG funds split by clientele. A share is considered as institutional if institutional investors detain more than 50% of its assets. A share is considered as retail if retail investors detain more than 50% of its assets. We regress share's flows on share's past excess returns. An asymmetry in investor response is tested with respect to past negative and positive performance. Moreover, we also test an asymmetry in investor response to past returns with respect to a share being considered an ESG or a conventional fund share. The following control variables are introduced: Ln(age) indicates the past natural logarithm of share's age (expressed in years), Ln(size) indicates the past natural logarithm of share's size, share's lagged flows and the standard deviation of the past 12 monthly returns. The sample covers January 2016 - December 2020 and is at a monthly frequency. ESG/E-funds are defined according to the use of certain words in funds' names. The first 2 columns show the results for all ESG funds (the Green ESG are considered instead of All ESG in the last 2 columns). Share fixed effects and crossed month and ESG fixed effects are introduced. Observations are clustered at a share level.

Table 4: The effect of share's clientele on the flow-performance relation of bond funds : ESG versus non-ESG peers
Specification using name classification and excess returns

	Bond funds			
	(1)	(2)	(3)	(4)
	Instit	Retail	Instit	Retail
	All ESG		Green ESG	
	Flows	Flows	Flows	Flows
Ret Pos ESG	-0.130	0.431	0.005	1.110***
	(-0.55)	(1.07)	(0.01)	(4.53)
Ret Pos NESG	0.024	0.191**	0.021	0.189**
	(0.42)	(2.52)	(0.36)	(2.50)
Ret Neg ESG	0.034	0.298	-0.415	0.671
	(0.12)	(0.87)	(-0.78)	(1.45)
Ret Neg NESG	0.124***	0.110*	0.126***	0.111*
	(2.60)	(1.82)	(2.64)	(1.84)
I(Lagged Return<0)	-0.002*	-0.001	-0.002*	-0.001
	(-1.78)	(-0.93)	(-1.82)	(-0.95)
I(ESG) x I(Lagged Return<0)	0.003	0.002	0.007	0.013*
	(0.62)	(0.25)	(0.77)	(1.91)
Ln(age)	-0.008**	-0.006	-0.008**	-0.004
	(-2.52)	(-1.15)	(-2.35)	(-0.72)
Ln(size)	-0.012***	-0.014***	-0.011***	-0.014***
	(-8.28)	(-5.22)	(-7.76)	(-4.99)
Lagged Flows	0.123***	0.252***	0.120***	0.250***
	(12.75)	(12.77)	(11.99)	(12.35)
Std Dev Ret	-0.002***	-0.008***	-0.002**	-0.008***
	(-2.67)	(-5.65)	(-2.53)	(-5.65)
Constant	0.235***	0.268***	0.228***	0.263***
	(9.10)	(5.44)	(8.49)	(5.14)
Share FE	Yes	Yes	Yes	Yes
Month x ESG FE	Yes	Yes	Yes	Yes
Cluster	Share	Share	Share	Share
H0: Ret Neg ESG = Ret Neg NESG	0.761	0.586	0.311	0.229
Adj. R^2	0.128	0.294	0.126	0.292
Observations	25 737	9 623	24 172	9 342
Sample	Name classification, Excess returns			

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

This table shows the flow-performance relationship for ESG and for non-ESG funds split by clientele. A share is considered as institutional if institutional investors detain more than 50% of its assets. A share is considered as retail if retail investors detain more than 50% of its assets. We regress share's flows on share's past excess returns. An asymmetry in investor response is tested with respect to past negative and positive performance. Moreover, we also test an asymmetry in investor response to past returns with respect to a share being considered an ESG or a conventional fund share. The following control variables are introduced: Ln(age) indicates the past natural logarithm of share's age (expressed in years), Ln(size) indicates the past natural logarithm of share's size, share's lagged flows and the standard deviation of the past 12 monthly returns. The sample covers January 2016 - December 2020 and is at a monthly frequency. ESG/E-funds are defined according to the use of certain words in funds' names. The first 2 columns show the results for all ESG funds (the Green ESG are considered instead of All ESG in the last 2 columns). Share fixed effects and crossed month and ESG fixed effects are introduced. Observations are clustered at a share level.

3.3 The effect of crisis periods

In this section, we analyse if our results are confirmed during periods of stress: more specifically, if ESG/green investors remain in the poorly performing funds during periods of high market uncertainty. Pastor and Vorsatz (2020) demonstrate that the outflows experienced by funds during the COVID-19 turmoil can be explained by the sustainability globes granted by Morningstar. They have proven that low-sustainability funds experienced the highest outflows, while their high-sustainability peers suffered significantly less outflows. In the conventional fund sample, Goldstein et al. (2017) demonstrate that investors redeem more following negative performances under stressed market conditions. This behaviour may intensify the first-mover advantages as selling assets without accepting a discount might prove to be difficult during crisis periods. From a financial stability point of view, it is therefore interesting to analyse whether ESG/green funds are resilient during turmoils. In order to test this hypothesis, we define a stress period when the VIX level is above 90^{th} percentile of its distribution. In our sample, we have several such periods with March 2020 being the most significant market turmoil seen since the Global financial crisis of 2008. The regression to be tested will therefore take the following form:

$$\begin{aligned}
Flows_{i,t} &= \alpha + \beta_1 RetPosESG_{i,t-1}Crisis + \beta_2 RetPosESG_{i,t-1}Non-Crisis + \\
&+ \beta_3 RetPosNESG_{i,t-1}Crisis + \beta_4 RetPosNESG_{i,t-1}Non-Crisis + \\
&+ \beta_5 RetNegESG_{i,t-1}Crisis + \beta_6 RetNegESG_{i,t-1}Non-Crisis + \\
&+ \beta_7 RetNegNESG_{i,t-1}Crisis + \beta_8 RetNegNESG_{i,t-1}Non-Crisis + \\
&+ \beta_9 I(LaggedReturn < 0)_{i,t-1} + \beta_{10} ESG + \beta_{11} Crisis_{i,t} + \\
&+ \beta_{12} I(LaggedReturn < 0)_{i,t-1} \times ESG + \beta_{13} ESG \times Crisis + \\
&+ \beta_{14} I(LaggedReturn < 0)_{i,t-1} \times Crisis_{i,t} + \\
&+ \beta_{15} I(LaggedReturn < 0)_{i,t-1} \times ESG \times Crisis_{i,t} + \\
&+ \gamma Controls_{i,t} + \delta_i + \lambda_{ESG,t} + \epsilon_{i,t}, \qquad (2)
\end{aligned}$$

where the dependent variable represents the share's relative net flows between month t and t-1. The eight main independent variables account for non-linearities with respect to the share's past excess return levels and the market conditions: *RetPosESG Crisis* is the past positive return of ESG shares during crisis periods and 0 otherwise. *RetPosESG Non-Crisis* is the past positive return of ESG shares during normal periods and 0 otherwise. *RetPosNESG Crisis* is the past positive return of non-ESG shares during crisis periods and 0 otherwise. *RetPosNESG Non-Crisis* is the past positive return of non-ESG share during normal periods and 0 otherwise. The four other return terms represent the cases where the past return was negative. *ESG* is an indicator variable equal to one if the fund is marketing itself as taking into account ESG criteria in its investment decisions and zero otherwise. $I(LaggedReturn < 0)$ is an indicator variable equal to one if the share displays a negative past excess performance and zero otherwise. Crisis is a dummy variable equal to one if the month's VIX level is above its 90^{th} percentile of its distribution and zero otherwise. The baseline coefficients of interest are based on a four-interaction term between the share's past return, the $I(LaggedReturn < 0)$ dummy, the *ESG* dummy and the *Crisis* dummy. The reported results and t-statistics are based on selected sums of coefficients. Annex 1 (table 8) provides an explanation of how the eight coefficients of interest are constructed. Controls and fixed-effects are the same as in specification (2.1). Table 5 reports the results for both equity and corporate bond funds. For ease of visualisation we report only the coefficients related to negative returns. Our baseline result is confirmed: during periods of stress, flows into ESG/E-funds remain less sensitive to past negative performance in both bond and equity sample (indeed, the coefficient *Ret Neg ESG Crisis* is insignificant across all four specifications). In contrast, investors redeem following negative performances in conventional funds. As demonstrated by Goldstein et al. (2017), investors in bond funds redeem more in response to negative returns under stressed market conditions (in columns 3 and 4, *Ret Neg NESG Crisis* is highly positive and significant, while the coefficient *Ret Neg NESG Non-Crisis* is positive but insignificant). Regarding the equity conventional sample of funds, investors redeem following negative performances under both normal and stressed market conditions.

Table 5: The effect of crises periods on the flow-performance relation : ESG versus non-ESG peers
Specification using name classification and excess returns

	Equity funds		Bond funds	
	(1)	(2)	(3)	(4)
	All ESG	Green ESG	All ESG	Green ESG
	Flows	Flows	Flows	Flows
Ret Neg ESG Non-Crisis	0.020	0.052	0.254	-0.262
	(0.66)	(1.20)	(1.06)	(-0.97)
Ret Neg ESG Crisis	0.009	0.063	0.013	-0.012
	(0.21)	(1.04)	(0.07)	(-0.07)
Ret Neg NESG Non-Crisis	0.072***	0.072***	0.000	-0.000
	(8.92)	(8.89)	(0.00)	(-0.01)
Ret Neg NESG Crisis	0.065***	0.065***	0.112***	0.113***
	(6.81)	(6.79)	(3.33)	(3.35)
I(ESG) x I(Lagged Return<0)	0.000	0.001	0.003	0.006
	(0.23)	(0.70)	(0.93)	(1.14)
I(Lagged Return<0) x I(Crisis)	0.000	0.000	0.004**	0.004**
	(0.57)	(0.58)	(2.14)	(2.14)
I(ESG) x I(Crisis) I(Lagged Return<0)	-0.000	0.002	-0.002	-0.001
	(-0.03)	(0.60)	(-0.33)	(-0.12)
I(Lagged Return<0)	-0.001***	-0.001***	-0.002***	-0.002***
	(-4.23)	(-4.22)	(-3.65)	(-3.68)
Constant	0.193***	0.194***	0.263***	0.257***
	(33.95)	(33.18)	(15.75)	(14.86)
Share FE	Yes	Yes	Yes	Yes
Month x ESG FE	Yes	Yes	Yes	Yes
Cluster	Share	Share	Share	Share
Controls	Yes	Yes	Yes	Yes
H0: Ret Neg ESG Crisis = Ret Neg NESG Crisis	0.21	0.978	0.601	0.505
Adj. R^2	0.197	0.198	0.154	0.153
Observations	324 022	307 903	64 467	61 417
Sample	Name classification, Excess returns			

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

This table shows the effect of crisis periods on the flow-performance relationship for ESG and for non-ESG funds. We regress share's flows on share's past excess returns. An asymmetry in investor response is tested with respect to past negative and positive performance. Moreover, we also test an asymmetry in investor response to past returns with respect to a share being considered an ESG or a conventional fund share. We use an indicator variable in order to capture periods of crisis: I(Crisis) equals one if the VIX in the respective month is above its 90th percentile. For ease of visualisation, the terms related to the positive returns are not reported. The following control variables are introduced: Ln(age) indicates the past natural logarithm of share's age (expressed in years), Ln(size) indicates the past natural logarithm of share's size, share's lagged flows and the standard deviation of the past 12 monthly returns. The sample covers January 2016 - December 2020 and is at a monthly frequency. ESG/E-funds are defined according to the use of certain words in funds' names. The first 2 columns show the results for equity funds (the Green ESG are considered instead of All ESG in the second column), while the 2 last columns show the results for bond funds. Share fixed effects and crossed month and ESG fixed effects are introduced. Observations are clustered at a share level.

3.4 The effect of the liquidity of the portfolio

In this section we are interested in analysing whether investors remain insensitive to past negative performances in the ESG corporate bond funds with less liquid assets. Indeed, Goldstein et al. (2017) demonstrated that the first-mover advantage is larger in funds with less liquid assets. Therefore, investors will react stronger to past negative returns in such funds since the fund will need to potentially sell less liquid assets in order to reimburse redeeming investors which could lead to bigger losses in value.

The regression to be tested takes the following form:

$$
\begin{aligned}
Flows_{i,t} &= \alpha + \beta_1 RetPosESG_{i,t-1}Liq + \beta_2 RetPosESG_{i,t-1}Illiq + \\
&+ \beta_3 RetPosNESG_{i,t-1}Liq + \beta_4 RetPosNESG_{i,t-1}Illiq + \\
&+ \beta_5 RetNegESG_{i,t-1}Liq + \beta_6 RetNegESG_{i,t-1}Illiq + \\
&+ \beta_7 RetNegNESG_{i,t-1}Liq + \beta_8 RetNegNESG_{i,t-1}Illiq + \\
&+ \beta_9 I(LaggedReturn < 0)_{i,t-1} + \beta_{10} ESG + \beta_{11} Illiquid_{i,t-1} + \\
&+ \beta_{12} I(LaggedReturn < 0)_{i,t-1} \times ESG + \beta_{13} ESG \times Illiquid_{i,t-1} + \\
&+ \beta_{14} I(LaggedReturn < 0)_{i,t-1} \times Illiquid_{i,t-1} + \\
&+ \beta_{15} I(LaggedReturn < 0)_{i,t-1} \times ESG \times Illiquid_{i,t-1} + \\
&+ \gamma Controls_{i,t} + \delta_i + \lambda_{ESG,t} + \epsilon_{i,t}, \qquad (3)
\end{aligned}
$$

where the dependent variable represents the share's relative net flows between month t and t-1. The eight main independent variables account for non-linearities with respect to the share's past excess return levels and the illiquidity of the fund's portfolio: *RetPosESG Liq* is the past positive return of ESG liquid shares and 0 otherwise. *RetPosESG Illiq* is the past positive return of ESG illiquid shares and 0 otherwise. *RetPosNESG Liq* is the past positive return of non-ESG liquid shares and 0 otherwise. *RetPosNESG Illiq* is the past positive return of non-ESG illiquid shares and 0 otherwise. The four other return terms represent the cases where the past return was negative. *ESG* is an indicator variable equal to one if the fund is marketing itself as taking into account ESG criteria in its investment decisions and zero otherwise. $I(LaggedReturn < 0)$ is an indicator variable equal to one if the share displays a negative past excess performance and zero otherwise. *Illiquid* is an indicator variable that equals one if a fund is illiquid and zero otherwise. We identify funds as illiquid if they hold less than 1% of their portfolio [9] in liquid assets[10]. The baseline coefficients of interest are based on a four-interaction term between the share's past return, the $I(LaggedReturn < 0)$ dummy, the ESG dummy and the *Illiquid* dummy. The reported results and t-statistics are based on selected sums of coefficients. Annex 1 (table 9) provides an explanation of how the eight coefficients of interest are constructed. Controls and fixed-effects are the same as in specification (2.1).

Table 6 shows the results for the corporate bond sample. For ease of visualisation we report only the coefficients related to negative returns. We observe that our main result remains robust. ESG investors turn out to be less sensitive to past performance even in funds with less liquid assets (indeed, the coefficient *Ret Neg ESG Illiq* is positive and insignificant in column 1). However, we observe that when considering green ESG funds, the coefficient of the variable *Ret Neg ESG Illiq* is negative and highly significant. This finding suggests that in response to a more negative performance, investors reward illiquid shares with inflows. However, this counterintuitive finding is essentially explained by a small number of observations of illiquid green ESG funds with negative past returns occurring in April 2020, when the industry recorded inflows, while the lagged values of returns correspond to the turmoil period in March.

In contrast, in the conventional bond sample, we observe that investors in less liquid non-ESG funds are more sensitive to past negative performance compared to investors in more liquid conventional funds (indeed, the coefficient *Ret Neg NESG Illiq* is positive and highly significant and its size is almost the double of the coefficient *Ret Neg NESG Liq*). This finding is in line with the results of Goldstein et al. (2017) who demonstrate that investors are highly sensitive to negative returns in less liquid funds. Nevertheless, the difference in coefficients of past negative returns between illiquid ESG and non-ESG funds remains statistically insignificant.

[9] The threshold is defined as the 25 percentile of the distribution. Other thresholds are considered, namely the median or the 10th percentile and the results remain unchanged.

[10] The fund's liquidity measure displays the percentage of the portfolio invested in high quality assets, namely cash and cash equivalents, bonds from euro area governments, supranationals, central banks as well as non-Euro Area government bonds that have an AA/AAA rating.

Table 6: The effect of liquidity on the flow-performance relation: ESG versus non-ESG peers
Specification using name classification and excess returns

	(1)	(2)
	All ESG	Green ESG
	Flows	Flows
Ret Neg ESG Liq	0.185	-0.200
	(1.04)	(-1.45)
Ret Neg ESG Illiq	0.208	-1.067***
	(0.99)	(-3.64)
Ret Neg NESG Liq	0.081***	0.081***
	(2.62)	(2.62)
Ret Neg NESG Illiq	0.159***	0.159***
	(3.84)	(3.83)
I(Lagged Return<0)	-0.001	-0.001
	(-1.54)	(-1.57)
I(Illiquid)	-0.001	-0.001
	(-0.71)	(-0.71)
I(Lagged Return<0) x I(Illiquid)	0.001	0.001
	(0.41)	(0.41)
I(ESG) x I(Lagged Return<0)	0.003	0.004
	(0.99)	(0.78)
I(Illiquid) x I(ESG)	-0.005	-0.010
	(-1.26)	(-1.50)
I(ESG) x I(Illiquid) x I(Lagged Return<0)	-0.001	0.007
	(-0.22)	(1.22)
Constant	0.262***	0.255***
	(13.29)	(12.54)
Share FE	Yes	Yes
Month x ESG FE	Yes	Yes
Cluster	Share	Share
H0: Ret Neg ESG Illiq=Ret Neg NESG Illiq	0.819	0.000***
Adj. R^2	0.154	0.152
Observations	49 081	47 064
Sample	Name classification, Excess returns	

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

This table shows the effect of the liquidity on the flow-performance relationship for ESG and for non-ESG funds. We regress share's flows on share's past excess returns. An asymmetry in investor response is tested with respect to past negative and positive performance. Moreover, we also test an asymmetry in investor response to past returns with respect to a share being considered an ESG or a conventional fund share. We use an indicator variable in order to capture the fund's liquidity: I(illiquid) equals one if the fund invests less than 1% of its portfolio in liquid assets. For ease of visualisation, the terms related to the positive returns are not reported. The following control variables are introduced: past level of the portfolio invested in liquid assets, Ln(age) indicates the past natural logarithm of share's age (expressed in years), Ln(size) indicates the past natural logarithm of share's size, share's lagged flows and the standard deviation of the past 12 monthly returns. The sample covers January 2016 - December 2020 and is at a monthly frequency. ESG/E-funds are defined according to the use of certain words in funds' names. The 2 columns show the results for bond funds (the Green ESG are considered instead of All ESG in the second column). Share fixed effects and crossed month and ESG fixed effects are introduced. Observations are clustered at a share level.

3.5 Discussion

Our results suggest that investors in ESG and Environmental-focused funds are less sensitive to past negative performance, with no significant difference between retail and institutional investors. The results are robust to alternative specifications. The lower sensitivity of ESG flows to negative returns is not explained by the recent growth trend in the ESG/E-fund sector, as we control for this trend by using time*ESG fixed effects. Also, investors in funds with an environmental objective remain less sensitive to negative returns in both calm and crisis times. Finally, the results are not explained by funds' liquidity: investors in ESG/E-funds with less liquid assets are still less sensitive to past negative returns.

However, in the bond fund sample, we find that the coefficients of the sensitivity to past negative returns for ESG and non-ESG funds are not statistically different. One possible explanation is that the ESG bond fund sample is relatively small or that ESG data suffer from greenwashing risk, due to the absence of clear standards for the identification of ESG funds. Indeed, ESG and non-ESG funds show similar performance over the considered period. But a quick glance at their portfolios suggests that their holdings do not differ significantly, at least, at a sectoral level. It is possible that ESG funds hold assets in firms with best-in-class ESG ratings, but this will be subject to future analysis. In the absence of clear and unique standards of what an ESG fund can hold, investors may not always be fully aware and certain of funds' commitments to their ethical goals. And this can affect investors' behavior as well.

4 Robustness

We have also tested different specifications of our four main hypotheses.

First, we test the robustness of our results with respect to the performance measure. In the literature there is no consensus regarding the best way to measure performance in the flow-performance relationship. Therefore, as an alternative definition, we employ past raw returns and unreported tables show that our results remain robust across specifications (tables 1 to 5 in the online Appendix).

Second, we also pursued a piece-wise regression in order to offset a potential multi-collinearity problem across our regressors. Such a collinearity problem could arise due to the use of multiple interaction terms present for example in our hypotheses (indeed, hypothesis 4 presents a 4-term interaction term). We, therefore, run our main regressions without the interaction terms of all dummies variables present in the interaction term (therefore keeping only interaction terms with the past return present). Unreported results show that our results remain global unchanged.

Third, we used the Lipper classification (instead of the SHSS classification) in order to differentiate between retail and institutional shares. Annex 3 presents the results: table 12 shows the results for the sample of equity funds and table 13 displays the results for the sample of bond funds respectively. While our results remain robust when using the Lipper classification for the equity fund sample, some differences appear in the bond sample results. In this latter sample, although our coefficient of interest ($RetNegESG$) remains globally insignificant across the retail or institutional specifications, we observe that the coefficient $RetNegNESG$ loses its significance in the institutional sample. This result contradicts previous findings (Goldstein et al. (2017) for example), although there is no consensus in the literature regarding the criteria to be used in order to differentiate between retail and institutional share classes.

5 Conclusion and policy implications

ESG funds have been growing rapidly in recent years, reflecting the increasing awareness of climate change-related risk among investors and their interest in financing the transition towards a net-zero emission economy. But further growth may be inhibited if greenwashing concerns related to the classification of these funds are left unaddressed. The Covid-19 market turmoil provided a natural opportunity to test the resilience of the ESG fund flows to negative performance. In March 2020 ESG and environmental-focused funds have experienced lower outflows, and a more pronounced and faster recovery compared to conventional funds.

In this paper, we show that both retail and institutional investors in ESG and E-funds are less sensitive to past negative performance. This behaviour persists also in crisis periods and for corporate bond funds investing in less liquid assets, reflect a more stable and committed investor base. These findings are indicative of a higher resilience of flows in ESG and E-funds. A weaker flow-performance relationship of ESG and E-funds suggests that effective green finance can help to foster an orderly transition and reduce vulnerability to climate-related risks. In addition, it is beneficial for financial stability, as ESG managers would not need to sell their assets in response to outflows in periods of market distress. However, the difference in the sensitivity to past negative performances between ESG/E funds and non-ESG peers is not statistically different in the bond fund sector, potentially due to the smaller sample of ESG/Environmental-focused funds or to the presence of a greenwashing risk.

It is challending to decide which funds should be defined as ESG/E in the absense of a common definition and/or regulatory label. The overlap between ESG labels provided by different data providers such as Morningstar, Lipper and Bloomberg is limited. While not being part of our analysis, we acknowledge that it may be also confusing for investors to define an ESG/E fund. We argue that consistent, harmonized and verified ESG/E labels can help address uncertainty around definition of ESG/E funds, risks of greenwashing and misselling, thereby contributing to further growth of the ESG fund sector and funding of the transition to low-carbon economy. The development of ESG equity markets may be particularly valuable given that countries with a higher share of equity funding tend to reduce their carbon footprint more rapidly.

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Annex 1

5.1 Table 1 coefficients

For ease of visualisation, we report in the baseline result table 1 interpretable coefficients related to the interaction term $Return_{i,t-1} \times I(LaggedReturn < 0) \times ESG$ (each possible outcome being considered). The following table displays how these different outcomes are built from the interaction term:

Table 7: Creation of the coefficients to be reported in the results table 1

Term	Formula
Ret Pos ESG	$Return_{i,t-1} + Return_{i,t-1} \times ESG$
Ret Pos NESG	$Return_{i,t-1}$
Ret Neg ESG	$Return_{i,t-1} + Return_{i,t-1} \times ESG$ $+Return_{i,t-1} \times I(LaggedReturn < 0)$ $+Return_{i,t-1} \times I(LaggedReturn < 0) \times ESG$
Ret Neg NESG	$Return_{i,t-1} + Return_{i,t-1} \times$ $I(LaggedReturn < 0)$

5.2 Table 5 coefficients

For ease of visualisation, we report in the result table 5 interpretable coefficients related to the interaction term $Return_{i,t-1} \times I(LaggedReturn < 0) \times ESG \times Crisis$ (each possible outcome being considered). The following table displays how these different outcomes are built from the interaction term:

Table 8: Creation of the coefficients to be reported in the results table 5

Term	Formula
Ret Pos ESG Crisis	$Return_{i,t-1} + Return_{i,t-1} \times ESG + Return_{i,t-1} \times Crisis + Return_{i,t-1} \times Crisis \times ESG$
Ret Pos ESG Non-Crisis	$Return_{i,t-1} + Return_{i,t-1} \times ESG$
Ret Neg ESG Crisis	$Return_{i,t-1} + Return_{i,t-1} \times I(LaggedReturn < 0) + Return_{i,t-1} \times I(LaggedReturn < 0) \times ESG + Return_{i,t-1} \times I(LaggedReturn < 0) \times ESG \times Crisis + Return_{i,t-1} \times ESG + Return_{i,t-1} \times Crisis + Return_{i,t-1} \times Crisis \times ESG + Return_{i,t-1} \times I(LaggedReturn < 0) \times Crisis$
Ret Neg ESG Non-Crisis	$Return_{i,t-1} + Return_{i,t-1} \times I(LaggedReturn < 0) + Return_{i,t-1} \times I(LaggedReturn < 0) \times ESG + Return_{i,t-1} \times ESG$
Ret Pos NESG Crisis	$Return_{i,t-1} + Return_{i,t-1} \times Crisis$
Ret Pos NESG Non-Crisis	$Return_{i,t-1}$
Ret Neg NESG Crisis	$Return_{i,t-1} + Return_{i,t-1} \times I(LaggedReturn < 0) + Return_{i,t-1} \times Crisis + Return_{i,t-1} \times I(LaggedReturn < 0) \times Crisis$
Ret Neg Nesg Non-Crisis	$Return_{i,t-1} + Return_{i,t-1} \times I(LaggedReturn < 0)$

5.3 Table 6 coefficients

For ease of visualisation, we report in the result table 6 interpretable coefficients related to the interaction term $Return_{i,t-1} \times I(LaggedReturn < 0) \times ESG \times Illiquid$ (each possible outcome being considered). The following table displays how these different outcomes are built from the interaction term:

Table 9: Creation of the coefficients to be reported in the results table 6

Term	Formula
Ret Pos ESG Illiq	$Return_{i,t-1} + Return_{i,t-1} \times ESG + Return_{i,t-1} \times Illiquid + Return_{i,t-1} \times Illiquid \times ESG$
Ret Pos ESG Liq	$Return_{i,t-1} + Return_{i,t-1} \times ESG$
Ret Neg ESG Illiq	$Return_{i,t-1} +_{i,t-1} \times I(LaggedReturn < 0) + Return_{i,t-1} \times I(LaggedReturn < 0) \times ESG + Return_{i,t-1} \times I(LaggedReturn < 0) \times ESG \times Illiquid + Return_{i,t-1} \times ESG + Return_{i,t-1} \times Illiquid + Return_{i,t-1} \times Illiquid \times ESG + Return_{i,t-1} \times I(LaggedReturn < 0) \times Illiquid$
Ret Neg ESG Liq	$Return_{i,t-1} + Return_{i,t-1} \times I(LaggedReturn < 0) + Return_{i,t-1} \times I(LaggedReturn < 0) \times ESG + Return_{i,t-1} \times ESG$
Ret Pos NESG Illiq	$Return_{i,t-1} + Return_{i,t-1} \times Illiquid$
Ret Pos NESG Liq	$Return_{i,t-1}$
Ret Neg NESG Illiq	$Return_{i,t-1} + Return_{i,t-1} \times I(LaggedReturn < 0) + Return_{i,t-1} \times Illiquid + Return_{i,t-1} \times I(LaggedReturn < 0) \times Illiquid$
Ret Neg Nesg Liq	$Return_{i,t-1} + Return_{i,t-1} \times I(LaggedReturn < 0)$

Annex 2

Table 10: The effect of European's clientele on the flow-performance relation of equity funds : ESG versus non-ESG peers
Specification using name classification and excess returns

	Equity funds			
	(1)	(2)	(3)	(4)
	EA	Non-EA	USD	EUR/GBP
	All ESG		All ESG	
	Flows	Flows	Flows	Flows
Ret Pos ESG	0.100***	0.056*	-0.006	0.073***
	(3.91)	(1.75)	(-0.12)	(3.61)
Ret Pos NESG	0.066***	0.042***	0.061***	0.054***
	(9.05)	(4.92)	(5.37)	(8.77)
Ret Neg ESG	0.023	-0.016	-0.014	0.015
	(0.61)	(-0.36)	(-0.23)	(0.49)
Ret Neg NESG	0.092***	0.049***	0.057***	0.082***
	(10.34)	(4.38)	(4.25)	(10.51)
I(Lagged Return<0)	-0.001***	-0.001***	-0.001*	-0.001***
	(-3.06)	(-3.17)	(-1.90)	(-4.45)
I(ESG) x I(Lagged Return<0)	0.000	-0.001	-0.002	0.001
	(0.41)	(-0.60)	(-0.87)	(0.86)
Ln(age)	-0.011***	-0.011***	-0.006***	-0.010***
	(-10.65)	(-7.53)	(-3.65)	(-11.61)
Ln(size)	-0.010***	-0.008***	-0.010***	-0.009***
	(-22.66)	(-14.72)	(-15.99)	(-24.00)
Lagged Flows	0.176***	0.170***	0.162***	0.171***
	(37.61)	(29.34)	(24.43)	(41.66)
Std Dev Ret	-0.003***	-0.002***	-0.003***	-0.002***
	(-12.28)	(-8.46)	(-7.91)	(-11.73)
Constant	0.204***	0.170***	0.193***	0.191***
	(26.19)	(17.38)	(17.51)	(27.64)
Share FE	Yes	Yes	Yes	Yes
Month x ESG FE	Yes	Yes	Yes	Yes
Cluster	Share	Share	Share	Share
H0: Ret Neg ESG = Ret Neg NESG	0.077*	0.148	0.254	0.029*
Adj. R^2	0.2	0.2	0.19	0.19
Observations	172 244	104 314	71 428	231 078
Sample	Lipper classification, Excess returns			

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

This table shows the flow-performance relationship for ESG and for non-ESG funds split by European or non-European clientele. A share is considered as having an European (non-European) clientele if at least 75% (less than 75%) of its assets are detained by European clients. We regress share's flows on share's past excess returns. An asymmetry in investor response is tested with respect to past negative and positive performance. Moreover, we also test an asymmetry in investor response to past returns with respect to a share being considered an ESG or a conventional fund share. The following control variables are introduced: Ln(age) indicates the past natural logarithm of share's age (expressed in years), Ln(size) indicates the past natural logarithm of share's size, share's lagged flows and the standard deviation of the past 12 monthly returns. The sample covers January 2016 - December 2020 and is at a monthly frequency. ESG/E-funds are defined according to the use of certain words in funds' names. The first 2 columns show the results split between European and non-European clientele, while in the last 2 columns we use the currency denomination of the share as a proxy for the geographical split by clientele. Share fixed effects and crossed month and ESG fixed effects are introduced. Observations are clustered at a share level.

Table 11: The effect of European's clientele on the flow-performance relation of bond funds : ESG versus non-ESG peers
Specification using name classification and excess returns

	Bond funds			
	(1)	(2)	(3)	(4)
	EA	Non-EA	USD	EUR/GBP
	All ESG		All ESG	
	Flows	Flows	Flows	Flows
Ret Pos ESG	0.128	-0.538**	-0.606	0.050
	(0.55)	(-2.29)	(-0.98)	(0.24)
Ret Pos NESG	0.056	-0.001	-0.003	0.117***
	(1.14)	(-0.02)	(-0.03)	(2.83)
Ret Neg ESG	0.107	0.042	1.699**	0.076
	(0.42)	(0.27)	(2.39)	(0.30)
Ret Neg NESG	0.105**	0.128***	0.238***	0.076*
	(2.50)	(3.32)	(3.76)	(1.76)
I(Lagged Return<0)	-0.002***	-0.000	-0.003	-0.004***
	(-2.85)	(-0.16)	(-1.62)	(-5.04)
I(ESG) x I(Lagged Return<0)	0.001	0.003	0.017	0.001
	(0.22)	(0.49)	(1.35)	(0.35)
Ln(age)	-0.009***	-0.006	-0.007	-0.008***
	(-3.02)	(-1.60)	(-1.23)	(-3.26)
Ln(size)	-0.012***	-0.017***	-0.014***	-0.014***
	(-9.33)	(-11.11)	(-8.13)	(-11.35)
Lagged Flows	0.153***	0.147***	0.140***	0.153***
	(16.78)	(11.63)	(8.20)	(19.81)
Std Dev Ret	-0.003***	-0.004***	-0.005***	-0.003***
	(-3.85)	(-5.04)	(-4.25)	(-3.78)
Constant	0.238***	0.313***	0.272***	0.263***
	(10.27)	(11.70)	(8.90)	(12.27)
Share FE	Yes	Yes	Yes	Yes
Month x ESG FE	Yes	Yes	Yes	Yes
Cluster	Share	Share	Share	Share
H0: Ret Neg ESG = Ret Neg NESG	0.995	0.595	0.042**	0.998
Adj. R^2	0.16	0.16	0.14	0.16
Observations	33 526	23 092	13 107	44 608
Sample	Lipper classification, Excess returns			

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

This table shows the flow-performance relationship for ESG and for non-ESG funds split by European or non-European clientele. A share is considered as having an European (non-European) clientele if at least 75% (less than 75%) of its assets are detained by European clients. We regress share's flows on share's past excess returns. An asymmetry in investor response is tested with respect to past negative and positive performance. Moreover, we also test an asymmetry in investor response to past returns with respect to a share being considered an ESG or a conventional fund share. The following control variables are introduced: Ln(age) indicates the past natural logarithm of share's age (expressed in years), Ln(size) indicates the past natural logarithm of share's size, share's lagged flows and the standard deviation of the past 12 monthly returns. The sample covers January 2016 - December 2020 and is at a monthly frequency. ESG/E-funds are defined according to the use of certain words in funds' names. The first 2 columns show the results split between European and non-European clientele, while in the last 2 columns we use the currency denomination of the share as a proxy for the geographical split by clientele. Share fixed effects and crossed month and ESG fixed effects are introduced. Observations are clustered at a share level.

Annex 3

Table 12: The effect of share's clientele on the flow-performance relation of equity funds: ESG versus non-ESG peers
Specification using Lipper classification and excess returns

	Equity funds			
	(1)	(2)	(3)	(4)
	Instit	Retail	Instit	Retail
	All ESG		Green ESG	
	Flows	Flows	Flows	Flows
Ret Pos ESG	0.054*	0.064***	0.092*	0.100***
	(1.80)	(2.98)	(1.91)	(3.24)
Ret Pos NESG	0.044***	0.054***	0.044***	0.054***
	(4.30)	(9.36)	(4.27)	(9.44)
Ret Neg ESG	0.036	0.004	0.033	0.067
	(0.72)	(0.14)	(0.44)	(1.58)
Ret Neg NESG	0.093***	0.059***	0.093***	0.059***
	(6.92)	(8.23)	(6.93)	(8.17)
I(Lagged Return<0)	-0.000	-0.001***	-0.000	-0.001***
	(-0.71)	(-5.26)	(-0.71)	(-5.23)
I(ESG) x I(Lagged Return<0)	0.001	-0.000	0.001	0.001
	(0.64)	(-0.05)	(0.59)	(1.07)
Ln(age)	-0.004***	-0.011***	-0.005***	-0.011***
	(-2.94)	(-12.96)	(-3.05)	(-12.46)
Ln(size)	-0.010***	-0.009***	-0.010***	-0.009***
	(-19.63)	(-22.73)	(-19.23)	(-22.23)
Lagged Flows	0.126***	0.194***	0.128***	0.195***
	(23.82)	(44.86)	(23.47)	(43.93)
Std Dev Ret	-0.002***	-0.002***	-0.002***	-0.003***
	(-6.61)	(-13.41)	(-6.41)	(-13.46)
Constant	0.203***	0.187***	0.202***	0.189***
	(20.85)	(26.92)	(20.31)	(26.32)
Share FE	Yes	Yes	Yes	Yes
Month x ESG FE	Yes	Yes	Yes	Yes
Cluster	Share	Share	Share	Share
H0: Ret Neg ESG = Ret Neg NESG	0.28	0.075*	0.43	0.857
Adj. R^2	0.13	0.23	0.13	0.23
Observations	94 047	229 975	88 216	219 687
Sample	Lipper classification, Excess returns			

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

This table shows the flow-performance relationship for ESG and for non-ESG funds split by clientele. A share is considered as institutional based on the Lipper classification. We regress share's flows on share's past excess returns. An asymmetry in investor response is tested with respect to past negative and positive performance. Moreover, we also test an asymmetry in investor response to past returns with respect to a share being considered an ESG or a conventional fund share. The following control variables are introduced: Ln(age) indicates the past natural logarithm of share's age (expressed in years), Ln(size) indicates the past natural logarithm of share's size, share's lagged flows and the standard deviation of the past 12 monthly returns. The sample covers January 2016 - December 2020 and is at a monthly frequency. ESG/E-funds are defined according to the use of certain words in funds' names. The first 2 columns show the results for all ESG funds (the Green ESG are considered instead of All ESG in the last 2 columns). Share fixed effects and crossed month and ESG fixed effects are introduced. Observations are clustered at a share level.

Table 13: The effect of share's clientele on the flow-performance relation of bond funds : ESG versus non-ESG peers
Specification using Lipper classification and excess returns

	Bond funds			
	(1)	(2)	(3)	(4)
	Instit	Retail	Instit	Retail
	All ESG		Green ESG	
	Flows	Flows	Flows	Flows
Ret Pos ESG	-0.235	-0.058	0.060	-0.126
	(-0.98)	(-0.34)	(0.19)	(-0.43)
Ret Pos NESG	0.020	0.025	0.018	0.025
	(0.45)	(0.65)	(0.41)	(0.66)
Ret Neg ESG	-0.117	0.480*	-0.277	0.288
	(-0.71)	(1.80)	(-1.52)	(1.06)
Ret Neg NESG	0.061	0.093***	0.062	0.093***
	(1.33)	(3.02)	(1.35)	(3.00)
I(Lagged Return<0)	-0.000	-0.002**	-0.000	-0.002**
	(-0.30)	(-2.34)	(-0.31)	(-2.35)
I(ESG) x I(Lagged Return<0)	0.001	0.002	0.006	0.005
	(0.16)	(0.63)	(0.70)	(1.37)
Ln(age)	-0.008**	-0.008***	-0.009**	-0.007**
	(-2.54)	(-2.69)	(-2.54)	(-2.28)
Ln(size)	-0.013***	-0.014***	-0.013***	-0.014***
	(-9.29)	(-11.43)	(-8.70)	(-10.94)
Lagged Flows	0.126***	0.173***	0.123***	0.172***
	(13.06)	(17.60)	(12.31)	(16.98)
Std Dev Ret	-0.002**	-0.005***	-0.002**	-0.005***
	(-2.15)	(-6.67)	(-2.00)	(-6.72)
Constant	0.254***	0.274***	0.247***	0.268***
	(10.09)	(12.25)	(9.45)	(11.67)
Share FE	Yes	Yes	Yes	Yes
Month x ESG FE	Yes	Yes	Yes	Yes
Cluster	Share	Share	Share	Share
H0: Ret Neg ESG = Ret Neg NESG	0.3	0.15	0.071*	0.475
Adj. R^2	0.12	0.17	0.12	0.17
Observations	24 526	39 941	23 153	38 264
Sample	Lipper classification, Excess returns			

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

This table shows the flow-performance relationship for ESG and for non-ESG funds split by clientele. A share is considered as institutional based on the Lipper classification. We regress share's flows on share's past excess returns. An asymmetry in investor response is tested with respect to past negative and positive performance. Moreover, we also test an asymmetry in investor response to past returns with respect to a share being considered an ESG or a conventional fund share. The following control variables are introduced: Ln(age) indicates the past natural logarithm of share's age (expressed in years), Ln(size) indicates the past natural logarithm of share's size, share's lagged flows and the standard deviation of the past 12 monthly returns. The sample covers January 2016 - December 2020 and is at a monthly frequency. ESG/E-funds are defined according to the use of certain words in funds' names. The first 2 columns show the results for all ESG funds (the Green ESG are considered instead of All ESG in the last 2 columns). Share fixed effects and crossed month and ESG fixed effects are introduced. Observations are clustered at a share level.

EUROPEAN CENTRAL BANK

EUROSYSTEM

Are ethical and green investment funds more resilient?

International Conference on Statistics for Sustainable Finance

14/09/2021

Disclaimer: The views expressed are those of the authors and do not necessarily reflect those of the ECB

Laura Capota,

Margherita Giuzio, Sujit Kapadia, Dilyara Salakhova

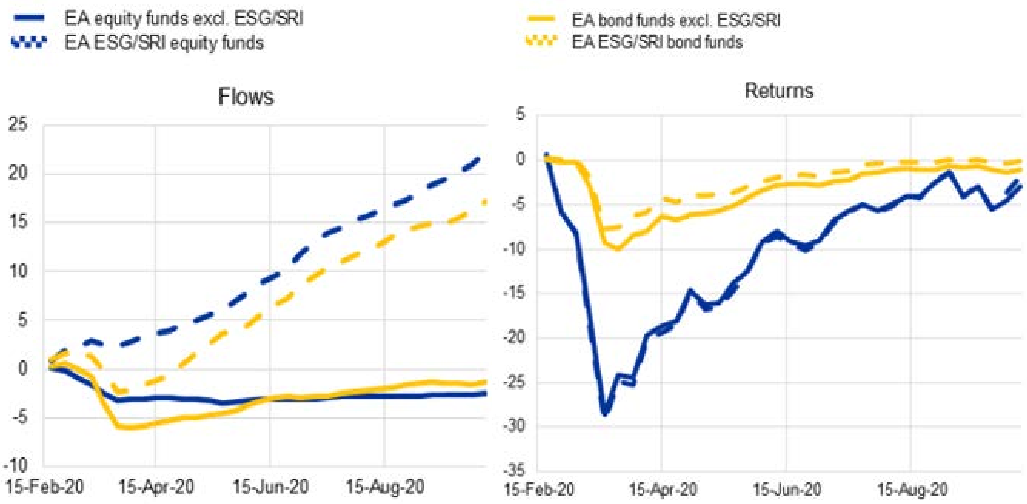
Overview

1.

Motivation

Motivation

ESG funds suffered lower outflows than non-ESG peers in March, despite achieving similar performance



Source: EPFR and ECB calculations.

Why are ESG funds more resilient?

- Ethical investors are **committed** to their mandates: they value sustainability more than performance (Hartmark and Sussmann, 2019; Pastor and Vorsatz, 2020; Dottling and Kim, 2020)
- Ethical investors have a **longer-term investment horizon**: they withstand short-term negative performance (Riedl and Smeets, 2017; Dottling and Kim, 2020)
- Ethical investors believe that ESG companies will have higher **future returns**

→ Is the flow-performance relationship different for ESG and non-ESG funds?

Our contribution

Literature on flow-performance relationship

- Bond traditional funds: investors are sensitive to low returns (Goldstein et al., 2017; Chen and Qin, 2017)
- Investors are more sensitive to low returns in less liquid bond funds (Goldstein et al., 2017)
- Equity traditional funds: convex shape (Sirri and Tufano, 1998)
- Equity ESG vs Non-ESG funds: ESG investors are less sensitive to past returns (Benson and Humphrey, 2008; Bollen, 2007)

Our project

- Compares the flow-performance relationship of ESG and traditional funds for **both bond and equity funds**
- Distinguishes **green ESG funds** from other ESG funds
- Considers a **longer time period** to capture a potential shift in investors' behavior and crisis episodes
- Classifies institutional and retail fund shares according to the euro area **Securities Holdings Statistics (SHSS)**
- Assesses funds' liquidity using a granular and **time-varying measure** of portfolio **liquidity**, based on **HQLA** definition

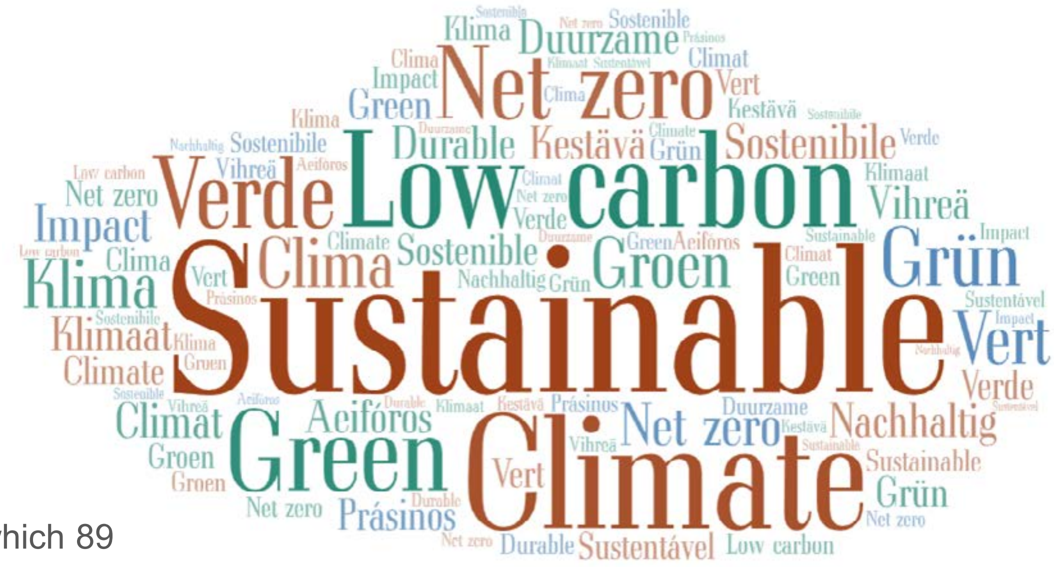
2.

Specification

ESG and green classification

ESG funds are classified as such according to the use of certain words in their names

We distinguish **green funds** from other ESG funds via a text search in fund names.



→ 206 ESG corporate bond funds shares, of which 89 are classified as green

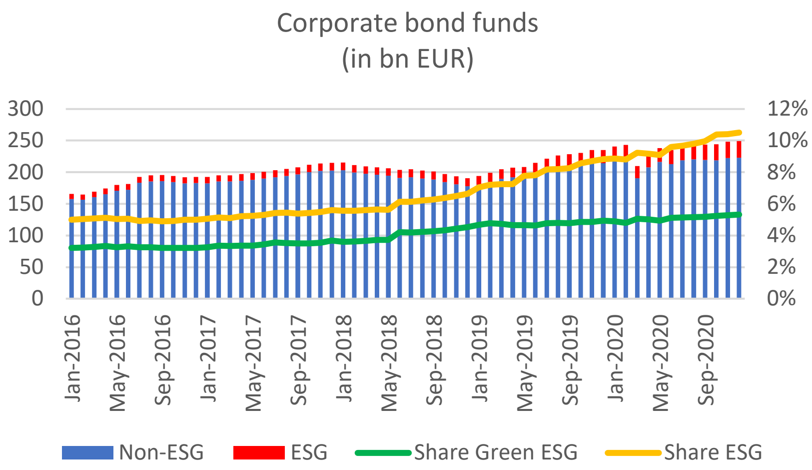
→ 1 274 ESG equity funds shares, of which 681 are classified as green

Sample

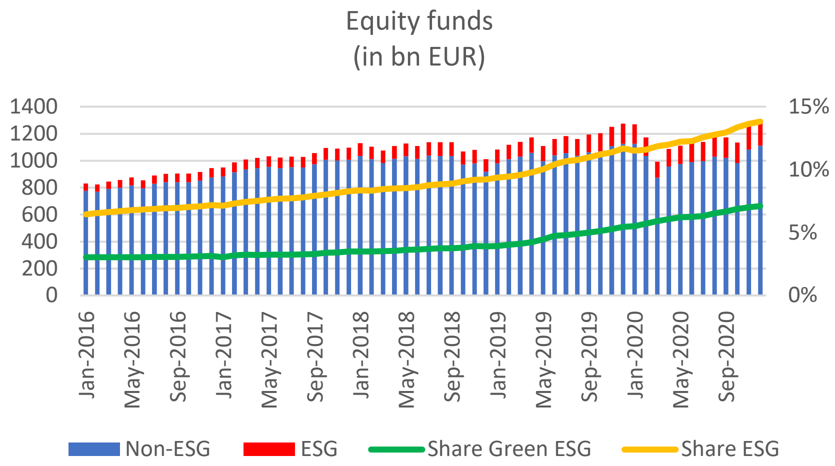
- Share-class level of EA-domiciled active funds
- Monthly return/TNA data, Jan 2016 - Dec 2020

→ ESG funds represent around 10% of the total number of corporate bond funds, but the assets they manage are growing rapidly

Evolution of TNA of corporate bond funds by type



Evolution of TNA of equity funds by type



Main specification

We adopt a specification based on Goldstein et al. (2017)

$$Flows_{i,t} = \alpha + \beta_1 Ret_{i,t-1}^{ESG+} + \beta_2 Ret_{i,t-1}^{non\_ESG+} + \beta_3 Ret_{i,t-1}^{ESG-} + \beta_4 Ret_{i,t-1}^{non\_ESG-} + \beta_5 Controls_{i,t-1} + \gamma_t + \delta_t \mathrm{x} ESG + \varepsilon_{i,t}$$

Where:

$Ret\_ESG_{i,t-1}^{+}$ is the lagged excess positive return for green/ESG funds and 0 otherwise, etc.

Controls include: age, size, lagged flows, volatility of returns

Share fixed effects, errors clustered at a share level

Main specification

We adopt a specification based on Goldstein et al. (2017)

$$Flows_{i,t} = \alpha + \beta_1 Ret^{ESG+}_{i,t-1} + \beta_2 Ret^{non\_ESG+}_{i,t-1} + \beta_3 Ret^{ESG-}_{i,t-1} + \beta_4 Ret^{non\_ESG-}_{i,t-1} + \beta_5 Controls_{i,t-1} + \gamma_i + \delta_t x ESG + \varepsilon_{i,t}$$

Where:

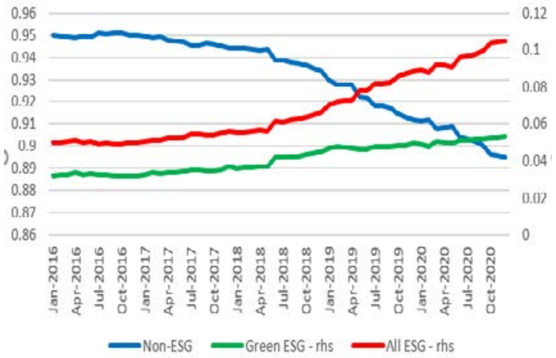
$Ret\_ESG^{+}_{i,t-1}$ is the lagged excess return for green/ESG funds and 0 otherwise

Controls include: age, size, lagged flows, volatility of returns

Share fixed effects, errors clustered at a share level

Time x ESG fixed effects in order to control for different time trends between ESG and non-ESG

Share of total assets managed by corporate bond funds, by group



3.

Results

Baseline: sensitivity to past performance

	Equity	Equity	Bond	Bond
	All ESG	Green ESG	All ESG	Green ESG
Ret Pos ESG	0.059***	0.097***	-0.172	-0.022
Ret Pos NESG	0.051***	0.051***	0.021	0.011
Ret Neg ESG	**0.015**	**0.056**	**0.127**	**-0.123**
Ret Neg NESG	**0.069*** **	**0.064*** **	**0.077*** **	**0.082*** **
Share FE	Yes	Yes	Yes	Yes
Time x ESG FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Observations	324,022	324,022	64,467	64,467
R-squared	0.21	0.19	0.15	0.15

Non-ESG investors **withdraw more** from funds with more negative past returns (a decrease of 1 pp of the negative returns leads to 0.06-0.08 pp higher outflows),

while ESG (and Green ESG) fund investors are not sensitive to past negative performance

Investor base

Based on SHSS:

- Institutional shares (if institutional investors hold more than 50% of the assets)
- Retail shares (if retail investors hold more than 50% of the assets)

- Institutional investors **do not redeem** from **green** funds in response to past negative performance (mandates' role?)
- However, they **react** to past negative performance in **non-ESG funds**
- Retail investors **do not react** to past negative performance in **green** funds

	Equity	Equity	Bond	Bond
	Institutional shares	Retail shares	Institutional shares	Retail shares
	Green ESG	Green ESG	Green ESG	Green ESG
Ret Pos ESG	0.102**	0.169***	0.006	1.111***
Ret Pos NESG	0.058***	0.067***	0.012	0.182**
Ret Neg ESG	**0.076**	**0.074**	**-0.417**	**0.665**
Ret Neg NESG	**0.095*** **	**0.064*** **	**0.125*** **	**0.109* **
Share FE	Yes	Yes	Yes	Yes
Time x ESG FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Observations	114,363	59,416	25,737	9,623
R-squared	0.15	0.34	0.13	0.29

Controlling for the liquidity of assets

Based on cash and HQLA bond data:

- Illiquid share if less than 1% of the portfolio is invested in liquid assets
- Liquid share otherwise

- Investors in **non-ESG** funds with **illiquid holdings withdraw more strongly** following negative performance
- Investors in **ESG illiquid** funds **do not redeem** following negative performance

	Bond	Bond
	All ESG	Green ESG
Ret Neg NESG Liq	0.081***	0.088***
Ret Neg NESG Illiq	**0.159*** **	**0.174*** **
Ret Neg ESG Liq	**0.185**	**-0.2**
Ret Neg ESG Illiq	**0.208**	**-1.061*** **
Share FE	Yes	Yes
Time x ESG FE	Yes	Yes
Controls	Yes	Yes
Observations	49,081	49,081
R-squared	0.15	0.15

Robustness

Considering different measures of performance:

- definition: monthly raw return in excess of category average, alphas
- horizon: 12-month raw return

4.

Conclusion

Conclusion and policy implications

Green and ESG funds do not exhibit outflows following negative performance

A more committed investor base, which is more willing to look-through short-term negative performance, indicates that green and ESG funds

→ may be able to provide a stable source of finance for the green transition

→ pose less risks to financial stability stemming from asset fire sales

Greenwashing risk needs to be addressed

→ A consistent and harmonized ESG label would help reduce uncertainty and greenwashing risk

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The pricing of carbon risk in syndicated loans: which risks are priced and why?[1]

Torsten Ehlers, BIS and IMF, Frank Packer, BIS, and Kathrin de Greiff, previously BIS

[1] This presentation was prepared for the conference. The views expressed are those of the authors and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

The pricing of carbon risk in syndicated loans: which risks are priced and why?[1]

Torsten Ehlers, Frank Packer and Kathrin de Greiff [2]

Abstract

Do banks price the risks of climate policy change? Combining syndicated loan data with carbon intensity data (CO_2 emissions relative to revenue) of borrowers across a wide range of industries, we find a significant "carbon premium" since the Paris Agreement. The loan risk premium related to CO_2 emission intensity is apparent across industries and broader than that due simply to "stranded assets" in fossil fuel or other carbon-intensive industries. The price of risk, however, appears to be relatively low given the material risks faced by some borrowers. Only carbon emissions directly caused by the firm (scope 1) are priced, and not the overall carbon footprint including indirect emissions. "Green" banks do not appear to price carbon risk differently from other banks.

Keywords: Environmental policy; climate policy risk; transition risk; loan pricing.

JEL classification: G2; Q01; Q5

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1. Introduction

Both the physical risks from climate events, and even more, the transition risks from a tightening of environmental regulations, can lead to potentially large revaluations of financial assets if not anticipated (Carney (2015), Dietz et al (2016)). The more informed investors and creditors are of the financial risks of climate change, the more they will reallocate from investments with high climate-related financial risks to more environmentally beneficial investments with lower risks. The pricing of climate-related financial risks, therefore, is an important factor in climate change mitigation.

We concentrate on carbon emissions as a source of financial risk for firms, often referred to in the literature as "carbon risk" (eg Bolton and Kacperczyk (2021), Goergen et al (2020), Andersson et al (2016)). In December 2015, 195 states and the European Union agreed in Paris to adopt a goal of limiting global warming to well below 2 degree Celsius, preferably to 1.5 degrees, above pre-industrial levels and pursue efforts consistent with that goal. Achieving this goal implies a very rapid reduction of CO_2 emissions (Rogelj et al (2016), IPCC (2015)). Very carbon intensive firms therefore face relatively high financial risks if, and when, governments take measures to comply with their commitments to reduce carbon emissions.

One instance of carbon risk that has received early attention in the literature is the case of stranded assets in the fossil fuel industry (Ansar et al (2013)). Stranded assets are physical assets whose value declines substantially due to the effects of climate change or climate change policies. The carbon reduction requirements in the Paris Agreement and related policies imply that some fossil fuel firms might not be able to fully utilize their existing fossil fuel reserves (McGlade and Ekins (2015)), leading to a decline in the financial value of those reserves. Under given climate policy scenarios, the carbon risk from stranded assets in the fossil fuel industry can be directly measured, making it a natural approach for studying climate-related financial risks.

Carbon risk, however, goes beyond stranded assets. Firms with relatively high emissions are at a greater risk of suffering financial penalties if environmental policies tighten. Direct penalties can result, for instance, from the extra costs of carbon taxes on firm emissions. These can apply to firms in all industries with a carbon footprint and are not limited to fossil fuel producers.

Our main contribution to the literature is to consider pricing of carbon risk in the context of syndicated bank loans. Lead banks in a loan syndicate have a strong incentive (and the means) to consider all relevant risk when pricing a loan – in particular when it is of large value and long maturity as is typical in the syndicated loan market. We document that for a significant share of firms in our sample, carbon risk is financially material. Hence, banks should be expected to price such risks.

We use carbon intensity – carbon emissions relative to revenue – as a proxy for carbon risk. We argue that carbon intensity can capture the severity of the potential financial impact of a tightening of carbon emission policies, such as an imposition of a carbon tax. Ultimately, costs related to carbon emissions are balanced against revenue, and firms with greater carbon emissions relative to revenue will find transition costs (such as carbon taxes) to be more burdensome.

The analysis of carbon risk across a broad set of industries is enabled by the increasing availability of carbon emissions data for a broad range of firms. We use carbon emissions data from S&P Trucost that covers listed firms in all major advanced and emerging economies. The availability of such data allows us to distinguish between inter- and intra-industry differences in carbon emissions. Also, the firm-level physical measures of carbon emissions enable us to analyze emissions directly attributable to the firm (scope 1), and those more broadly measured to include indirect emission from consumed energy (scope 2) and production inputs of the firm ("upstream" scope 3).

To preview our results, we find that the pricing of carbon risk in the syndicated loan market changed significantly after the Paris Agreement. The difference in risk premia due to CO_2 emission intensity is apparent across industry sectors. It is not driven by any specific industry sectors and therefore reflects a phenomenon broader than simply "stranded assets" in fossil fuel or other carbon-intensive industries. These results are robust to including loan fees, and the premium is not prevalent in the years before the Paris Agreement. We argue that the Paris Agreement increased the awareness of banks to carbon risk, analogous to survey evidence for institutional investors (Krueger et al (2020)).

While our results suggest that banks have started to internalize possible risks from the transition to a low-carbon economy across a broad range of industries, we find that they have done so only for the narrowly defined scope 1 carbon emissions (ie those directly caused by the firm). Our results suggest that carbon emissions indirectly caused by production inputs were not priced at the margin, suggesting that the overall carbon footprint is less of a concern to banks than direct emissions caused by the firms' activities. This seeming indifference of banks to higher scope emissions of borrowers parallels one finding of Bolton and Kacperczyk (2021), who show that the likelihood of divestment by institutional investors significantly increases with the degree and intensity of scope 1 emissions of the target firm, but not with emissions of other broader scopes. This suggests potential for "green-washing": scope 1 emissions of a firm can be reduced by simply outsourcing carbon intensive activities (Ben-David et al (2021)), without reducing the firm's broader carbon footprint.

Apart from the narrow scope of carbon risk that we find to be priced in syndicated bank loans, the price of risk also appears to be relatively low. On average, our regression results imply a carbon risk premium since 2016 of about 3-4 basis points (ie a 0.03-0.04% loan rate premium). For the high emitters (the 90th percentile in our sample), the premium increases to 7 basis points. High carbon emitters are firms with a carbon intensity of >1000 tonnes of CO_2 per $ million of revenue in our sample. Ceteris paribus, the introduction of a carbon price of $100 per tonne of CO_2 would imply that these firms would have to spend at least 10% of total revenues on carbon taxes alone.[3] Carbon risk would hence be highly material for such firms and the potential financial impact is unlikely to be fully internalized by a 7 basis points premium.

We further investigate whether syndicated loans arranged by "green banks" (as lead arrangers) price climate change risks more than other banks. We look at both banks that signal they are green (as members of the United Nations Environmental Programme Finance Initiative (UNEP FI) or parties to the Equator Principles (EP)) and

[3] The carbon price on the European Union's Emission Trading System (EU ETS), currently the largest such scheme in the world, was around €50 (around $60) per CO2 tonne at the beginning of May 2021. The EU ETS is a so-called "cap and trade" system, where companies have to purchase emission rights if they exceed a given (and periodically decreasing) emission allowance. As we discuss below, an *average* carbon price of $100 (ie an average across all emissions and not only those exceeding a given threshold) is plausible considering estimates of optimal carbon prices from the literature.

"de facto" green banks that lend less to carbon-intensive sectors. We cannot find any evidence that green banks put a higher price on carbon risk, though there is some evidence that green banks belonging to the UNEP FI or adopting the EP screen out companies with high carbon exposure – analogous to the evidence for asset managers in Bolton and Kacperczyk (2021).

Academic research to date on the pricing of climate change risk, including on carbon risk, has tended to focus on the pricing of climate-related risks in equity markets. Existing research indicates a transition risk premium in equity and option markets which seems to be more pronounced in times of high public climate change awareness (Ilhan et al (2021), Bolton and Kacperczyk (2021), Goergen et al (2020), Ramelli et al (2018), among others).[4]

By contrast, the literature on the pricing of climate-related risks in bank loan markets is more limited. Ongena et al (2018) examine syndicated loan data for fossil fuel firms to assess whether banks price the risk of stranded assets. Their study reveals that only post-2015 (after the establishment of the Paris Agreement) did banks begin pricing the risk of stranded fossil fuel reserves. In contrast, our paper's set-up allows us to test whether it is oil and gas alone that is driving the results for carbon emissions. At the same time, our finding that scope 1 emissions are priced while other scopes are not, provides an important insight into the (lack of) efficiency with which syndicated loan markets are pricing transition risks. Kleimeier and Viehs (2018) also exploit syndicated loan data to investigate whether firms voluntarily disclosing their carbon emissions to CDP (formerly Carbon Disclosure Project) are able to lower their costs of credit. They find that firms that voluntarily disclose CO_2 emissions face lower costs of credit compared to non-disclosing firms.

The rest of the paper will proceed as follows. In the next section, we introduce the data available to us for the empirical investigation, including bank and borrower-level syndicated loan data, and firm-level carbon intensity data. In the third section, we discuss the materiality of carbon risk, while the fourth section presents the econometric model and the baseline results with a particular focus on inter vs. intra-industry effects. The fifth investigates the extent to which the pricing impact differs across different measures of carbon emissions, while part six discusses the extent to which the greenness of the banks providing the finance affects the pricing of carbon risk. After some robustness checks in part seven, part eight concludes.

2. Data

We merge annual carbon emissions data for corporate borrowers with syndicated loans data for the period 2005-2018. The combined data set covers 567 different firms in total from 2005 to 2018 from 31 countries. Table 1 provides a description of our key variables.

Compared to the existing research on the pricing of climate risks in the syndicated loan market, we have access to carbon emissions data for a significantly broader set of listed firms. We obtain data on firm's carbon emissions from Trucost, a data vendor that is part of S&P Global. The database provides carbon emissions,

4 Physical climate change risks, however, do not seem to be priced in correctly (Hong et al (2019), Murfin and Spiegel (2020), among others).

including scope 1-3 carbon emissions, on an annual basis since 2006 for around 12,000 firms in 2018. Those are virtually all listed firms in advanced and the major emerging economies. The data are taken by Trucost either from companies' reports to CDP, corporate Annual Reports, Corporate Social Responsibility reports, corporate websites and companies' feedback via the Trucost Environmental Register. Importantly, Trucost estimates missing data using an input-output model, recommended by the greenhouse gas (GHG) protocol to estimate the impact of

Description of key variables

Table 1

Variable	Description	Source
A. *Dependent variables*		
Margin (bp)	Numerical value of tranche margin measured in basis points	Dealogic
All-in-Pricing (bp)	Numerical value of tranche margin plus any kind of fees measured in basis points	Dealogic
Fees (bp)	The difference of All-in-Pricing and Margin.	Dealogic
B. *Explanatory variables: Interest rates and loan characteristics*		
Term Spread	Spread between a governments bond of equivalent maturity to the syndicated loan over the reference rate of the syndicated loan in the currency of denomination of the syndicated loan	Central banks, Bloomberg
Log(Loan Value)	Log of the loan facility amount ($ millions).	Dealogic
Maturity	Loan duration in years.	Dealogic
Leveraged	Dummy equal to one if it is a leveraged loan	Dealogic
Subordinated	Dummy equal to one if it is a subordinated loan	Dealogic
C. *Explanatory variables: Borrower characteristics*		
Borrower Rating	Borrower S&P rating at signing in a numerical form ranging from 20 for AAA to 0 for a C rating.	Dealogic
Log(Revenues)	Log of borrowers annual revenues ($ millions).	Trucost
Carbon Intensity	Carbon Intensity Scope 1 measured as annual scope 1 carbon emissions over annual revenues (CO_2 tonnes/$ millions) in a given fiscal year of a borrowing firm.	Trucost
Carbon Intensity Scope 1 + 2	Sum of Carbon Intensity Scope 1 and 2.	Trucost
Carbon Intensity Scope 1 – 3	Sum of Carbon Intensity Scope 1, 2 and 3. Scope 3 covers upstream activities (production inputs) only.	Trucost
D. *Explanatory variables: Bank characteristics, country climate policy stringency and oil prices*		
Green Bank (EP)	Dummy equal to one from the year onwards in which the bank signed the Equator Principles (EP).	Principle's webpage
Green Bank (UNEP-FI)	Dummy equal to one from the year onwards in which the lender signed the green principles of the United Nations Environment Programme Finance Initiative (UNEP-FI).	Principle's webpage
Climate Change Performance Index (CCPI)	The CCPI assesses each country's performance in four categories: GHG Emissions, Renewable Energy, Energy Use and Climate Policy, as well as extent the respective country acts adequately to achieve the Paris climate targets.	Germanwatch
Oil Price	Average of three major spot prices (Brent, West Texas Intermediate, and the Dubai Fateh) in $/barrel.	IMF

investments.[5] Trucost compares the estimates with the emissions that firms report and adds "missing" emissions if necessary.[6] For our sample period, scope 3 emissions are only available for upstream activities, ie those related to production inputs and supplies. Emissions are measured annually over the course of a firms' fiscal year.

Still there might be a remaining concern with the fact that all firms voluntarily disclose carbon emissions, and the selection issues that might arise. Firms potentially do not disclose carbon emissions because they are reluctant to acknowledge high carbon intensity or else due to the simple absence of correct carbon intensity measures. As for the latter case, Trucost data includes estimates that actually allow us to include such firms in our analysis. We later examine evidence whether carbon emissions that are estimated by Trucost rather than disclosed by the firm itself bias our results in any way. We further address firm specific differences by controlling for firm characteristics.

We obtain global loan-level syndicated loan data from Dealogic. Our main dependent variable is the margin, which equals the spread of the loan facility. For our regressions, to reduce the effect of outliers, we winsorize the sample for margins below the 1% percentile and above the 99% percentile. Berg, Saunders, and Steffen (2016) show the importance of fees in the overall pricing of loans. Thus, in robustness checks we use a measure of all-in pricing that includes all types of fees charged by the lender, including commitment fees (paid on unused amount of loan commitments), utilization fees (paid on the drawn amount once a threshold has been exceeded), and fixed upfront fees. We control for the rating of the borrower, the maturity of the loan facility, the size of the loan amount, the size of the borrower and whether or not the loan is leveraged. We restrict the sample to loans with maturities of at least 1 year, as we assume that short-term loans are unlikely to be subject to carbon risk. We further exclude observations with financial companies as borrowers, as emissions data are unlikely to properly reflect the climate-related risk exposures of these companies. We concentrate on loans identified as having the purpose to finance new investments or projects. We therefore exclude loans made for refinancing or buyout purposes.

Our final sample covers a maximum of 1469 observations across a wide range of industries (Table 2). About 350 out of the 567 borrowing firms take out more than one syndicated loan. The average maturity of the loans in the sample is slightly more than 4 years, with a total aggregate value of loans of around $1.4 trillion. According to our numeric transformation – that corresponds to AAA=20, AA+=19, and so on down to C=0 – the mean rating is equivalent to BBB (12). That said, in our regressions we use rating dummies throughout, so that the scaling of this transformation is not an issue in the analysis. For numerical precision of the coefficient estimates, we divide the carbon intensity by 1000 (ie CO_2 tonnes/$ thousand revenue) for our regression analyses in sections 4-7.

5 Trucost's so-called environmentally extended input-output model combines industry-specific environmental impact data with quantitative macroeconomic data on the flow of goods and services between different sectors in the economy to estimate carbon emissions of firms.

6 Thus, Trucost's methodology is applied consistently across voluntary carbon emission disclosers and non-disclosers, ie, if Trucost views the voluntary disclosures as insufficient, they will add to the carbon emissions estimates. For this reason, the availability of CO_2 emission data is complete across listed firms of major exchanges and it is not necessary to estimate selection models for disclosure as do Ilhan et al (2021).

Summary statistics

Table 2

Industry Group	Carbon Intensity[1]		Loan Margin[2]		Borrower Rating[3]	Loan Maturity[4]	Loan Value[5]	Obs
	Mean	Std	Mean	Std	Mean	Mean	Total	No
Automobile	12	3	170	106	11	4	83	35
Capital goods	54	169	117	94	13	4	176	180
Commercial services	295	538	152	78	11	4	31	43
Consumer durables and apparel	34	41	159	129	11	4	48	63
Consumer services	37	64	238	121	9	4	40	64
Energy	484	473	163	107	11	4	236	176
Food & Staples Retailing	16	9	160	189	11	4	22	26
Food, Beverage & Tobacco	56	53	114	87	12	4	70	67
Health Care	20	40	137	79	11	4	42	40
Household & Personal Products	165	288	177	204	12	4	7	9
Materials	628	1,057	137	87	12	4	101	131
Media	5	3	180	102	10	4	32	33
Pharma & Life Sciences	14	8	68	73	16	4	96	32
Real Estate	20	40	173	119	11	4	69	149
Retailing	15	9	140	102	11	4	61	71
Semiconductors	31	29	150	113	11	5	20	27
Software & Services	5	6	131	70	12	4	68	58
Technology Hardware	14	13	144	123	11	4	46	57
Telecommunication	5	3	180	147	11	4	86	46
Transportation	639	473	163	136	13	5	22	26
Utilities	4,226	4,606	131	107	12	4	95	136
All	544	1,877	149	111	12	4	1,449	1,469

[1] In tonnes of CO_2 per $ million revenue. [2] In basis points. [3] Rating translated into numeric values. 20 for AAA, 19 for AA+ etc. [4] In years. [5] In $ billions.

Sources: Dealogic; S&P Trucost; authors' calculations.

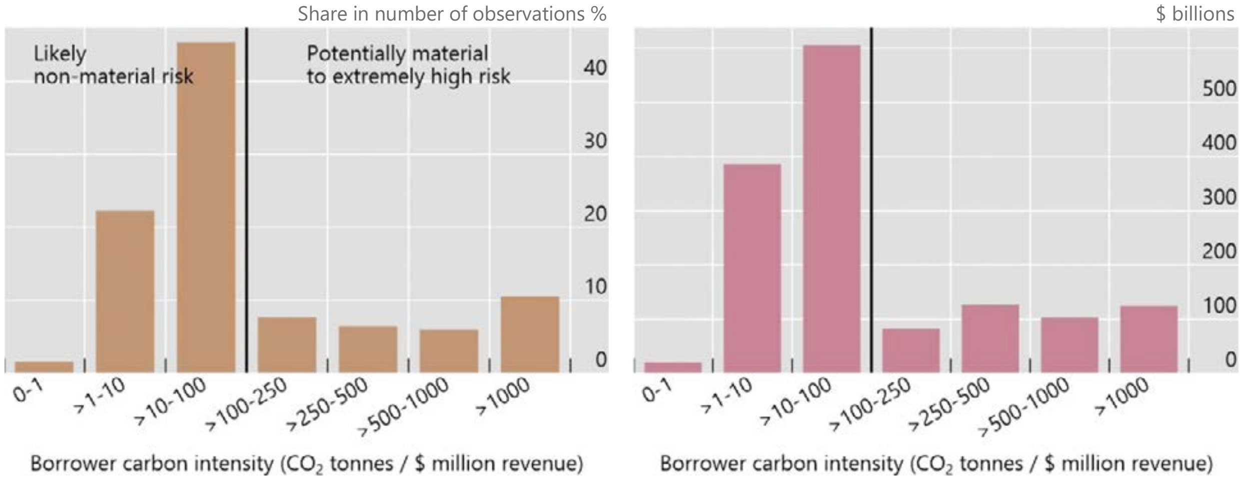
3. Materiality of carbon risk

Before turning to the pricing of carbon emission risks, it is pertinent to establish whether those risks are material enough for creditors to consider. An increasing number of firms do consider environmental factors, most importantly carbon emissions, as a material risk and disclose them accordingly in their Annual Reports (FSB (2019)). The recommendations of the FSB Task Force for Climate Related Financial Disclosures as well as mandatory disclosure requirements in major jurisdictions (eg for listed and larger unlisted firms in the UK) are testament to the fact that both market participants and regulators are increasingly demanding more information from firms on climate-related financial risk exposures (CDSB (2016)). Ilhan et al. (2020) find that institutional investors have a strong preference for firms that disclose (scope 1) emissions, suggesting that carbon risks are perceived as financially material.

To illustrate the potentially severe financial impact of the materialization of carbon emission-related risks, we do a simple thought experiment. Using the Trucost data on carbon intensities (CO_2 emissions (scope 1) in tonnes per $ million revenue), we can determine the impact of a hypothetical but realistic carbon tax[7] on firms' revenue margins. The left-hand panel of Graph 1 shows the distribution of average carbon intensities over the sample period for all firms in our sample, while the right-hand panel shows the distribution by loan value. Prominent estimates for the optimal price of carbon provide reference points for a potential carbon tax. At the lower range of optimal carbon pricing estimates are those by Nordhaus (Royal Swedish Academy of Sciences (2018)) which do not consider the need to limit global temperature increases to come close to Paris Agreement targets. According to these calculations, the economically optimal price of carbon for 2020, is around \$35/CO_2 tonnes, rising to around \$50 in 2025 and \$65 in 2030. However, using Nordhaus' model and parameters, the required carbon prices to limit temperature increases to 2.5 degree Celsius relative to the 1900 average range far above \$100 (\$186 in 2020) rising to \$350 in 2030. For intermediate estimates, the Stern-Stiglitz report (High-Level Commission on Carbon Prices 2017) suggested prices of \$40-\$80 in 2020 and \$50-\$100 in 2030 to achieve the Paris Agreement goal of limiting temperature increases relative to the 1900 average to below 2 degree Celsius.

Distribution of carbon intensity[1] Graph 1

By number of observations | By total loan amounts



1 Based on scope 1 carbon emissions.

Source: S&P Trucost; Dealogic; authors' calculations.

For a significant share of the sample firms, carbon emission risks appear to be material, even severe. With a price of \$100/CO_2 tonnes, a firm with a carbon intensity of 100 CO_2 tonnes per $ million of revenue (more than 30% of firms and loan value exceed this carbon intensity) results in a 1% loss of revenue margin – an amount that is potentially material when it comes to assessing credit risks and hence determining

7 Apart from carbon taxes, there is a multitude of policies that could lead to a materialization of environmentally-related financial risks (Nordhaus (2007)). Cap-and-trade systems, for instance, which are already in effect for carbon-intensive industries operating in the European Union, may impose costs only if carbon emissions cross a given threshold. The range of optimal prices of carbon is nevertheless a useful reference point, as they imply that any policy to achieve the Paris Climate goals would effectively have to impose an average cost of carbon equal to the optimal price. Further, from the viewpoint of a creditor bank, carbon taxes are arguably an instrument that has a high probability of being implemented on a broad scale in practice (Weitzman (2014)).

loan margins. For 10% of the firms (9% of loan value) in our sample, the carbon intensity exceeds 1000 CO_2 tonnes/$ millions of revenue. Even with carbon prices in the lower range of the above widely known estimates (eg $40/$CO_2$ tonnes), the implied losses in revenue margin (>4%) would have a significant impact on the financial health of those firms.

4. Regression analysis

Banks have an incentive to price any material risks which affect the ability of the borrower to repay. While banks can sell off syndicated loans, often to non-bank financial institutions, the originating lead-bank has a reputation at stake in the performance of syndicated loans even if it retains only a limited share. In this paper, we concentrate on the risks arising from carbon emissions. Borrowers with higher carbon emissions are more likely to face higher costs, or even hard emission constraints, if corresponding regulations tighten. For more traditional credit risks, banks and third party providers, such as rating agencies, have built extensive databases and models – not least to comply with banking regulations. Financial risks related to climate change, however, have only recently come into focus for banks, as well as regulators and supervisors. In recent years, several data providers for emission and other environmental data have emerged, including S&P Trucost, CDP, and Thomson Reuters among many others.

We start our analysis of the nature of emission-related risk pricing with an initial hypothesis that banks have started to price financial risks related to carbon emissions as the awareness of these risks and the likelihood of their materialization has increased.[8] We argue that the Paris Agreement struck in December 2015 was particularly relevant in this context, as it provided a strong and clear signal of potential tightening of carbon emission regulations. Not only did it contribute to heightening the awareness of the risks of carbon emission, it also specified quantifiable reduction targets for carbon emissions, thus providing banks with a clearer picture of the possible future path of emissions regulations.

Of course, the willingness and ability of policy makers to implement regulations to reach the emission targets specified in the Paris Agreement are subject to uncertainty. Policy makers can potentially retreat from their commitments, or entirely drop out as was briefly the case with the US.[9] Nevertheless, the clarity of the emission targets – in combination with an unusually well and strongly communicated intention of the respective governments whether or not they commit to the targets – has increased the awareness and facilitated the assessment of risks related to a tightening of carbon emission regulations.

8 The argument that awareness of climate risks affects pricing is similar to Choi et al (2020), who find that attention to climate change increases when local temperature is abnormally high. This causes stocks of carbon-intensive firms underperform firms with low carbon emissions in abnormally warm weather.

9 Though President Trump declared the intention to withdraw in June 2017, notice period requirements meant that it did not take effect until November 4, 2020. President Biden subsequently re-joined in February 2021.

4.1. Econometric model

The main variable of interest is the margins of syndicated loans, which proxies for the credit risks priced by banks. Our key hypothesis is that banks have started to price the financial risks related to carbon emissions once the Paris Agreement was struck. Our baseline panel data regression is as follows:

$$\begin{aligned} margin_{l,f,b,t} = {} & \alpha\, Carbon\ Intensity_{f,t_{year-1}} \\ & + \beta Carbon\ Intensity_{f,t_{year-1}} \times D_{post\ Paris} + \gamma X_{l,f,t} + \delta D_{b,c,t} \\ & + \varepsilon_{l,f,b,t} \end{aligned}$$

where we test whether $\beta > 0$ and $\alpha = 0$. The dummy $D_{post\ Paris}$ is a time dummy taking the value one after 2015, given that the Paris Agreement was announced in mid-December 2015. X represents a vector of dependent firm/loan variables, while D represents a vector of dummy variables capturing industry, bank and time effects. The subscript l denotes the individual loan, f the borrowing firm, b the bank syndicate and t denotes the origination date of the loan. Carbon intensity in the baseline regression is scope 1 emissions measured in tonnes of annual CO_2 emissions per \$ thousand of annual revenue (not \$ million as in Graph 1) for a given borrowing firm f. Scope 1 carbon intensity is the value at the end of the previous fiscal year, as lead banks originating the loan are assumed to have information about annual carbon emission from the past year only.

4.2. Baseline results

After presenting specifications that contain various borrower and loan-level controls, we introduce carbon intensity. We start with a specification that does not contain the interaction term of carbon intensity and the Paris Agreement to see whether banks have priced carbon-emissions related climate risks independent of the Paris Agreement (Table 3, column (3)). For the full sample period (2006-2018) we do not find an effect of carbon emission intensity on the loan margins of a given borrower. It appears that loan margins for the entire sample period are driven mainly by credit ratings of the borrower, the term spread, as well as other loan characteristics including maturity, whether a loan is leveraged and the loan amount (columns (1) and (2)). Borrower-country fixed effects as well as fixed-effects for the bank lending syndicate[10] absorb an additional large share of variation in the data.

Clearly, the determination of loan spreads by the lead bank will largely be based on borrower and loan characteristics. It is important, however, to note that the ratings in our sample do not exhibit any meaningful correlation with carbon intensity. The correlation between numeric ratings and carbon emission intensity is virtually zero (-0.049). If carbon intensity is indicative of material climate-related credit risks, they are hardly reflected in ratings in our data sample.

[10] There are hardly any bank syndicates that appear in more than one year in exactly the same composition in our sample. Hence we do not include bank syndicate x time fixed-effects. Including borrower x time fixed effects is not possible, since our main explanatory variable – carbon emission intensity – also varies over borrowers and time.

Baseline regressions[1]

Table 3

Dependent variable: loan margin in basis points; p-values in brackets.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Term Spread (bp)	0.488***	0.500***	0.499***	0.497***	0.518***	0.374***	0.587***	0.586***
Maturity (years)		-14.25***	-14.19***	-14.08***	-13.89***	-11.33***	-15.34***	-14.19***
Maturity-squared		0.457***	0.455***	0.443***	0.436***	0.401***	0.463***	0.462***
Rating: B or worse	221.7***	178.1***	177.7***	176.1***				
Rating: B+ to BB+	136.0***	103.4***	103.1***	102.7***				
Rating: BBB- to BBB	76.69***	61.96***	62.11***	61.27***				
Rating: BBB+ to A-	46.42***	34.44***	35.22***	34.90***				
Rating: A or better (Omitted – Base)								
D(Leveraged Loan)		26.60**	26.94**	26.45**	25.53**	18.05	23.32***	29.39**
D(Subordinated Loan)		261.1***	261.2***	261.8***	247.6***	254.1***	159.7**	237.8***
Log(Loan Value)		-10.80**	-10.87**	-11.08**	-7.342*	-7.230**	-4.909	-6.493*
Log(Revenue)		-2.590	-2.674	-2.975	-2.694	0.436	-4.153	-3.325
D(post Paris)				4.593	1.747	-7.308	0.139	
				(0.624)	(0.845)	(0.861)	(0.989)	
Oil Price								-0.603***
								(0.000)
Carbon Intensity			**-0.822**	**-1.367**	**-1.969**	**-7.166****	**-1.217**	**5.380**
			(0.407)	**(0.169)**	**(0.154)**	**(0.048)**	**(0.382)**	**(0.161)**
Carbon Intensity x D(post Paris)				**6.700****	**6.705****	**8.356***	**5.712***	**6.003***
				(0.023)	**(0.040)**	**(0.077)**	**(0.079)**	**(0.053)**
Observations	1,107	1,098	1,098	1,098	1,098	845	1,038	1,098
Adjusted R-squared	0.645	0.694	0.694	0.695	0.717	0.664	0.729	0.728
Borrower Country FE	Y	Y	Y	Y	Y	N	Y	Y
Bank Syndicate FE	Y	Y	Y	Y	Y	Y	Y	Y
Crisis FE	N	Y	Y	Y	Y	Y	Y	Y
Rating Dummies	N	N	N	N	Y	Y	Y	Y
CCPI x D(post Paris)[2]	N	N	N	N	N	Y	N	N
Additional Borrower Controls[3]	N	N	N	N	N	N	Y	N
Oil Price Interactions[4]	N	N	N	N	N	N	N	Y

[1] Standard errors double-clustered by borrowing firm and bank syndicate. [2] Climate Change Performance Index by Germanwatch interacted with the post Paris dummy as an additional control variable. See Table 1 for a description. [3] Additional borrower controls include operating margins, book-to-market and leverage. See main text for details. [4] In addition to the composite oil price in US dollars in the previous month included on its own, the same variable is interacted with i) the post-2015 dummy and ii) carbon intensity as additional control variables. See Table 1 and main text for more details. ***=p-value<1%, **=p-value<5%, *=p-value<10%.

When we add the interaction term of carbon intensity and the Paris Agreement dummy, its coefficient is positive at high levels of statistical significance (column (4)). This is robust to using rating dummies for single notches (AAA, AA+, AA, AA- etc) instead of ratings groups (column (5)). Our results support the findings in Ongena et al (2018), but are based on a broader sample that not only focusses on fossil fuel producers and their risks from stranded assets. Also, the nature of the risks from carbon emissions we emphasize is not necessarily the same as those related to stranded assets. Risks from carbon emissions are broader and therefore apply in principle to all industries.

While most of our specifications include borrower country fixed effects these do not allow for country hypotheses which are time-varying. As one additional exercise in specification (6) we include as a control variable an index for regulatory regime called the Climate Change Performance Index (CCPI) interacted with the post Paris dummy. This index measures how strict climate policies are in a given country. The main loan pricing results remain intact and the coefficient on the CCPI index itself is not significant.[11] That said, ceteris paribus, estimations with simple borrower country fixed effects (eg specification (5)) have a higher adjusted R-squared which suggests that in addition to differences across regulatory regime, there are other unspecified country factors that affect loan pricing.[12]

In column (7) we include additional borrower control variables from Refinitiv. These include operating margins (average over the past 3 years), the market-to-book ratio as well as the leverage of the borrower. None of the coefficients is significant, suggesting that they do not add much information beyond borrower ratings and the loan-level controls. For the regressions that follow, we leave them out.

To address the possibility that the significance for post Paris interaction terms might have been driven by declining oil prices that would have disproportionately affected high carbon emitters, in column (8) we include a specification that also controls for a composite oil price (see Table 1) in the month before loan origination as well as an interaction term of the composite oil price with firm carbon intensity (and an interaction term of the oil price with the post Paris dummy to account for a potentially different effect after the Paris Agreement). We also examined (unreported) specifications where the three month average of the oil price before loan origination was taken, and simpler specifications where we control only for oil prices and a post Paris interaction term. The main results did not change when controlling for oil prices in any of these specifications.[13]

Further, to check whether the borrowers for which carbon emissions data are estimated rather than disclosed change our main results, in an unreported regression, we added a triple interaction of carbon intensity, the post Paris dummy and a dummy that is one if its emission data is partially of fully estimated by Trucost to the column (4) specification. The triple interaction was not significant and the coefficient on the carbon intensity and post Paris interaction term remained significant and was of a similar magnitude.

11 We use the index of the previous calendar year, as for instance the 2016 index builds on 2015 data. Also, we do not use index data before 2008, as the calculation method of the index was different before the 2008 report. Hence, we loose one year of observations when using the CCPI. We also explore other country-level climate indices, including the Climate Risk Index (also by Germanwatch) that measures physical risks for a given country, and the ND-GAIN index (by the University of Notre Dame), which combines the exposure to physical risk and mitigation measures taken by countries. None of these indices can explain a significant variation of the post-2015 loan margins. There is the caveat, however, that our setup and data is not well placed to look at country variation. Most borrowers in our sample are multinational companies that operate in many countries.

12 We also test whether the carbon risk premium for US borrowers changed after the Trump administration announced the withdrawal of the US from the Paris agreement in June 2017. We cannot find any evidence, though we caution that our sample may not be long enough to yield dependable results.

13 Further evidence is provided later in Table 4, where, if risk-based pricing had been driven by the impact of declining oil prices beyond that captured in credit ratings, we would have found the sensitivity of loan margins to carbon emissions to be greater in those sectors most exposed to oil prices, ie, oil & gas & coal or utilities. However, the findings of Table 4 do not show that carbon risk premia are significantly greater in those sectors.

4.3. Carbon risk premia are not driven by any single industry

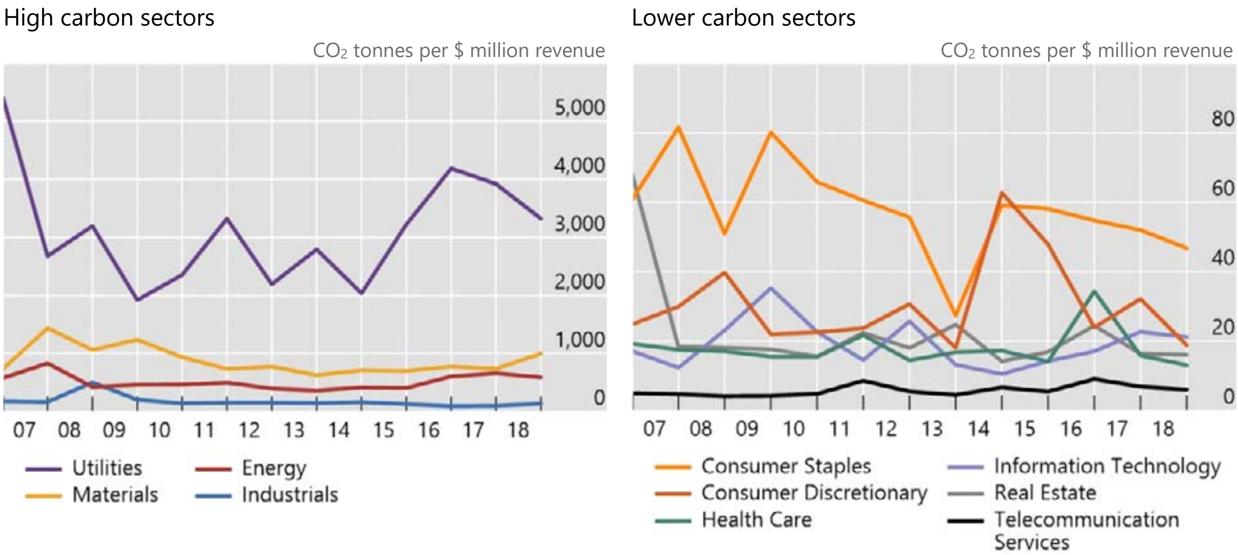
Even if banks price the potential materialization of carbon risk based on actual carbon emissions, they may still attach relatively higher prices to certain industry sectors. Mitigation policies could be mainly targeted at the most carbon-intensive sectors to achieve a large amount of reductions more quickly. Graph 2 illustrates that average carbon emissions (weighted by loan amounts) across Global Industry Classification Standards (GICS) sectors have remained relatively stable over time in our sample. Hence, sectoral differences have been highly persistent.

Our results suggest, however, that the sensitivity of loan margins with respect to carbon intensities is driven by the carbon intensity of the cross-section of firms across industries and not by the firms in any specific sector. We start with the inclusion of dummies for borrowers in oil, gas and coal-related sectors in the post 2015 (ie post Paris) period (Table 4, column (1)) based on granular GICS sub-industries. Again, in relation to previous findings in Ongena et al (2018), we take this as evidence for a more general pricing of carbon emission risks, which is not limited to sectors subject to stranded assets. We successively add dummies for other carbon-intensive sectors and find the same qualitative result. Utilities exclude water utilities, which are not typically associated with high carbon emissions. Analogously, Transport excludes GICS sub-industries related to railroad transportation. Column (5) includes separate interaction terms for each of these high-carbon sectors, with very similar results.

We view the above findings as evidence that banks price carbon risk based on actual carbon emission intensities and not only for industries subject to stranded assets.

Carbon intensity by sector[1]

Graph 2



[1] Value weighted by US dollar value of total loan origination in a given year. Sectors are determined by the GICS classification of the borrowing firm.

Source: Dealogic; Trucost; authors' calculations.

Carbon pricing is not solely driven by high-carbon industry sectors[1]

Table 4

Dependent variable: loan margin in basis point (bp), p-values in brackets.

	(1)	(2)	(3)	(4)	(5)
Carbon Intensity	-1.969	-1.972	-1.972	-1.971	-1.954
	(0.155)	(0.154)	(0.151)	(0.153)	(0.157)
Carbon Intensity	**6.776****	**7.046****	**8.411*****	**7.724*****	**7.117****
x D(post Paris)	**(0.049)**	**(0.027)**	**(0.0033)**	**(0.0099)**	**(0.025)**
D(Oil & Gas & Coal) x	-2.229				-5.633
D(post Paris)	(0.947)				(0.874)
D(Oil & Gas & Coal, Utilities) x		-2.850			
D(post Paris)		(0.911)			
D(Oil & Gas & Coal, Utilities,			-14.79		
Materials) x D(post Paris)			(0.502)		
D(Oil & Gas & Coal, Utilities,				-8.670	
Materials, Transport) x				(0.677)	
D(post Paris)					
D(Utilities) x D(post Paris)					-27.76
					(0.150)
D(Materials) x D(post Paris)					-5.470
					(0.779)
D(Transport) x D(post Paris)					57.03
					(0.297)
Observations	1,098	1,098	1,098	1,098	1,098
Adjusted R-squared	0.717	0.717	0.718	0.718	0.718
Loan-level & Borrower Controls[2]	Y	Y	Y	Y	Y
Borrower Country FE	Y	Y	Y	Y	Y
Bank Syndicate FE	Y	Y	Y	Y	Y
Crisis FE	Y	Y	Y	Y	Y
Rating Dummies	Y	Y	Y	Y	Y
Borrower Sector FE	Y	Y	Y	Y	Y

[1] Standard errors double-clustered by borrowing firm and bank consortium. ***=p-value<1%, **=p-value<5%, *=p-value<10%. FE indicates fixed effects. Crisis FE is a dummy equal to one for all loans made in 2008 or 2009. [2] For simplicity, Loan-level & Borrower Controls include all controls from the baseline model in Table 3 column (5) and not shown here.

Further evidence is provided in Table 5, where we include separate interaction terms for the sectors based on the Global Industry Classification Standards (GICS) in column (1) and all GICS industry groups in our sample in column (2). With one exception for the industry group Software & Services, where firms tend to have negligible scope 1 emissions and hence a significantly lower premium, industry groups do not seem to command a carbon premium that is different from that implied by the carbon intensity.

Intuition for our result is provided by the considerable variation of carbon intensity within sectors shown in Table 6. Pricing carbon risk based on industry averages rather than on actual firm-level emission intensities would omit the fact that there are very significant differences across firms. The findings are consistent with policy measures to achieve the Paris Climate goals that are not targeted at specific industries but rather at reducing overall carbon emissions to limit global temperature increases.

Carbon pricing is not solely driven by any industry sectors[1]

Table 5

Dependent variable: loan margin in basis point (bp), p-values in brackets.

GICS Sectors	(1)	GICS Industry Groups	(2)
Carbon Intensity x D(post Paris)	**7.106****	**Carbon Intensity x D(post Paris)**	**9.239****
	(0.041)		**(0.033)**
D(Consumer Staples) x D(post Paris)	36.56	D(Capital Goods) x D(post Paris)	0.0435
	(0.400)		(0.99)
D(Energy) x D(post Paris)	-4.624	D(Professional Services) x D(post Paris)	-32.25
	(0.912)		(0.249)
D(Health Care) x D(post Paris)	-30.00	D(Consumer Durables & Apparel) x	22.30
	(0.255)	D(post Paris)	(0.715)
D(Industrials) x D(post Paris)	1.328	D(Energy) x D(post Paris)	-7.070
	(0.954)		(0.854)
D(Information Technology) x	5.841	D(Food & Staples Retailing) x	4.046
D(post Paris)	(0.817)	D(post Paris)	(0.909)
D(Materials) x D(post Paris)	-26.26	D(Food, Beverage & Tobacco) x	-13.54
	(0.386)	D(post Paris)	(0.731)
D(Real Estate) x D(post Paris)	-7.547	D(Health Care) x D(post Paris)	-46.95
	(0.769)		(0.104)
D(Utilities) x D(post Paris)	-1.372	D(Household & Personal Products) x	145.3
	(0.966)	D(post Paris)	(0.186)
		D(Materials) x D(post Paris)	-29.63
			(0.252)
		D(Pharma & Life Sciences) x D(post	21.69
		Paris)	(0.393)
		Real Estate x D(post Paris)	-7.931
			(0.772)
		D(Retailing) x D(post Paris)	-15.76
			(0.580)
		D(Semiconductors) x D(post Paris)	12.69
			(0.658)
		D(Software & Services) x D(post Paris)	-51.54*
			(0.084)
		D(Technology Hardware) x	70.45
		D(post Paris)	(0.350)
		D(Transportation) x D(post Paris)	30.31
			(0.415)
Observations	1,098	Observations	1,098
Adjusted R-squared	0.719	Adjusted R-squared	0.726
Loan-level & Borrower Controls[2]	Y	Loan-level & Borrower Controls	Y
Borrower Country FE	Y	Borrower Country FE	Y
Bank Syndicate FE	Y	Bank Syndicate FE	Y
Crisis FE	Y	Crisis FE	Y
Rating Dummies	Y	Rating Dummies	Y

[1] Standard errors double-clustered by borrowing firm and bank consortium. ***=p-value<1%, **=p-value<5%, *=p-value<10%. FE indicates fixed effects. Crisis FE is a dummy equal to one for all loans made in 2008 or 2009. [2] For simplicity, Loan-level & Borrower Controls include all controls from the baseline model in Table 3 column (5) and not shown here.

The Consumer Discretionary GICS sector is the base in column (1) and hence omitted. The base for column (2) is the GICS Automobiles & Components industry group and hence omitted.

Financial firms, however, including banks and other private investors (CFA Institute (2017)) as well as public investors (Elsenhuber and Skenderasi (2020)), often use a so-called "best-in-class" approach when minimising carbon or ESG exposures more generally. This approach focusses on the best (or excludes the worst) performers within a given industry. In following a "best-in-class" strategy, banks may demand a higher premium for the highest polluters within a given sector. However, the results in Table 7 do not support this conjecture, again pointing to the pricing of carbon risk based on actual carbon intensities.

Mean and standard deviation of borrowers' carbon intensity by sector[1] — Table 6

Sector	Consumer Discretionary	Consumer Staples	Energy	Health Care	Industrials	Information Technology	Materials	Real Estate	Tele-communication Services	Utilities
Mean	29	113	466	20	203	23	863	20	6	3121
Std	96	253	585	20	720	55	2130	58	6	7491

[1] GICS sector of the borrowing firm. All numbers value weighted by US dollar value of total loan origination.

Source: Trucost; Dealogic; authors' calculations.

4.4. Economic significance

An important question from the policy perspective is what do the coefficients from the baseline regressions suggest about the economic magnitudes of the effects? More broadly, does the current level of premia that have been observed in syndicated loan markets since 2016 suggest that climate risks are being correctly priced, ie providing a deterrent to carbon emission producing activity that is in line with global efforts to mitigate climate change?

To start with the more narrow question, our baseline specification, model (5) of Table 3, has a coefficient of 6.7 on the regressor Carbon Intensity x D(post Paris). Since the average scope 1 carbon intensity within the sample after 2015 is 0.5 CO_2 tonnes per \$ thousand, this yields an average premium of around 3-4 basis points. For relatively high emitters, at the 90th percentile (1 CO_2 tonnes per \$ thousand) the implied premium is around 7 basis points. For firms with emissions 1 standard deviation above the mean in our sample (2.5 CO_2 tonnes per \$ thousand), the implied premium is around 17 basis points.[14]

Back of the envelope calculations suggest that the price of carbon risk in syndicated loan markets since 2016 is low relative to the material risks outlined in part 3. The top 10% of carbon emitters in our sample have a carbon intensity of >1 tonnes of CO_2 per \$ thousand of revenue (or 1000 tonnes of CO_2 per \$ million of revenue as in Graph 1). Ceteris paribus, the introduction of a carbon price of \$100 per tonne of CO_2 – well within the range of estimates of optimal carbon taxes discussed in part 3 – would imply that at least 10% of the total revenues of those firms would have to be spent on carbon taxes alone, and likely much more.[15] In our sample, the

[14] These estimates are similar to Ongena et al (2018) who find an average 2 basis point premium for their climate policy exposure measure, and a 16 basis point premium for a one standard deviation higher policy measure.

[15] The average carbon intensity of the top 1% of the emitters is 10900 tonnes CO_2 per \$ million, which implies a more than 100% hit to total revenues at a carbon price \$100 per tonne of CO_2. Even at a conservative price of \$40 per tonne of CO_2, it would imply a more than 40% hit to total revenues, which dwarfs the average operating margins of the top 1% emitters of 18.7% in our sample. The eventual financial impact would ultimately depend on the ability of firms to adjust their production

10% highest emitters have an average operating margin (earnings over revenues, before fixed costs, interest payments or taxes) over the last three years of around 13.4%. For such firms, carbon risk would be highly material and the potential financial impact is unlikely to be fully internalized by the implied 7 basis points premium.

Carbon pricing is not different for high emitters within industry sectors[1] Table 7

Dependent variable: loan margin in basis point (bp), p-values in brackets.

	(1)	(2)	(3)
Carbon Intensity	-2.066	-2.039	-2.071
	(0.144)	(0.147)	(0.145)
Carbon Intensity x D(post2015)	**7.540*** **	**5.053***	**6.199** **
	(0.00273)	**(0.0789)**	**(0.0359)**
D(above avg carbon intensity within sector) x	-3.232		
D(post Paris)	(0.801)		
D(75th percentile carbon intensity within sector) x		18.99	
D(post Paris)		(0.252)	
D(90th percentile carbon intensity within sector) x			18.21
D(post Paris)			(0.300)
Observations	1,098	1,098	1,098
Adjusted R-squared	0.705	0.706	0.706
Loan-level & Borrower Controls[2]	Y	Y	Y
Borrower Country FE	Y	Y	Y
Bank Syndicate FE	Y	Y	Y
Crisis FE	Y	Y	Y
Rating Dummies	Y	Y	Y

[1] Standard errors double-clustered by borrowing firm and bank consortium. ***=p-value<1%, **=p-value<5%, *=p-value<10%. FE indicates fixed effects. Crisis FE is a dummy equal to one for all loans made in 2008 or 2009. [2] For simplicity, Loan-level & Borrower Controls include all controls from the baseline model in Table 3 column (5) and not shown here.

Thought experiments based on the rating composition of the high emission issuers in our sample are just as uncompromising. The 10% highest emitters have an average rating of BBB, and the conservative assumption of a 10% decline in operating profit margin due to a carbon tax would lead most of these companies into margins of around 3%. But in our sample, average margins of around 3% are only observed for single B or lower-rated entities. According to the ICE BofA US high yield indices, BBB and B-rated credits in the markets were priced in mid-2018 at option-adjusted spreads at 163 and 386 basis points, respectively. Hence, a plausible change in creditworthiness resulting from the prospective tax burden corresponds to the a difference of the option-adjusted spreads of around 220 basis points – more than thirty times higher than the estimated 7 basis points carbon premium for high emitters.

5. The pricing of different carbon intensities

The literature thus far has mostly focused on scope 1 emissions – emissions from owned or controlled sources of a firm (Capasso et al (2020) and Kleimeier and

or their pricing power, ie the ability of the firms to roll over their additional costs onto their customers. But the scale of the challenge would be immense.

Viehs (2019)). However, potential financial risks from carbon emissions are not limited to a companies' controlled resources. If a company uses carbon intensive inputs in its production process, a tightening in carbon regulations and a resulting increase in input prices have a direct effect on the profitability of the firm. Analogously, increased costs for downstream activities such as carbon intensive transportation and distribution would also lower margins.

The Greenhouse Gas (GHG) Protocol, the carbon accounting standard that more than 90% of reporting firms in our sample apply, defines two additional scopes of emissions (GHG Protocol (2017)): Scope 2 emissions – indirect emissions from electricity consumption; and scope 3 emissions, which cover further indirect emissions along the value chain such as from production of purchased materials, transport-related activities and outsourced activities.[16]

Do banks also price the risks from scope 2 and 3 emissions? Our results suggest that banks primarily focus on scope 1 emissions. Table 8 presents the results for our baseline specification, comparing different carbon scopes. In columns (2) and (3) we successively add higher scopes with the effect that the carbon intensity terms become a lot less significant. In column (4) we include separate interaction terms for each carbon scope. Scope 2 emissions do show up as significant and positive post Paris (ie after 2015). However, the point estimates are an order of magnitude smaller than for scope 1 emissions and average scope 2 emissions are only about one-tenth of scope 1 emissions in our sample. Further, the coefficient estimate of the scope 1 carbon intensity and post Paris interaction term changes only marginally from that reported in the baseline model in column (1).

Overall, we take this as evidence that banks' view on carbon risk is still relatively narrow. Policy measures aimed at reducing overall carbon emissions affect the entire value chain of a company. A focus on risks from direct emissions, as captured in scope 1, may seem rational at first. Highly electric energy-intensive production, as captured in scope 2, could be moved and outsourced to jurisdictions where carbon reduction policies are not in place and less likely to be implemented. A growing literature has documented such effects (eg Ben-David et al (2021)). Scope 3 emissions would look though such "carbon emission exporting", but the GHG protocol standards allow considerable discretion for reporting firms to define the perimeter for calculating scope 3 emissions. Carbon emission exporting, however, cannot lower the underlying risks and could well turn out to be inefficient, as policy makers become more capable of implementing effective carbon emission reduction measures.

6. Do "green" banks price carbon risk differently?

A natural question about our main result is whether the pricing of carbon risk post 2015 after the Paris Agreement is driven by "greener" banks. We consider a bank as "green" if it openly recognizes the challenges posed by environmental and social issues and introduces needed actions into all aspects of its operations. Practically, we

[16] While our data from Trucost fully covers borrowing firms' scope 2 emissions, it only covers "upstream" scope 3 emissions from production inputs and not the entirety of scope 3 emissions as usually defined.

Pricing of carbon intensity – scopes 1-3[1]

Table 8

Dependent variable: loan margin in basis point (bp), p-values in brackets.

	(1)	(2)	(3)	(4)
Carbon Intensity Scope 1	-1.969			-1.232
	(0.154)			(0.350)
Carbon Intensity Scope1 x D(post Paris)	**6.705****			**6.118***
	(0.0399)			**(0.0677)**
Carbon Intensity Scope 1+2		-1.819		
		(0.191)		
Carbon Intensity Scope 1+2 x D(post Paris)		5.548		
		(0.130)		
Carbon Intensity Scope 1-3			-1.855	
			(0.200)	
Carbon Intensity Scope 1-3 x D(post Paris)			5.545	
			(0.101)	
Carbon Intensity Scope2				-0.0979**
				(0.0270)
Carbon Intensity Scope 2 x D(post Paris)				0.189**
				(0.0398)
Carbon Intensity Scope3				-0.0161
				(0.299)
Carbon Intensity Scope 3 x D(post Paris)				0.0226
				(0.404)
Observations	1,098	1,098	1,098	1,098
Adjusted R-squared	0.717	0.717	0.717	0.721
Loan-level & Borrower Controls[2]	Y	Y	Y	Y
Borrower Country FE	Y	Y	Y	Y
Bank Syndicate FE	Y	Y	Y	Y
Crisis FE	Y	Y	Y	Y
Rating Dummies	Y	Y	Y	Y

[1] Standard errors double-clustered by borrowing firm and bank consortium. ***=p-value<1%, **=p-value<5%, *=p-value<10%. [2] For simplicity, Loan-level & Borrower Controls include all controls from the baseline model in Table 3 column (5) and not shown here.

classify banks as green banks if they signed the Equator Principles or the United Nations Environment Programme – Finance Initiative (UNEP FI). The Equator Principles are a risk management framework of environmental and social risk in project finance which defines roles and responsibilities of lenders and borrowers in determining, assessing, and managing these risks. The Principles have been adopted by 92 commercial financial institutions. The UNEP Finance Initiative is a global partnership between UNEP and the financial sector. The initiative aims to understand the effect of environmental and social considerations on financial performance. Over 200 members (banks, insurers, and fund managers) have joined the initiative.[17]

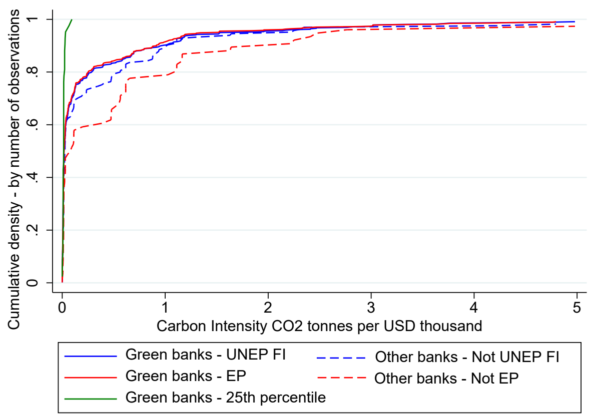
For purposes of comparison, we also group the loans from lead banks with loans that have relatively low average carbon intensities (those lead banks in the lowest 25% percentile range of the carbon intensity distribution as far as their syndicated loans go). We label these as "de facto" green banks.

[17] The list of participating banks for the Equator principles is available at (http://equator-principles.com/members-reporting/ Accessed April 2020) and that for UNEP FI at (http://www.unepfi.org/members/banking/ Accessed April 2020))

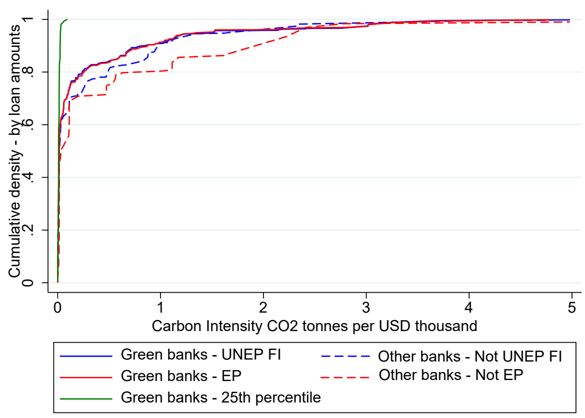
Within our sample, banks identified as green by either the United Nation (UNEP FI) or the Equator Principles (EP) do tend to have a greater proportion of loans with lower carbon intensity, both absolutely, or weighted by loan value, than other banks (Graph 3). Clearly, the proportions of the loan books occupied by lower carbon vs. high loan emitters are related to the UN or EP bank designations. That said, Graph 3 shows that the so-labelled green banks are far away from the de facto green banks.

Carbon Intensity Scope 1 distribution for green banks — Graph 3

Cumulative density



Cumulative density weighted by loan value



Source: S&P Trucost; authors' calculations.

In Table 9 we test if loans originated by "green" lead banks—either identified as such by the United Nations or those officially adhering to the Equator Principles, or simply "de facto" green banks—exhibit a higher price of carbon risk– for instance, due to a higher awareness of climate-related risks of the lead banks. As some syndicated loans have more than one lead bank, we identify a syndicated loan as a loan from a green bank, if at least one lead bank fulfils the corresponding green criterion. Columns (1) and (2) show the results using the two institutional classifications of green banks, which all imply that the pricing of carbon risk is not significantly different across "green" vs. other lead banks. If anything, green banks seem to be attaching a lower price of carbon risk (though the coefficients are not statistically significant at conventional levels). Neither do the lead banks of syndicated loans of particularly low average carbon-intensity – less than the 25th percentile of lead banks in the sample – exhibit a significant difference in their carbon pricing (column (3)). Further, lead banks that are exceptionally tolerant in their lending toof high carbon emitters (greater than the 75th percentile) also show no significance differences in pricing (column (4)).

Since pricing of carbon emissions risks does not differ when the loans are arranged by lead banks identified as green, this is consistent with a competitive loan market in which climate change transition risks are priced by all banks. Thus, the risks of loans related to carbon emissions are priced similarly regardless of the banks' internal policies and relative exposure. Adjustment of the labelled or de facto green lead banks' quantities of loans outstanding is not associated with an observed differential price impact.

"Green" banks and carbon risk pricing[1]

Table 9

Dependent variable: loan margin in basis point (bp), p-values in brackets.

	(1)	(2)	(3)	(4)
Carbon Intensity x D(post Paris)	12.94	33.99	7.223**	8.104***
	(0.346)	(0.183)	(0.0276)	(0.0045)
D(UNEP FI member) x Carbon Intensity x D(post Paris)	**-7.363**			
	(0.603)			
D(Equator Principles signee) x Carbon Intensity x D(post Paris)		**-28.82**		
		(0.258)		
D(25th percentile carbon intensity of loan portfolio) x Carbon Intensity x D(post Paris)			**-15.61**	
			(0.336)	
D(75th percentile carbon intensity of loan portfolio) x Carbon Intensity x D(post Paris)				**-12.54**
				(0.577)
Observations	1,098	1,098	1,098	1,098
Adjusted R-squared	0.708	0.708	0.708	0.708
Loan-level & Borrower Controls[2]	Y	Y	Y	Y
Borrower Country FE	Y	Y	Y	Y
Bank Syndicate FE	Y	Y	Y	Y
Rating Dummies	Y	Y	Y	Y

[1] Standard errors double-clustered by borrowing firm and bank consortium. ***=p-value<1%, **=p-value<5%, *=p-value<10%. [2] For simplicity, Loan-level & Borrower Controls include all controls from the baseline model in Table 3 column (5) and not shown here.

7. Robustness checks

The fact that carbon risk is priced after 2015 is very robust and survives various controls and specifications is discussed above. In Table 10 we test whether carbon risk was priced even earlier. The evidence is strongest for a pricing of risks post-2015, as the Chow test statistic for a structural break after 2015 has the lowest p-value (p=0.040), though a break a year earlier, starting from 2015, cannot be ruled out (p=0.052). One interpretation may be that the awareness with respect to environmental risks started to build in 2015, culminating in the Paris Agreement in December. We do not take this as evidence against the robustness of the pricing of carbon risk post-2015, however.

Our key dependent variable is loan margins. Margins, however, do not necessarily cover all borrowing costs, as banks normally charge additional fees. We therefore run our baseline regressions with an "all in pricing" margin measure that includes both the margin and all fees that banks are charging on an ongoing basis. In particular, this includes utilization fees, which banks charge when a large part of the loan is disbursed to compensate for regulatory capital costs, as well as facility fees, which are paid by the borrower for a standing credit line with the syndicate. The results are summarized in Table 11. The results are almost identical (columns (1) and (2)) to those of the regressions with margins as the dependent variable (Table 3, columns (4) and (5)). Fees themselves (Table 11, columns (3) and (4)) do not seem to have any relation with the carbon intensity of the borrower.

Year by year regressions[1]

Table 10

Dependent variable: loan margin in basis point (bp), p-values in brackets.

	(1)	(2)	(3)	(4)	(5)	(6)
Carbon Intensity x D(post 2010)	-0.287					
	(0.929)					
Carbon Intensity x D(post 2011)		2.897				
		(0.359)				
Carbon Intensity x D(post 2012)			3.015			
			(0.345)			
Carbon Intensity x D(post 2013)				4.876		
				(0.146)		
Carbon Intensity x D(post 2014)					6.243*	
					(0.0521)	
Carbon Intensity x D(post Paris)						**6.705****
						(0.0399)
Chow test[2] p-value	0.929	0.359	0.345	0.146	0.052*	**0.040****
Chow test[2] F-stat	0.008	0.846	0.896	2.124	3.817	**4.277**
Observations	1,098	1,098	1,098	1,098	1,098	1,098
Loan-level Controls	Y	Y	Y	Y	Y	Y
Loan-level & Borrower Controls[3]	Y	Y	Y	Y	Y	Y
Bank Syndicate FE	Y	Y	Y	Y	Y	Y
Rating Dummies	Y	Y	Y	Y	Y	Y
Cluster by Firm & Bank Syndicate	Y	Y	Y	Y	Y	Y

[1] Standard errors double-clustered by borrowing firm and bank consortium. ***=p-value<1%, **=p-value<5%, *=p-value<10%. [2] Joint test of estimated coefficients for the time dummy D(post Year)=0 and equality of estimated coefficients on Carbon Intensity and the interaction term Carbon Intensity x D(post Year). [3] For simplicity, Loan-level & Borrower Controls include all controls from the baseline model in Table 3 column (5) and not shown here.

8. Conclusions

The evidence from our analysis for the pricing of carbon risk in the syndicated loan market is mixed. We do find a risk premium charged to borrowing firms with higher carbon intensities since the Paris Agreement, and the premium is not driven by firms in particular industries. But the level of the premium appears small relative to the material risks. Further, only those emissions narrowly attributable to the firm's own resources (scope 1) are priced, rather than the broader carbon footprint of the firm including indirect emissions related to energy consumption (scope 2) and production inputs (scope 3). Though self-identified and de facto "green banks" may be lending less to high carbon emitters than other banks, they do not appear to be charging a higher carbon premium.

The above results point towards clear normative policy implications. Regulators and supervisors of financial institutions should design incentives to ensure regulated participants fully internalize the environmental impact of their activities, in particular on *higher-level* carbon emissions. One way of doing this is to implement incentives and penalties to key off ratings based on higher-level carbon emissions (see Ehlers et al (2020) for a stylized example of such a scheme). While regulators and supervisors of financial institutions are already taking measures to raise awareness of climate risks among banks (BCBS (2020)), they should redouble their efforts to ensure

All-in pricing and fees[1]				Table 11
	(1) All in Pricing	(2) All in Pricing	(3) Fees	(4) Fees
Term Spread (bp)	0.529***	0.530***	0.0103	0.0107
Maturity (years)	-15.64***	-15.39***	-1.545**	-1.574**
Maturity-squared	0.483***	0.474***	0.0355*	0.0358*
D(Leveraged Loan)	21.47*	22.37*	-4.015	-3.921
D(Subordinated Loan)	244.3***	247.8***	-3.598	-3.322
Log(Loan Value)	-7.732*	-7.774*	0.0571	0.105
Log(Revenue)	-2.370	-2.666	0.00758	-0.131
D(post Paris)	-1.501		-2.955	
Carbon Intensity	**-2.223**	**-2.124**	**-0.225**	**-0.210**
	(0.149)	**(0.176)**	**(0.343)**	**(0.374)**
Carbon Intensity x	**6.829****	**7.203****	**0.0389**	**0.0153**
D(post Paris)	**(0.0463)**	**(0.0456)**	**(0.947)**	**(0.980)**
Observations	1,099	1,099	1,095	1,095
Adjusted R-squared	0.731	0.733	0.548	0.550
Borrower Country FE	Y	Y	Y	Y
Bank Syndicate FE	Y	Y	Y	Y
Crisis FE	Y	Y	Y	Y
Rating Dummies	Y	Y	Y	Y
Sector FE x D(post Paris)	N	Y	N	Y

[1] Standard errors double-clustered by borrowing firm and bank consortium. ***=p-value<1%, **=p-value<5%, *=p-value<10%.

those institutions are prepared for and internalizing the potential for the higher levels of carbon taxes implied by the Paris emission reduction goals (NGFS (2020)). An issue that has received relatively little attention in policy discussions is the decisive scope of emissions. Transition risks can affect firms not only through their direct emissions but also through reliance on carbon-intensive inputs. Ensuring greater disclosure and availability of such measures through, for example, the application of environmental standards based on broader scopes, would be highly desirable.

Central banks, both as a provider of services to the banking system and through their implementation of monetary policy decisions, can also contribute to a pricing of carbon risk that is commensurate with the corresponding risks. As a start, central banks could send a strong signal by taking into account such risks in their monetary operations, such as credit provision, collateral policies or asset purchases (NGFS (2021)). For example, central banks could adjust the eligibility of collateral that define the range of securities that can be used for credit operations, to reflect the climate risk profile of the issuers of said collateral. Similarly, the haircuts at which such collateral is accepted could be calibrated to reflect the carbon risk of the issuer.

While climate change mitigation through carbon emission reduction is a key global environmental goal, there are others. Efforts to ensure that the pricing of outcomes related to water security, biodiversity or climate adaptation are in line with the internalization of policy objectives will also be an important item for the "green" policy agenda going forward (Dasgupta (2021), Sustainable Finance Platform (2020)).

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The pricing of carbon risk in syndicated loans

Which risks are priced and why?

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Disclaimer: The views expressed here are those of the authors and do not necessarily represent those of the IMF or BIS

Motivation

- Climate-related risks (eg necessary policy measure for a transitioning to a low carbon economy) can lead to potentially large **revaluations** of financial assets (Carney (2015), Batten et al (2016), Dietz et al (2016))

- The resulting vulnerability of banks to rapid revaluation of carbon-intensive assets poses **credit risks** (Weyzig et al 2014; Bank of England 2015; ESRB 2016; Battiston et al 2016)

- ECB Banking Supervision – Risk Assessment for 2020:

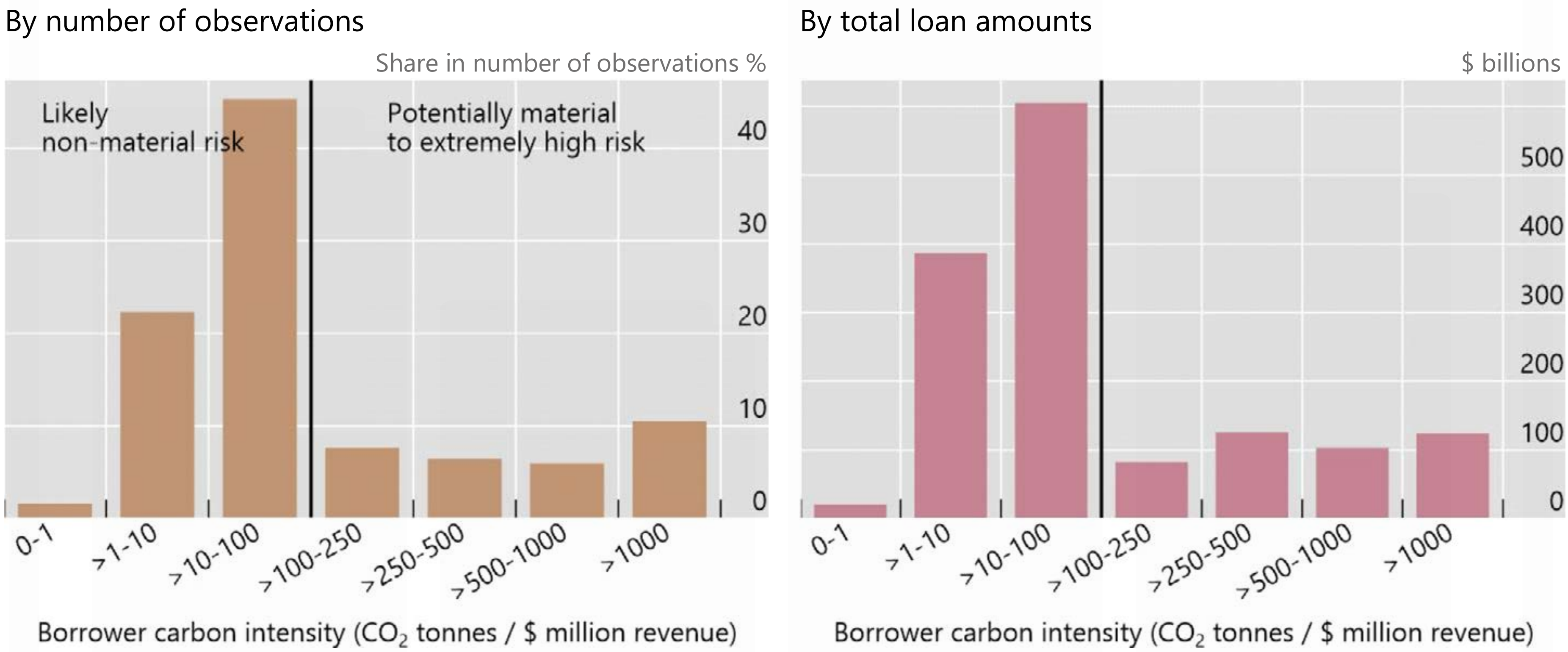
"The economic costs of physical risks are growing steadily, and, at the same time, transitional risks are on the rise, as public policies are increasingly targeting the climate neutrality and environmental sustainability of economic activities."

Research question and setup

- Does borrower-specific carbon emission-related credit risks affect the pricing in the corporate loan market?
- The pricing of risk is pertinent to channeling more investments into “green” projects (which is one of the stated goals of the Paris Accord)
- Risks are higher, if companies have higher carbon emissions
  - Eg costs that would occur if carbon taxes or emission trading schemes are introduced or levies are increased
  - This is a relevant credit risk, as it impacts the ability to repay debt -> banks should price these risks
- We match firm-specific actual carbon emission data (12000+ listed firms, >90% of global market cap) with syndicated loan data

Are environmentally-related credit risks material (enough)?

Distribution of carbon intensity[1] Graph 1



[1] Based on scope 1 carbon emissions.

Source: S&P Trucost; Dealogic; authors' calculations.

Key results

- The premia for carbon risk, as measured by firm-specific CO_2 emission intensities, are significantly priced, but only since the Paris accord agreement (end-2015)

- The difference in risk premia due to CO_2 emissions is apparent both within industry sectors as well as across industry sectors

- Only greenhouse gas emissions directly caused by the firm are priced (scope 1), and not those indirectly caused by production inputs, transportation or use of final products (scopes 2 or 3)

- "Green" banks—either self-identified or those that lend less to carbon-intensive sectors—do not appear to price risks differently from other banks.

- The carbon risk premium appears to be low relative to the implied credit risks

Econometric model

- $margin_{l,f,b,t} = \alpha\ Carbon\ Intensity_{f,t-1} + \beta\ Carbon\ Intensity_{f,t-1} \times D_{Paris\ Accord}$
$$+\gamma X_{l,f,t} + \delta D_{b,c,t} + \varepsilon_{l,f,b,t}$$

Data	Description	Source
Carbon Intensity	Disclosed and estimated scope 1 emission intensity	*TruCost (S&P Global)*
$D_{Paris\ Accord}$	Post 2015 dummy = 1 post 2015	
X	**Term spread, loan and firm controls**: amount, maturity, collateral, rating, leverage	*Central banks, Bloomberg; Syndicated loan data*
D	**fixed effects**: time, borrower country, and bank effects	*Syndicated loan data*

- *Hypothesis:* Banks have started to price the financial risks related to carbon emissions as the Paris Accord was struck => $\boldsymbol{\beta > 0}$.

Baseline regressions[1] | Table 3

Dependent variable: loan margin in basis points; p-values in brackets.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Term Spread (bp)	0.488***	0.500***	0.499***	0.497***	0.518***	0.374***	0.587***	0.586***
Maturity (years)		-14.25***	-14.19***	-14.08***	-13.89***	-11.33***	-15.34***	-14.19***
Maturity-squared		0.457***	0.455***	0.443***	0.436***	0.401***	0.463***	0.462***
Rating: B or worse	221.7***	178.1***	177.7***	176.1***				
Rating: B+ to BB+	136.0***	103.4***	103.1***	102.7***				
Rating: BBB- to BBB	76.69***	61.96***	62.11***	61.27***				
Rating: BBB+ to A-	46.42***	34.44***	35.22***	34.90***				
Rating: A or better (Omitted – Base)								
D(Leveraged Loan)		26.60**	26.94**	26.45**	25.53**	18.05	23.32***	29.39**
D(Subordinated Loan)		261.1***	261.2***	261.8***	247.6***	254.1***	159.7**	237.8***
Log(Loan Value)		-10.80**	-10.87**	-11.08**	-7.342*	-7.230**	-4.909	-6.493*
Log(Revenue)		-2.590	-2.674	-2.975	-2.694	0.436	-4.153	-3.325
D(post Paris)				4.593	1.747	-7.308	0.139	
				(0.624)	(0.845)	(0.861)	(0.989)	
Oil Price								-0.603***
								(0.000)
Carbon Intensity			**-0.822**	**-1.367**	**-1.969**	**-7.166****	**-1.217**	**5.380**
			(0.407)	**(0.169)**	**(0.154)**	**(0.048)**	**(0.382)**	**(0.161)**
Carbon Intensity x D(post Paris)				**6.700****	**6.705****	**8.356***	**5.712***	**6.003***
				(0.023)	**(0.040)**	**(0.077)**	**(0.079)**	**(0.053)**
Observations	1,107	1,098	1,098	1,098	1,098	845	1,038	1,098
Adjusted R-squared	0.645	0.694	0.694	0.695	0.717	0.664	0.729	0.728
Borrower Country FE	Y	Y	Y	Y	Y	N	Y	Y
Bank Syndicate FE	Y	Y	Y	Y	Y	Y	Y	Y
Crisis FE	N	Y	Y	Y	Y	Y	Y	Y
Rating Dummies	N	N	N	N	Y	Y	Y	Y
CCPI x D(post Paris)[2]	N	N	N	N	N	Y	N	N
Additional Borrower Controls[3]	N	N	N	N	N	N	Y	N
Oil Price Interactions[4]	N	N	N	N	N	N	N	Y

[1] Standard errors double-clustered by borrowing firm and bank syndicate. [2] Climate Change Performance Index by Germanwatch interacted with the post Paris dummy as an additional control variable. See Table 1 for a description. [3] Additional borrower controls include operating margins, book-to-market and leverage. See main text for details. [4] In addition to the composite oil price in US dollars in the previous month included on its own, the same variable is interacted with i) the post-2015 dummy and ii) carbon intensity as additional control variables. See Table 1 and main text for more details. ***=p-value<1%, **=p-value<5%, *=p-value<10%.

Carbon emissions: disclosure and scopes

- An increasing number of firms (around 4500 in the TruCost database) disclose their emissions (in annual reports or supplementary reports)

- Emissions for other firms (6000+ in the TruCost database) are calculated based on an industry-standard model ("process-based EEIO model" based on the "GHG Protocol Corporate Standard")

- Three different types of carbon emission measures
  - Scope 1: direct emissions from owned or controlled sources
  - Scope 2: indirect emissions from the generation of purchased energy
  - Scope 3: all indirect emissions (not included in scope 2) that occur in the value chain of the reporting company (ie inputs, distribution etc) -> in our sample only "upstream"

Carbon emission scopes

Pricing of carbon intensity – scopes 1-3[1]

Table 8

Dependent variable: loan margin in basis point (bp), p-values in brackets.

	(1)	(2)	(3)	(4)
Carbon Intensity Scope 1	-1.969			-1.232
	(0.154)			(0.350)
Carbon Intensity Scope1 x D(post Paris)	**6.705****			**6.118***
	(0.0399)			**(0.0677)**
Carbon Intensity Scope 1+2		-1.819		
		(0.191)		
Carbon Intensity Scope 1+2 x D(post Paris)		5.548		
		(0.130)		
Carbon Intensity Scope 1-3			-1.855	
			(0.200)	
Carbon Intensity Scope 1-3 x D(post Paris)			5.545	
			(0.101)	
Carbon Intensity Scope2				-0.0979**
				(0.0270)
Carbon Intensity Scope 2 x D(post Paris)				0.189**
				(0.0398)
Carbon Intensity Scope3				-0.0161
				(0.299)
Carbon Intensity Scope 3 x D(post Paris)				0.0226
				(0.404)
Observations	1,098	1,098	1,098	1,098
Adjusted R-squared	0.717	0.717	0.717	0.721

[1] Standard errors double-clustered by borrowing firm and bank consortium. ***=p-value<1%, **=p-value<5%, *=p-value<10%. [2] For simplicity, Loan-level & Borrower Controls include all controls from the baseline model in Table 3 column (5) and not shown here.

Other robustness checks

- Is the result driven by high-carbon intensive sectors (literature thus far has concentrated on those) -> No

- What about fees not reflected in margins? -> Fees themselves are not significant, but margins plus all fees ("All-in pricing") yield very similar results

- Are carbon risks priced before the Paris Agreement -> No, though we find weakly significant pricing a year earlier already

- Does climate policy stringency (on a country level) change the results -> we do not find evidence, though our setup is not designed for this (firm-level analysis)

Economic significance

- Our baseline specification has a coefficient of around 6.7 on the regressor $Carbon\ Intensity_{f,t-1} \times D_{Paris\ Accord}$, sample avg (std) carbon intensity (scope 1) after 2015 is 0.5 (2.5), for the 10% highest emitters about 1 CO2 tonnes per *thousand* USD
  - Yields an **average premium of around 3-4bp**
  - **For the 10% highest emitters, the premium is 7 bp**
  - For the **emitters 1 std above mean, the implied premium is around 17bp**

- Premia appear to be **low relative to the implied credit risks**
  - Ceteris paribus, the introduction of a carbon price of \$100 per tonne of CO2 would imply that at least 10% of the total revenues of the 10% highest emitting firms would have to be spent on carbon taxes alone
  - The significant impact on credit risks looks small relatively to 17bp premium

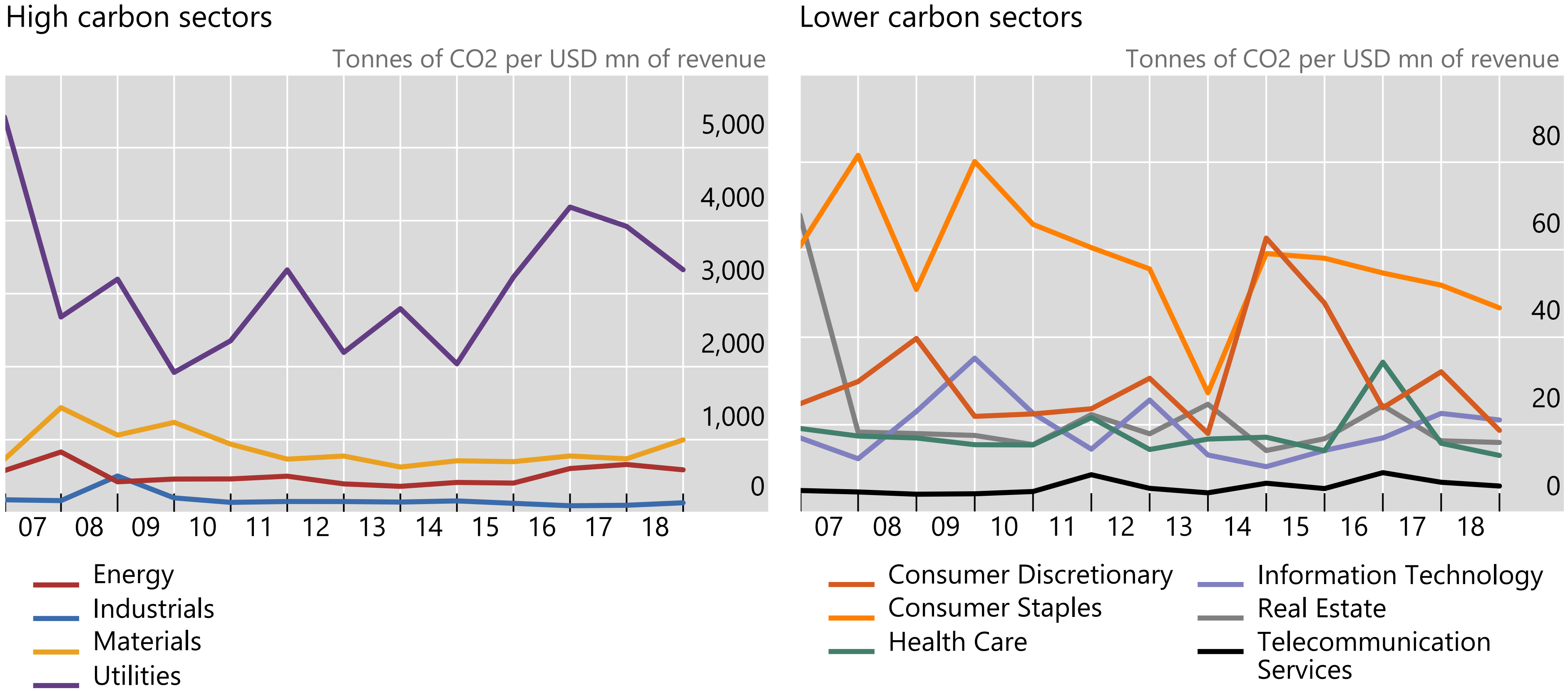
BIS

Additional slides

Carbon intensity (scope 1) by sector

Carbon Intensity by sector[1]

Graph 2



[1] Value weighted by US dollar value of total loan origination.

Source: Dealogic; TruCost; authors' calculations.

Materiality – thought experiment

- Say scope 1 carbon intensity is 3000 tonnes of CO_2 per USD mn (annual) – slightly lower than the sample average for the utilities sector
- Assume the optimal price / social cost of carbon is 50 USD per tonne of CO_2 (lower end)
- Implies that the cost of carbon emissions of 15% of total revenue (50USD/ton*3000tonnes/1000000USD=0.15)
- Compare this to (net) operating profit margins which were around 11.5% (17.5% pre-tax) for the utilities sector (averages for 2018)
- For the materials sector, scope 1 carbon intensity around 1000 ton of CO_2 per USD mn (annual), net operating profit margins are 8%

Carbon intensities vary widely *within* sectors

Mean and standard deviation of borrowers' carbon intensity by sector[1] — Table 6

Sector	Consumer Discretionary	Consumer Staples	Energy	Health Care	Industrials	Information Technology	Materials	Real Estate	Tele-communication Services	Utilities
Mean	29	113	466	20	203	23	863	20	6	3121
Std	96	253	585	20	720	55	2130	58	6	7491

[1] GICS sector of the borrowing firm. All numbers value weighted by US dollar value of total loan origination.

Source: Trucost; Dealogic; authors' calculations.

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Everything you always wanted to know about green bonds (but were afraid to ask)[1]

Danilo Liberati and Giuseppe Marinelli,
Bank of Italy

[1] This presentation was prepared for the conference. The views expressed are those of the authors and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

Everything you always wanted to know about green bonds (but were afraid to ask)

Danilo Liberati and Giuseppe Marinelli[1]

Abstract

This paper presents a comprehensive study of the ESG (Environmental, Social and Governance) bond market which has experienced a dramatic expansion in the last few years and is about to gain an additional boost due to the forthcoming implementation of the Next Generation plan of the European Union. We use a security-by-security data set comprising a large sample of ESG bonds (15,500) exchanged on the main global security markets integrated with microdata employed in official statistics such as financial accounts and security holdings. First we describe the most salient features of the global supply of ESG bonds by analyzing issuers' and securities' characteristics, the differences across countries, sectors and their evolution over time. Second, we shed light on Italian residents' holdings of ESG bonds with a focus on sectoral holdings in the context of the financial accounts statistics. Third, we employ a twofold approach to the assessment of the *greenium*, i.e. the negative yield difference between ESG bonds and their conventional counterparts. We estimate monthly time-series of yield curves, we derive the implied yield difference and investigate whether it is statistically significant. Finally we exploit an econometric strategy based on security-level panel regressions and we find strong evidence for the existence of the *greenium* and for its increase following the Covid-19 shock.

Keywords: ESG bonds, *greenium*, Covid-19

JEL classification: C33, G12, G21, Q56

[1] Bank of Italy, Directorate General for Economics, Statistics and Research. We would like to thank Paolo Angelini, Silvia Fabiani, Laura Graziani Palmieri, Luigi Infante, Giorgio Nuzzo, Alfonso Rosolia, Roberto Sabbatini, Luigi Federico Signorini and the participants who attended the Bank of Italy seminar (Rome, July 2021) and the International Conference on Statistics for Sustainable Finance (Paris, September 2021) for the useful comments.. The opinions expressed and conclusions drawn are those of the authors and do not necessarily reflect the views of the Bank of Italy and of the Eurosystem.

Contents

1. Introduction

Climate change and its impact on financial markets and institutions have recently become a significant topic in the economic debate.[2] The development of a transitional economic model allowing a sustainable growth is one of the key-challenges for policy makers, economic agents and financial markets in the coming years. The pandemic crisis brought about a wake-up call on the correct assessment of the climate-related risks, as pointed out by Schumacher (2020) and Schnabel (2020):

> *The pandemic is therefore a stark reminder that preventing climate change from inflicting permanent harm on the global economy requires a fundamental structural change to our economy, inducing systematic changes in the way energy is generated and consumed.*

The *green finance gap*, i.e. the lack of the necessary financial resources to be addressed towards green investments, represents a relevant limitation for the green structural change of the economy. Apparently, green projects can be judged as not sufficiently attractive for investors due to the seemingly low rate of return[3] and the associated risks.[4] Nevertheless, the rapid growth of the environmental, social and governance (ESG) bond[5] market suggests that a vigorous interest of investors does exist. ESG bonds are debt securities whose proceeds are invested by the issuer so as to pursue environmental, sustainability and social purposes such as the reduction of CO_2 emissions, the increase of energy efficiency, enhancement of the health care and of workers' conditions in terms of safety, inclusion. The increasing importance of such instruments is proven by the fact that the main stock exchanges of the world have all launched sustainable/green market segments or have come to participate in the Sustainable Stock Exchanges initiative.[6]

The ESG bond market can be analyzed in several aspects. A first focus area is represented by the implications that the environmentally-sustainable finance has on the issuing firms value. Issuances of ESG bonds are generally more expensive than those of conventional securities due to the external and independent reviewer cost to certificate that the use of the proceeds of the green bonds is aligned to ESG criteria. On the other hand, issuing ESG debt securities represents a positive signal in terms

[2] See the 2015 Paris Agreement and the 2030 Sustainable Development Agenda.

[3] See Yoshino et al. (2019).

[4] Hafner et al. (2020) claims that investors' reluctance regarding green investments depends on several factors as the lack of confidence given the technology risks, lack of information and experience, unstable energy policies, high transition and commercialization costs, etc..

[5] We will be using `ESG bonds' and `ESG debt securities' interchangeably throughout the paper when referring to the whole set of debt securities with the ESG label and belonging to the commonly-known sustainable market. Indeed, green bonds represent 85% percent of our ESG dataset; furthermore, in some few cases we find a misclassification among sources for the same security, in particular for green and sustainable securities.

[6] See https://sseinitiative.org and https://www.climatebonds.net.

of transparency and firms' value may increase in the long-run[7] benefiting from a reduced level of information asymmetry.

Second, green bonds may turn out to be a convenient source of funding. Many studies have tried to verify the existence of a *greenium* puzzle, i.e. a negative premium on ESG debt securities,[8] thus implying that investors obtain lower returns from such instruments when compared to the conventional counterparts. At the same time this would result in lower borrowing costs for issuers offering ESG instruments to investors.

Third, the transition to a low-carbon economy can be favored by the role of policy makers as central banks and regulators. Hence, both macroprudential and non-standard monetary policies might affect investments in climate-friendly or sustainable assets mitigating CO_2 emissions and favoring green projects financing. This claim becomes even more relevant starting from 2020, with the Covid-19 shock hitting the global economy and slowing down green investments, as shown by Guérin and Suntheim (2021). A special role could be played by Governments leading and managing the ecological transition:[9] following the positive experiences of Germany and France, in March 2021, to finance public expenditures with positive environmental impact, Italy successfully issued its first green bond with an enthusiastic response of investors.[10]

The contribution of this paper is threefold. First, we comprehensively describe the global supply of ESG bonds over time, across countries and sectors with an analysis of the amount issued, the number of issuers, maturity, riskiness and liquidity. Second, we focus on Italian residents' holdings of ESG debt securities and we show the increasing weight of such instruments in financial portfolios of banks and institutional investors. Finally, we contribute to the debate on the *greenium* puzzle with robust econometric results showing the existence of a negative premium on ESG bonds and its heterogeneity across sectors and over time due to the Covid-19 shock. The rest of the paper is structured as follows. The next section provides a review of the growing literature on ESG instruments; section 3 describes the construction of the data set whereas section 4 and section 5 focus on the characteristics of the global supply of ESG bonds and on Italian residents' holdings, respectively. Section 6 sheds light on the *greenium* puzzle and section 7 concludes.

7 On the other hand, the "*greenwashing*" phenomena may arise when the communication strategy of firms addressed to enhance their environmental reputation is not supported by data and results, or it is voluntary used to distract investors from the true profile of the company.

8 The expression "*greenium*" is usually specifically referred to green bonds but for the sake of brevity we will be using it for the entire set of ESG bonds.

9 See also the recent remarks by Banca d'Italia Governor at the `Financing Carbon Neutrality' Round Table of the annual conference of the Boao Forum for Asia and the presentation of the G20 TechSprint 2021 on sustainable finance.

10 See the MEF Press Release.

2. Literature Review

Green bond markets can play a pivotal role in financing the transition to a low carbon economy and a more sustainable growth (Sartzetakis, 2020). This process can be supported by financial intermediaries: despite, the increase in green bonds' issues banks do not seem to play a relevant role in the promotion of green projects. Xiao et al. (2021) show that the regulatory arbitrage mechanism is a more relevant motivation for Chinese commercial banks to issue green bonds rather than the climate goal. Barua and Chiesa (2019) focus on the factors affecting the amount of funds raised through the green bond supply: they find that the average funding size is significantly lower for high-grade bonds whereas no significant effects are found in the case of banking issuances. In this respect, based on the maturity mismatch between the asset and liability sides of banks' balance sheets and the comparable costs between green and conventional securities issues, Gianfrate and Lorenzato (2018) provide best practices to promote capital allocation towards green projects by non-bank financial institutions, such as mutual funds and insurance companies. Moreover, Riedl and Smeets (2017) find that social preferences and signaling play a more relevant role with respect to the financial motives for socially responsible investment (SRI) decisions. Hartzmark and Sussman (2019) point out that sustainability can be viewed as positively predicting future performance in US mutual funds market, even if no evidence supports that high-sustainability funds outperform low-sustainability ones.[11]

Nowadays, climate-related objectives can be read in the agenda of central banks both from a macroprudential and monetary policies point of view (Bernardini et al., 2021). On the macroprudential side, a special focus is devoted to the effects of the so-called *brown penalizing factor*, i.e. a setup where carbon-intensive assets are penalized with a relatively higher risk-weight in capital requirements' calculations, in contrast to the a "*green supporting factor*" that adjust capital requirements for green bonds (Thomä and Gibhardt, 2019). In this respect a critical review of the current prudential framework is provided by D'Orazio and Popoyan (2019) who find that a unique instrument for all scenarios does not exist even if buffers built during the carbon-intensive credit cycle could be favorable too. From a monetary policy perspective, by using a stock-flow-fund ecological macroeconomic model, Dafermos et al. (2018) provide evidence for a climate-induced financial instability characterized by a rise of defaults and an asset price deflation process that may be reduced by a green quantitative easing (QE) programme; similarly, strong effects in reducing detrimental emissions, are found by Ferrari and Nispi Landi (2020) by running a temporary green QE in a DSGE model based on the assumption that green and conventional bonds are not perfect substitutes. Returns of the two kind of securities may be affected by exogenous shocks such as the Covid-19 pandemic one. Yi et al. (2021) find that the pandemic shock increased the cumulative abnormal returns of the Chinese green bond markets due to the production stop – in particular for industries financed by green bonds – which determined both a decrease of the demand for green energies and the increase in the duration of the green bond projects. In this respect, a recent analysis by Ayaydin et al. (2021) argue that, following the COVID-19 pandemic, the performance of green securities may outperform that obtained by brown bonds. Moreover, based on the new definition of ESG risk scores

[11] See also ECB (2020) (Box 7) for an overview of the performance and resilience of the euro-denominated ESG funds and green bonds.

– measuring firms' exposure to ESG-related risks – provided by Morningstar, Ferriani and Natoli (2020) show how, after the Covid-19 outbreak, investors preferred to invest in low-ESG-risk funds (that have performed better than their peers) in order to hedge against further market downturns.[12]

Empirical literature on the existence and the sign of a premium for investing in ESG bonds focuses on the green market and on the commonly denominated *greenium* showing mixed results.[13] By examining data on US-issued green bonds reported by Bloomberg at the end of 2017, Zerbib (2019), after running a matching procedure, estimate a negative yield differential between a small sample of green bonds and a counterfactual group of conventional securities. Similar conclusions are reached by Ehlers and Packer (2017) for the primary market even if no differences in the performance between green and conventional assets are found in the secondary market.[14] A negative premium is also estimated by Baker et al. (2018) for US municipal bonds after-taxes adjustments and by Gianfrate and Peri (2019) for the euro-denominated green bonds. Nonetheless, security and issuer characteristics can play a role in determining the existence of a *greenium*: Fatica et al. (2021) find a negative and statistical significant *greenium* when issuers are supranational institutions or corporates but no evidence arises if the issuer is a financial institute; similar results are found by Kapraun and Scheins (2019). Alessi et al. (2019) show that the risk premium related to the green financing investing is also negative when one considers the companies' greenhouse gas emissions and the quality of their environmental disclosures. Tang and Zhang (2020) find no statistically significant premium in favor of green bonds in a sample of securities drawn from Bloomberg and the Climate Bond Initiative (CBI). This result is confirmed by Larcker and Watts (2020) when only US municipal securities are considered; moreover Doronzo et al. (2021) find a substantial alignment between yield of green and conventional bonds both in the primary and secondary markets (also during the Covid-19 crisis) when only sovereign issuers are analyzed. Higher returns for green bonds are instead found by Bachelet et al. (2019) who also verify whether volatility and liquidity of green assets is affected by the presence of a third-party certification of greenness of the bonds. Higher returns for green bonds are also found by Karpf and Mandel (2017) by using the Oxaca-Blinder decomposition over a large sample of US municipal bonds.

3. Data

An official register of ESG bonds does not exist. According to International Capital Market Association (ICMA)[15] ESG data base providers do not usually disclose securities' standard identification codes, such as the ISIN ones, or do not allow for a massive filtering based on the green label ag. Furthermore, ESG bonds can be labeled or not: the green bond label is only assigned to instruments that meet specific criteria

[12] See Faiella and Malvolti (2020) for an assessment of the climate risk for the Italian finance.

[13] For surveys on this topic see Liaw (2020) and Cheong and Choi (2020).

[14] Ehlers and Packer (2017) point out as issuing green bonds is a costly transaction due to the third-party validations in order to reduce informational asymmetry and the risk of greenwashing (Baker et al., 2018). In this respect, Hyun et al. (2020) examine the green bond market investors' pricing, by finding that green bonds have lower yields than the conventional ones.

[15] For more details see the summary of Green/Social/Sustainable Bonds Databases.

defined by international guidelines such as those published by ICMA and CBI. In this respect, data providers may publish both labeled and unlabeled ESG bonds and/or use different certification standards.[16] To overcome such practical issues, we construct a unique multi-source database by exploiting public information on ESG bonds with no distinction on the type of certification standard used to assign the ESG flag (subsection 3.1). Detailed information on the characteristics of securities and issuers are subsequently derived by using structured databases as the Centralised Securities Database, the Securities Holdings Statistics and the intermediary supervision statistical reporting (subsection 3.2).

3.1 Identification of ESG bonds

The first and crucial component of our comprehensive list is represented by ESG debt securities which are quoted on dedicated ESG bond market segments of the most prominent exchanges around the world up to the end of March 2021. The initial list of ESG debt securities comprises 15,529 ISIN codes. The main part of the list of ESG securities has been compiled thanks to a web-scraping procedure extracting the ISIN codes[17] of the debt securities listed on the ad-hoc segments of the on-line market platforms. Since the sustainable bonds represent a recent phenomena and given their average long maturity, our dataset contains almost all of the securities issued and/or exchanged on the market. Almost all securities contained in this component are labeled ones and received favorable pre-issuance external reviews.

A second block of our list has been hand-collected by exploiting publicly available information on ESG bonds published by providers such as CBI, Environmental Finance (EF) and ICMA.[18] By using information on the issuer (such as the residence country and the type) and on the issuance (face value, currency, issue and maturity dates) we scan issuers' official web sites and the main financial data market platforms to find the relevant ISIN codes.[19]

A third component of the list is derived from the published basket composition – if available at ISIN level – of some of the main green indexes, such as the Solactive Green Index or the China Green Bond Index, or the sample definitions of previous

16 Evaluation steps and methodologies to ag a bond as \green" may slightly change based on different procedures. Generally, on voluntary basis, ESG issuers try to design their ESG framework/bonds to respect the most important criteria and guidelines as the Green, Social and Sustainability-Linked Bonds Principles (https://www.icmagroup.org/sustainable-finance/), the Climate Bonds Standard (https://www.climatebonds.net/market/best-practice-guidelines) or the recent release of the EU Green Bond Standard. Nonetheless, validation provided by independent external reviewers can be distinguished in different types of services (Second Party Opinion, Verification, Certification or Bond Scoring/Rating) based on the tightness, timing (before or after the issuance) and focus of the evaluation. For more details see Ehlers and Packer (2017) and the Guideline for the external reviewers published by the ICMA.

17 In some cases the ISIN codes are not available. In particular, for US and Canadian' securities we detect their CUSIP codes – specific identifiers used by the North-American States – and convert them in ISIN codes by using the Luhn algorithm specified in ISO/IEC 7812-1.

18 See subsection A.1.

19 The platform Cbonds is a useful tool for a global bond market screening: it provides detailed information on securities from 180 countries (100% coverage of Eurobonds worldwide) and attaches the `green bond' label when applicable. Moreover, in presence of US municipalities a useful instrument to obtain the securities' identifiers and to control for the multi-tranche cases is the Electronic Municipal Market Access (EMMA) Dataport where it is possible to download all official statements of issues by US municipalities.

studies of investment banks' or research institutes. Finally, we exploit information from the web sites of the main national and supranational institutions reporting their ESG issuances and programs.

The relative importance of a source can be understood through the number and volumes of ESG securities being listed. The same security may be listed on different platforms or used by more reports (Table A.1). By focusing only on the green segments of exchanges we can observe the weight of the Luxembourg Stock Exchange whose green segment contains 961 ESG securities for a nominal value of euro 475 billion, of which the largest shares are referred to green and sustainable bonds. Other significant sources are the German and the Italian exchanges reporting ESG securities for a total volume of euro 260 billion each (Table A.2). Additionally, an important source of information is Euronext that lists ESG bonds from the Amsterdam, Brussels, Dublin, Lisbon, Oslo and Paris exchanges.

3.2 Securities' information

After the identification of the ESG bonds we use other databases to obtain details on the instruments and on their issuers. To this end we draw information from the Bank of Italy Securities Data Base and the European Central Bank Centralised Securities Data Base (CSDB) from which we obtained security and issuer characteristics such as the country and the institutional sector of the latter and the price, maturity and currency of the former. Since CSDB data provides information on securities issued by EU residents and/or held and transacted by EU residents as well as securities denominated in euro, some ESG bonds, mainly those issued by US municipalities, are excluded once we merge the ESG list with the CSDB. Remarkably, many US ESG bonds are issued by municipalities or are asset-backed securities (ABS) issued by government-sponsored agencies such as Fannie Mae or Freddie Mac.

Once we have identified ESG bonds and found their characteristics, we investigate if and to what extent they are present in Italian residents' portfolios. The third component of our data set is based on data drawn from Bank of Italy supervisory statistics on individual banks' and mutual funds' balance-sheets. Data on banks have been aggregated at banking group level when applicable.[20] Such information are collected at security level which allows us to precisely identify the ISIN codes belonging to the above-mentioned list of ESG bonds. We complemented data on banks' and mutual funds' balance-sheets with those drawn from the Bank of Italy Securities Holdings Statistics (SHS) in order to exploit detailed information on the portfolios of other institutional sectors, i.e. insurance corporations and pensions funds, households and non-financial corporations. Finally we extensively use the official harmonized statistics on sectoral financial accounts compiled by the Bank of Italy on a quarterly basis (Banca d'Italia, 2018) as we need them to scale the sectoral issues and holdings of ESG bonds and to compare the dynamics of sectoral portfolios of financial assets.

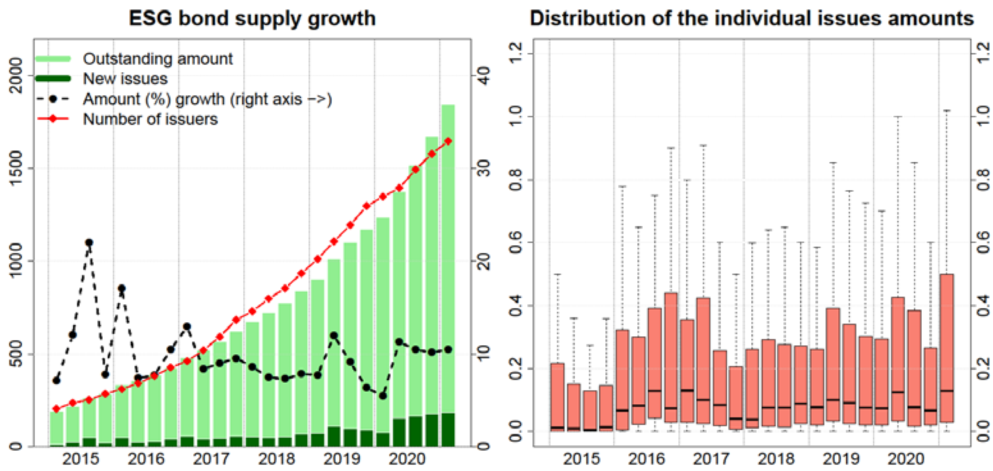
[20] The observational unit is the banking group or the stand-alone bank if not affiliated to any banking group. For the sake of brevity we will be using the term 'bank' to indicate the above-mentioned observational unit.

4. ESG Bond Supply

Based on the information of the ESG securities present in the SHS archive, it possible to observe as the supply of ESG bonds has experienced a dramatic rise in the last few years (Figure 1): at the beginning of 2015, including supranational entities, the outstanding amount of debt securities issued was equal to euro 193 billion whereas at the end of the first quarter of 2021 has reached almost euro 1,850 billion. The annual net flows were euro 104 billion in 2015 and 567 billions in 2020 (185 in the first quarter of 2021) with a quarterly growth rate of 10% in the last few quarters after the slowdown due to the Covid-19 shock. Similarly, in the same time span the number of issuers has widened from 204 to more than 1,600 (Table A.3).[21] The distribution of the face value of the securities is rather dispersed (Figure 1, right panel) reflecting the wide variety of countries and sectors whose bonds are covered in our sample. The median volume of the bonds is always lower than euro 100 million whereas the 75th percentile ranges between euro 150 and 480 million.

Figure 1: ESG Bond Supply Expansion

(euro billions and percentage values)



[1] Source: elaborations on data drawn from the ECB Centralised Securities Data Base. The left panel of the figure depicts the outstanding amount reported in euro billions, the corresponding quarter-on-quarter growth rate and the number of issuers of ESG debt securities between 2015 and 2021. In rightmost panel the box and whiskers plot represent the distribution of individual amount ESG debt securities issues between 2015 and 2021. The three lines of the box represent, from bottom to top, the 25th, 50th and 75th percentiles of the distribution in a given quarter whereas the lower and the upper whiskers represent the 5th and 95th percentiles.

Leaving aside the role of the supranational issuers, a geographical overview of the ESG security issuers in our data set is illustrated in Figure A.1 and Figure A.2 showing that in our sample China is the most represented country having a share

[21] The "climate awareness bond", issued by the European Investment Bank (EIB) in 2007, is generally considered the first green bond. On the other hand Tang and Zhang (2020) and Lebelle et al. (2020), among the others, document that the sustainable instruments market started to be relevant only after 2013 due to the increase of issues by commercial banks and corporation and the release of the Green Bond Principles by ICMA.

equal to 21 and 17% in terms of, respectively, amount issued and deals. [22] Other key-countries in the ESG bond supply are the US, South Korea, Japan and Canada. As already mentioned, the relative importance of the countries represented in our sample reflects the fact that the initial comprehensive list of securities is merged with the CSDB, thus leading to a loss of non-euro-denominated instruments or other instruments which are not held by euro area residents. In Europe, whose securities represent almost half of the volumes of the ESG bonds in our sample, the most significant countries are Germany and France (Figure A.3). At the end of the first quarter of 2021 the largest amount of ESG securities is issued by China (euro 328 billion) followed by France and Germany with a bit more than euro 200 billion (Table A.4). The median volumes of security tranches is less than euro 100 million whereas the average maturity is rather long, coherently with the long duration of the projects financed by green bonds.[23] ESG securities issued by UK (20.3 years), US (13.3 years) and Canada (13.7 years) tend to have longer maturities whereas residents in Asian countries – namely China (7.6 years), Republic of Korea (5.2) and Honk Kong (7.2) – tend to issue shorter maturity instruments. When considering the median value of the ESG bonds, French, German and US issuances are characterized by lower face values – less than euro 50 million – whereas Dutch, Italian and Belgian ones are ten times bigger (euro 500 million). The number of issuers is in the order of hundreds in China, US and Japan, it is more limited in Italy (33) and Spain with France and Germany in the middle.

Most of the securities in our sample are denominated in euro and US dollars (Table A.3): in the first quarter of 2021 two-thirds of the ESG bonds were euro or US dollar denominated. Italian issuers represent 1.9 per cent of the total whereas German and French issuers are about 22 per cent of the total. Interestingly, the Chinese sustainable market seems to have a very relevant role from the beginning of our sample period. In this respect, Table A.5 reports information about the ESG bonds' supply by country and sector of the issuer: overall, financial issuers have a prominent role in addressing resources by issuing ESG bonds. Nonetheless, this view slightly change at country level. Hence, on the one hand in Germany and France a pivotal role is played by the Government, consistently with a public strategy for the green financing; on the other hand, in China and US the non-government sectors prevail and over 50% of the volumes are issued by non-financial corporations. In Italy one can observe a certain balance between financial and non-financial private institutions whereas the government has launched its first green bond issuance (BTPs Green) only in March 2021.[24]

The ESG bond supply by Italian residents has expanded at the same pace as the global one. The total amount of ESG debt securities issued by Italian residents has jumped to euro 34 billion in the first quarter of 2021 thanks to the already-mentioned euro 8.5 billion issuance by the Italian government. Nonetheless the largest issuers

[22] The China Green Bond Index provided by the Luxembourg Stock Exchange includes bonds which are compliant with different green bond principles. In this respect, the minimum share of the proceeds should be used in green projects to mark a security as `green' ranges between 50% (in the case of People's Bank of China – PBOC – Green Bond Endorsed Project Catalogue and the National Development and Reform Commission – NDRC – Green Bond Guidelines) and 95% (in the case of CBI Climate Bonds Standards). This explains our sample's higher coverage of Chinese bonds than those reported on the CBI platform. For more details on the key differences between international and domestic standards see also Clifford Chance (2020).

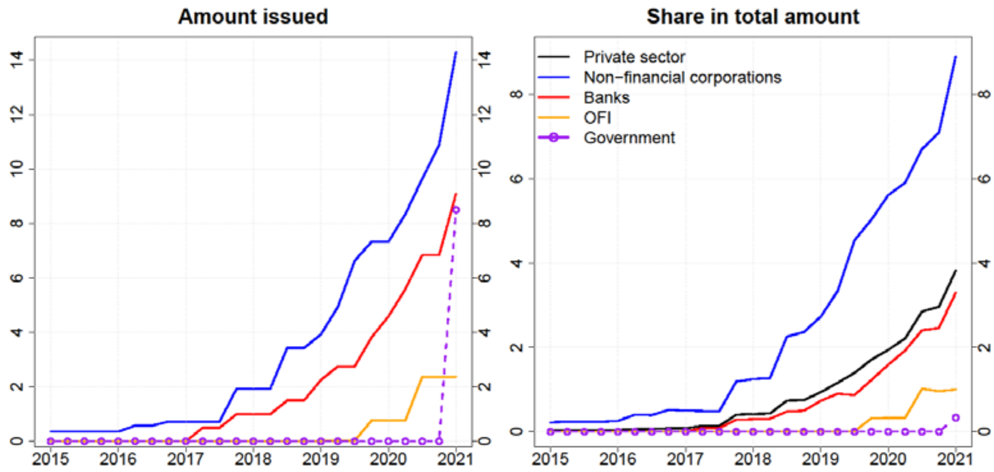
[23] In August 2019, a French State-owned company issued the world's first ever 100-year green bond.

[24] For more details see also Banca d'Italia (2021).

are the non-financial corporations and the banking sectors with, respectively, euro 14 and 8 billions of bonds issued (Figure 2, left panel). Over the total amount of debt securities issued by the private sector, ESG bonds reached 3.8% in March 2021 (Figure 2, right panel). Such share is even higher for non-financial corporations (9%) and slightly smaller for banks.

Figure 2: ESG Bonds issued by Italian Residents

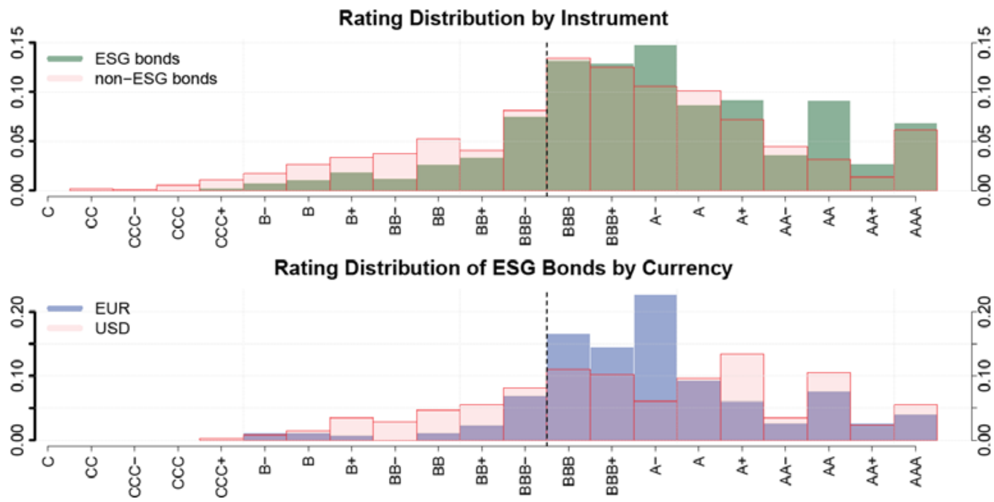
(euro billions and percentage values)



[1] Source: elaborations on Bank of Italy's Financial Accounts. The figure reports data on the amount of ESG bonds issued by Italian residents (right panel) and the share of this amount in total volumes of debt securities issued by issuer sector.

The risk profile of the ESG bonds supply is skewed towards the lower-risk area when compared to conventional ones. The top panel of Figure 3 shows that the rating distribution for ESG bonds is more concentrated in the investment grade area than their conventional counterparts with peaks in the A- and AA levels. The lower panel of Figure 3 shows the comparison between euro-denominated and USD-denominated securities within the ESG subsample. The rating distribution of euro-denominated bonds is more concentrated in the investment grade area especially around the A- level. The rating distribution of USD-denominated ESG bonds is characterized by less pronounced peaks in the investment grade area. Differences in the rating distribution may reflect differences in the characteristics of the issuers. Low-risk corporations or triple-A governments may be more willing to issue ESG bonds as they are considered more credible in their commitment to use the bond proceeds in green or sustainable projects. Hence we suspect that the lower-risk profile of ESG bonds merely reflects a self-selection bias.

Figure 3: Debt Securities Ratings - March 2021



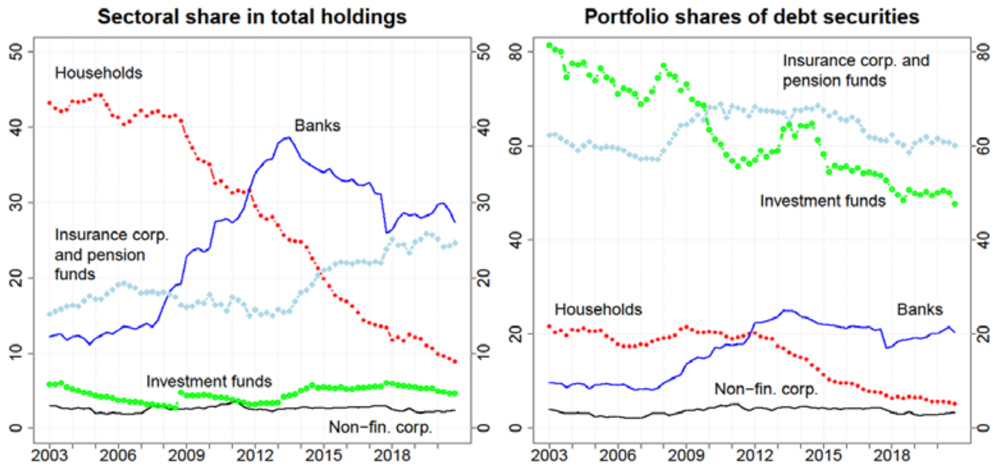
[1] Source: elaborations on data drawn from the ECB Centralised Securities Data Base. This figure depicts the distribution of ratings across categories of securities in the sample. The dotted vertical line at BBB- delimits the investment grade region from the non-investment grade one.

5. Italian Residents' Holdings of ESG Bonds

Debt securities are a key component of Italian residents' portfolio with the share of total financial assets being equal to, on average, 19% in the last two decades even though their weight has been declining since the 2011 sovereign debt crisis and the Italian banking crises of the following years. The households sector held more than 40% of Italian residents' debt securities before the Lehman collapse at the end of 2008 and has progressively reduced its exposure down to less than 10% in 2020 (Figure 4, left panel). Banks, insurance corporations and pension funds have replaced households as leading sectors in bond holdings with a share of, respectively, 25% and 30% in 2020. The picture within sectors is mostly consistent with that across sectors. Banks have experienced an increasing weight of bonds in their portfolios from 10 to 20% (Figure 4, right panel) whereas the portfolio share of insurance corporations and pension funds has been stable around 60% and that of investment funds has been declining from 80% to 50%.

Figure 4: Debt Securities held by Italian Residents

(percentage values)



[1] Source: Bank of Italy's Financial Accounts. The left panel of the figure depicts the sectoral share in total debt securities held by Italian residents between 2003 and 2020. The rightmost panel depicts the portfolio share of debt securities across Italian sectors between 2003 and 2020.

Against this background, the rise of the global supply of ESG bonds has been mirrored by a similar growth of their weight in Italian residents' portfolios. The amount of ESG instruments in Italian residents' portfolios, which was negligible 5 years ago, has steadily increased up to euro 16.6 billion in 2019 and has more than doubled in the last 5 quarters reaching euro 37.4 billion at the end of the first quarter of 2021 (Table A.6). The share of ESG bonds in total holdings of debt securities amounts to 1.4% at the end of 2020 and to 1.9% in the following quarter. The vast majority of the ESG instruments are denominated in euro (92%) and exchanged on regulated markets (88%). Portfolios are rather diversified when considering the number of issuers – almost 500 –, securities – more than 1,000 – and countries. Nevertheless ESG securities issued by Italian residents represent less than one third of the bond portfolios (Table A.7) whereas among the non-resident issuers France, Netherlands, Germany and Spain represent 40%. Other prominent ESG issuers, whose securities are held by Italian residents, are supranational entities, namely the European Union (EU), the International Bank for Reconstruction and Development (IBRD) and the European Investment Bank (EIB) together accounting for 15% of bond portfolios. The share of ESG instruments exchanged on regulated markets is almost 100% for securities issued by non-residents whereas it falls to two thirds for those issued by residents.

More than 70% of Italian residents' portfolios of ESG bonds are represented by securities issued by non-resident institutions (Table A.8). Instruments issued by supranational entities[25] and non-resident financial intermediaries represent more than one fourth of the ESG bond portfolio, followed by those issued by foreign non-financial corporations and general governments. Lower shares concern domestic banks and non-financial corporations and non-resident banks.

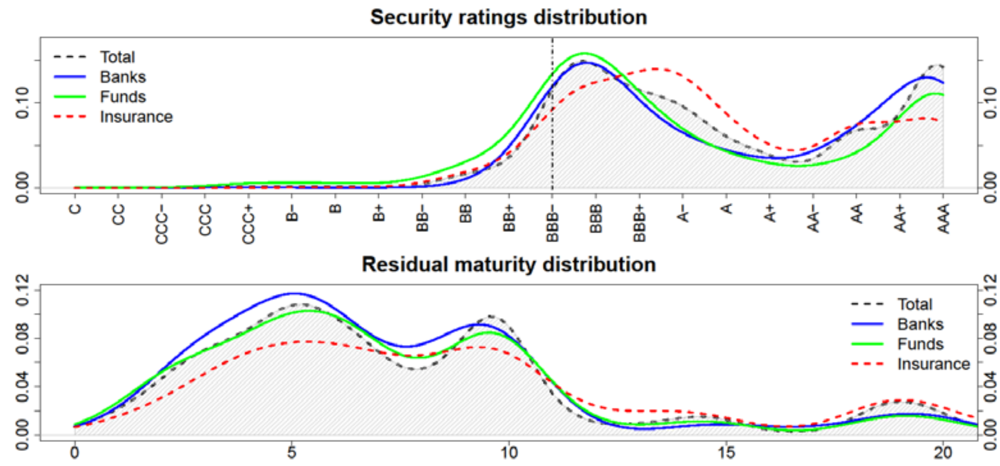
[25] The European Union, the European Investment Bank (EIB) and the World Bank (WB)

In March 2021 the most significant ESG bond holding sectors are the insurance corporations (37%) and the banking sector (35%) thus accounting for almost three quarters of all the ESG debt securities held by Italian residents (Table A.9). Other important ESG bond holding sectors are that of the investment funds whose share is 15% and, to a lesser extent, households and pension funds (5%). Yet, one has to consider that two thirds of resident investment funds' shares are held by households thus total holdings of ESG bonds are in principle higher due to the indirect holdings. This is the idea behind the methodology commonly known as the look through approach entailing the reclassification of asset management products from the institutional investors sector to that of their subscribers, mostly households.

The risk profile of Italian residents' portfolios invested in ESG bonds is moderate-low. Most of the securities held by Italian residents are classified into the investment grade category[26] (Figure 5). The risk profile is rather similar across sectors with insurance corporations holding a slightly higher share of investment grade securities but not on the highest end – AA or higher – of the rating range.

Figure 5: Holdings characteristics by sector

(rating class and years)



[1] Source: elaborations on data drawn from the Bank of Italy Securities Data Base. The top panel depicts the distribution of the ratings and of the residual maturity of ESG debt securities held by Italian residents. The 21 categorial rating classes of the three main rating agencies – Moody's, Fitch and Standard & Poor's –have been mapped into a sequence of integers going from 1 (C rating) to 21 (AAA rating) on which the estimation has been performed. The curves have been estimated through weighted kernel density estimation with the portfolio share being the weight. The vertical line at BBB- in the top panel figure delimits the investment grade area from the non-investment grade one.

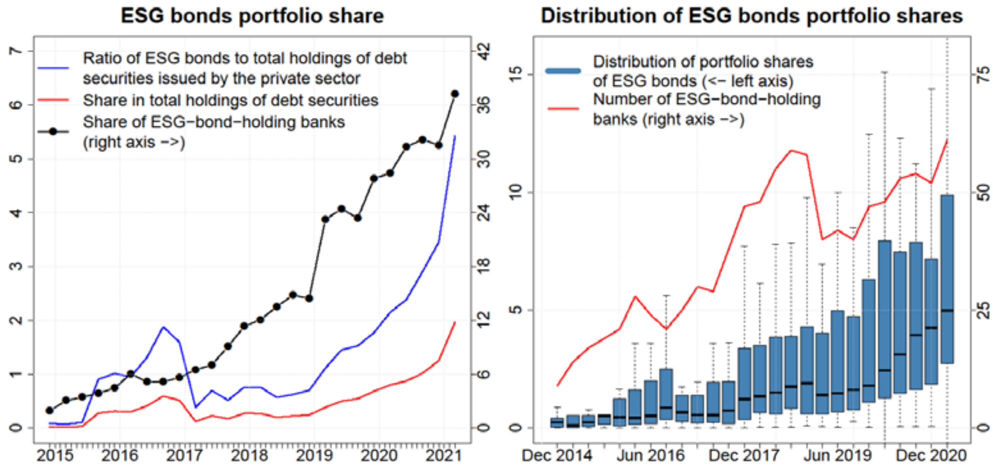
The weight of ESG bonds in Italian banks' portfolios has risen in the last few years. The share of ESG bonds in total holdings of debt securities has reached 1.2% at the end of 2020, whereas such share was less than 0.5% two years before (Figure 6, left panel). The expansion is even more notable when the holdings of ESG debt securities are scaled by the holdings of debt securities issued by the private sector with a proportion of 3.4% at the end of 2020 and a bit more than 1% two years before.

[26] Securities with a BBB- or higher rating are considered as investment grade ones.

Similarly, the number of banks holding ESG bonds in their portfolios has surged from less than 20 at the end of 2015 to more than 50 intermediaries out of 165 holding debt securities[27] five years later (Figure 6, right panel). Among such banks, the distribution of ESG portfolio shares has moved upwards with the median value reaching 4.5% and with at least one fourth of the ESG-bond-holding banks having a portfolio share of 7%.[28] The larger ESG bonds investors are bigger banks as suggested by the weighted mean being higher than the median portfolio share. Such trend has been reducing in the last two years with a wider number of medium banks investing in ESG securities.

Figure 6: Banks' holdings of ESG bonds

(percentage values)



[1] Source: elaborations on Bank of Italy Supervision Statistics. This figure depicts the share of ESG debt securities in banks' portfolios between 2015 and 2021 at aggregate level in left panel. In the rightmost panel the box and whiskers plot represent the distribution of ESG debt securities share in banks' portfolios. The three horizontal lines of the box represent, from bottom to top, the 25th, 50th and 75th percentile of the distribution in a given quarter whereas the lower and the upper whiskers represent the 5th and 95th percentiles.

Mutual funds have experienced a similar pattern of growth of ESG debt securities in their portfolios. Their share in total holdings of debt securities was 3% at the end of 2020, whereas the proportion in total holdings of debt securities issued by the private sector has risen to more than 5% (Figure 7, left panel). The share of mutual funds that have invested in ESG bonds has increased to 40%, whereas 70% of asset management companies (AMC) manage a green-bondholding mutual fund (Figure 7, left panel). Analogously, the number of ESG-bond-holding funds has surged to 400[29] at the end of 2020 with one fourth of the distribution lying above 4% in terms of ESG

[27] The total number of banking groups and stand-alone banks in Italy at the end of March 2021 was 276.

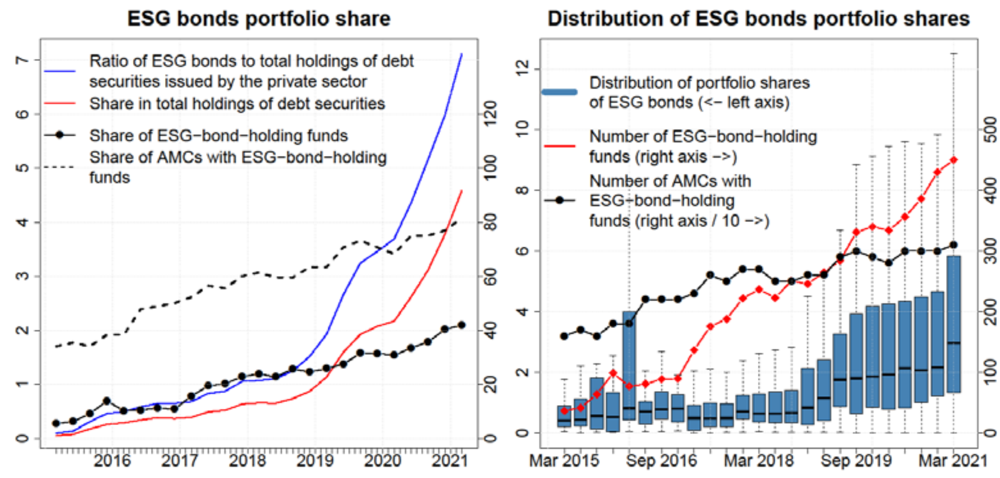
[28] Considering that 50 banks were holding green debt securities at the end of 2020, this implies that 25 of them had at least a portfolio share of 4.5% and 12 held green bonds accounting for at least 7% of their non-Italian government portfolio.

[29] The universe of open-end mutual funds which are resident in Italy consists of 1,190 funds at the end of 2020.

portfolio share and one fourth having a share ranging between 2 and 4% (Figure 7, right panel).

Figure 7: Investment funds' holdings of ESG bonds

(percentage values)

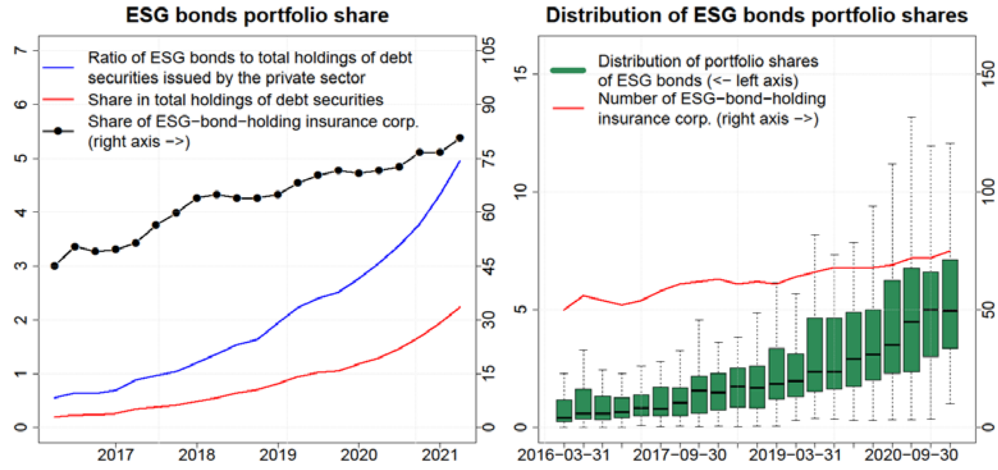


[1] Source: elaborations on Bank of Italy Supervision Statistics. This figure depicts the share of ESG debt securities in banks' portfolios between 2015 and 2021 at aggregate level in left panel. In the rightmost panel the box and whiskers plot represent the distribution of ESG debt securities share in funds' portfolios. The three horizontal lines of the box represent, from bottom to top, the 25th, 50th and 75th percentile of the distribution in a given quarter whereas the lower and the upper whiskers represent the 5th and 95th percentiles.

As already mentioned, insurance corporations represent the sector with the largest share of ESG debt securities among Italian residents. The portfolio share invested in ESG bonds amounts to nearly 2% and the ratio to holdings of debt securities issued by the private sector is more than 4% at the end of 2020 (Figure 8, left panel). Three quarters of Italian insurance corporations have invested in ESG bonds and for half of them the portfolio share is higher than 5% (Figure 8, right panel).

Figure 8: Insurance corporations' holdings of ESG bonds

(percentage values)



[1] Source: elaborations on Bank of Italy Supervision Statistics. This figure depicts the share of ESG debt securities in banks' portfolios between 2015 and 2021 at aggregate level in left panel. In the rightmost panel the box and whiskers plot represent the distribution of ESG debt securities share in insurance corporations' portfolios. The three horizontal lines of the box represent, from bottom to top, the 25th, 50th and 75th percentile of the distribution in a given quarter whereas the lower and the upper whiskers represent the 5th and 95th percentiles.

6. The Greenium Puzzle

In the previous sections we have delineated the supply characteristics of the ESG bond market and we have provided a detailed description of the sectoral holdings of these instruments by focusing on Italian residents. Now we assess to what extent the pricing and the underlying yields of ESG debt securities are different from their conventional counterparts. More precisely, we investigate whether a negative premium on ESG bonds, commonly known as *greenium*, exists and whether it is heterogeneous across issuer sectors. The puzzling aspect of such topic is that the existence of the *greenium* would imply that financial investors are willing to purchase ESG debt securities at higher prices than those of analogous securities in terms of liquidity, riskiness and maturity. Yet, financial theory predicts that securities with the same characteristics should guarantee the same yield regardless of the ESG label. A possible explanation can be attributed to inner nature of investing in a socially-responsible way, which entails that the investor evaluates the assets not only in terms of portfolio payoffs but also in light of her own tastes as she would do for consumption goods (Fama and French, 2007). A second explanation can be contextualized in the asset pricing theory (APT) where green bonds would bear lower risk thanks to the certification process which would guarantee a more regular monitoring and, in turn, higher transparency (Fama, 1998). In the same APT context, a third explanation is related to the ESG assets being less exposed to long-term climate change risks, be them a carbon tax or physical risks.

We will also test the hypothesis that negative premia on ESG debt instruments may have changed after the Covid-19 shock in 2020 due to a *wake-up call* mechanism which is analogous to that described by Goldstein et al. (1998) for the Asian crisis of the 1990s and by Giordano et al. (2013) for the more recent sovereign debt crisis. Our hypothesis is that the pandemic has triggered the acquisition of new information leading to a higher awareness and to the reassessment of the climate change risk in the medium-long term. Prior to the shock, the bond fundamentals would have already justified a shift in preferences towards ESG bonds before but the risks were not correctly perceived by investors. Such wake-up call can be seen as analogous to that of the sovereign debt crisis when fiscal and macroeconomic fundamentals would have justified a shift from riskier bonds of more indebted countries to those issued by Germany even before the outbreak of the crisis. We employ a twofold approach for the assessment of the *greenium* and of a Covid-19 shock.

In subsection 6.1 we present a yield-curve-based approach whereas in subsection 6.2 the analysis is based on a security-level panel regression analysis with high-dimensional fixed effects.

6.1 Yield Curves Analysis

The estimation of yield curves is carried out using a dataset consisting of monthly observations on the prices of debt securities issued by financial and non-financial corporations resident in the euro area and in the rest of the world. Data are drawn from the Bank of Italy Securities Data Base reporting information on end-of-month instruments' prices and yields at single security (ISIN code) level. The descriptive statistics on the distribution of the yields-to-maturity of the debt securities selected into the sample (Table A.10 and Table A.11) indicate that ESG bonds are characterized by higher yields in the first two years of the sample period and by lower yields in the subsequent two years.

The Nelson and Siegel (1987) yield curve model is the one we chose to characterize the relationship between yields and residual maturities of the debt securities in our sample. The Nelson-Siegel approach and its Svensson (1994) refinement are the two most widely used specifications across central banks for the estimation of yield curves, as summarized by Bank for International Settlements (2005). According to such model, the yield $y_t(\tau)$ of a zero coupon bond with time to maturity τ at the end of month t is given by a function of four parameters:

$$y_t^{NS}(\tau_s) = \beta_{1,t} - \beta_{2,t}\left[\frac{1 - exp(-\lambda_t\tau_s)}{\lambda_t\tau_s}\right] - \beta_{3,t}\left[\frac{1 - exp(-\lambda_t\tau_s)}{\lambda_t\tau_s} - exp(-\lambda_t\tau_s)\right] \qquad (1)$$

where $\beta_{1,t}$, $\beta_{2,t}$ and $\beta_{3,t}$ can be seen as three latent factors whose loadings are represented by $L_1(\lambda,\tau) = 1$, $L_2(\lambda,\tau) = \frac{1-exp(-\lambda\tau)}{\lambda\tau}$ and $L_3(\lambda,\tau) = \frac{1-exp(-\lambda\tau)}{\lambda\tau} - exp(-\lambda\tau)$. The three latent factors can be interpreted in terms of curve characteristics, the level L_t, the slope S_t and the curvature S_t respectively associated to the long-term, short-term and medium-term factors. Such interpretation derives from the observation of the factor loadings with the first one being constant and equal to one, thus the corresponding factor $\beta_{1,t}$, can be viewed as a long-term factor. The second loading is equal to one on the shortest maturity and rapidly decays to zero, hence it can interpreted as the short-term factor. The third factor loading is equal to zero at the beginning, increases, reaches its maximum and finally decays to zero in the long-term, which leads to the medium-term interpretation of the corresponding factor. The functional form of the third factor is governed by the λ parameter determining the maturity that maximizes the loading. The estimation entails the minimization of the residuals of the Nelson-Siegel specification[30] with respect to the vector of unknown parameters $(\beta_1\ \beta_2\ \beta_3\ \lambda)$.

$$\underset{\{\beta_{1,t}\ \beta_{2,t}\ \beta_{3,t}\ \lambda_t\}}{minimize}\ Med(|y_t(\tau_s) - y_t^{NS}(\tau_s)|)$$

$$s.t.\ \beta_{1,t} > 0,\ \beta_{1,t} + \beta_{2,t} > 0,\ \lambda_t > 0 \tag{2}$$

In accordance with other studies such as Ibanez (2015), three constraints were imposed to the optimization, i.e. a positive λ and $\beta_1 > 0$ and $\beta_1 + \beta_2 > 0$. In each monthly reference date between June 2017 and March 2021 we run the estimation on the original sample and subsequently draw 250 samples of securities belonging to 8 categories based on the disaggregation by ESG/non-ESG, currency of denomination (euro and USD) and institutional sector of the issuer (non-financial and financial corporations). We omit the securities issued by the government sector as the sample would be extremely small giving rise to unreliable estimates. The securities selected into each of the 8 subsamples are those with an investment grade rating, i.e. equal or over BBB- whereas all the remaining securities with a rating below that threshold have not been considered in the estimation of the yield curve. By doing so, we make sure that the securities are homogeneous in terms of riskiness. The result of the estimation is a data set of more than 90,000 observations[31] comprising the estimated vector of parameters $(\beta_1\ \beta_2\ \beta_3\ \lambda)$ for each of the 8 categories of bonds in each month of the sample period. Next we evaluate the 90,000 estimated yield curves at each residual maturity between 1 month and 20 years (240 residual maturities in 1 month steps). The estimation results are reported in Table A.13 with the breakdown of the sample into the 4 subcategories of instruments by type and issuer country of residence. The final estimate of the yield curve is obtained by collapsing the data set by instrument, reference area, reference date and residual maturity through the calculation of the mean of the 250 yields corresponding each to one of the drawn samples.

Overall, once we calculate the average values of the yields across the various maturities, we can compare the average yield curve derived from the subsample of ESG debt securities to the one derived from the subsample of non-ESG bonds issued by non-financial corporations distinguishing euro-denominated from USD-denominated instruments. The average yield curve of euro-denominated ESG bonds lies below the non-ESG curve (Figure 9) resulting in a constantly negative spread between ESG and non-ESG bonds. More precisely, the yield spread on euro-denominated bonds increases in the residual maturity of the instruments: it starts from less than 3 basis points for up-to-one-year maturity, rapidly grows to 10 basis points at 10 years and ends at 11 basis points at the 20-year maturity (Figure 9, left

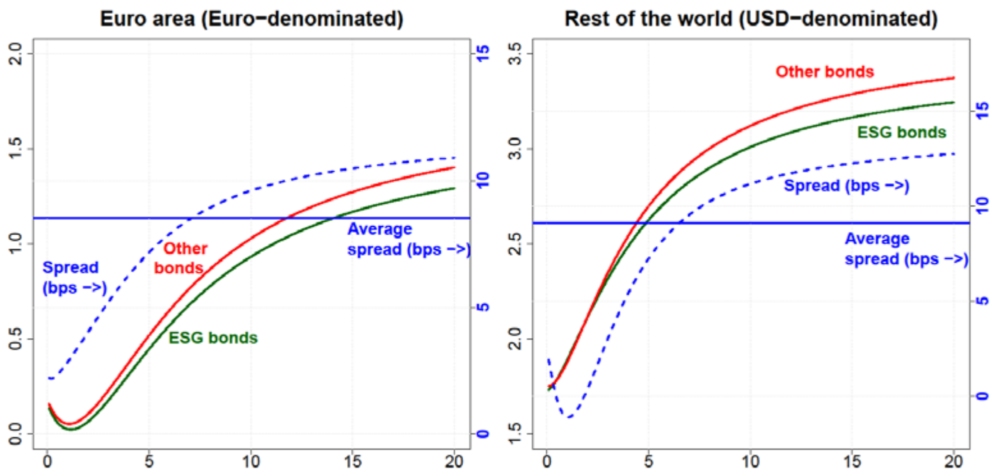
[30] The model has been estimated for each month of the sample period using a non-linear optimization procedure aimed at minimizing the median absolute errors (MAE) through the Augmented Lagrangian Minimization Algorithm for optimizing smooth nonlinear objective functions with constraints. The estimation is carried out on the subsamples of ESG euro and USD-denominated securities and of conventional euro and USD-denominated ones issued by non-financial and financial corporations.

[31] 45 reference dates between June 2017 and March 2020 x 251 samples (250 drawn samples + the original one) x 8 categories (ESG/conventional-sector-currency).

panel). The yield spread between USD-denominated ESG bonds and non-ESG bonds is close to zero at very short maturities and subsequently increases at an analogous pace reaching 13 basis points at 20-year residual maturity (Figure 9, right panel). The overall mean value of the yield spread is extremely similar (9 basis points).

Figure 9: Average yield curves between 2017 and 2021
Non-financial corporations

(percentage values and basis points)

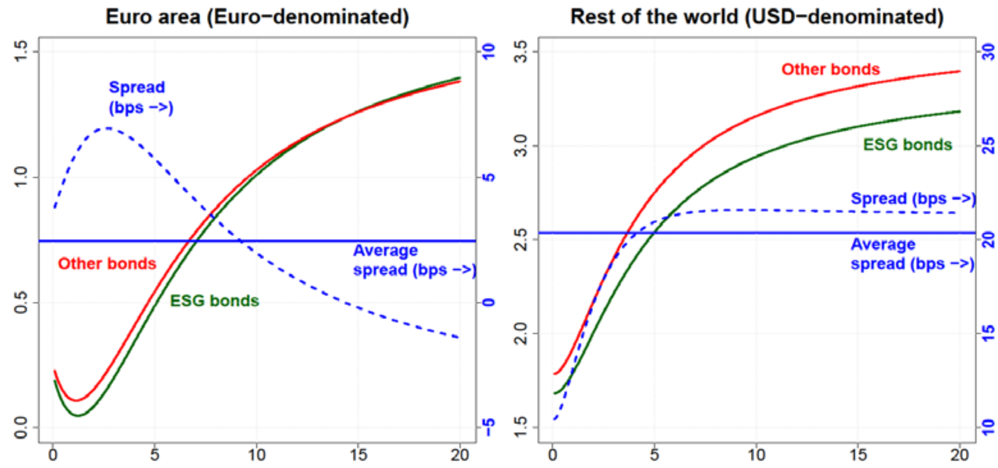


[1] Source: elaborations on data drawn from the Bank of Italy Securities Data Base. This figure depicts the average estimated yield curves estimated according to the Nelson-Siegel specification using end-of-month yields-to-maturity for ESG and non-ESG debt securities between June 2017 and March 2021. The figure depicts the average yields by residual maturity – expressed in years – of ESG and non-ESG instruments and their difference in terms of basis points over the sample period.

The same exercise has been carried out on the sample of securities issued by financial corporations and its results are shown in Figure 10 with the same currency breakdown. We find a *greenium* on euro-denominated securities which is decreasing in the residual maturity and amounting on average to 2 basis points (Figure 10, left panel). On the other hand the average spread is 20 basis points for USD-denominated bonds with the range being between 10 and 21 basis points depending on the maturity (Figure 10, right panel).

Figure 10: Average yield curves between 2017 and 2021
Financial corporations

(percentage values and basis points)



[1] Source: elaborations on data drawn from the Bank of Italy Securities Data Base. This figure depicts the average estimated yield curves estimated according to the Nelson-Siegel specification using end-of-month yields-to-maturity for ESG and non-ESG debt securities between June 2017 and March 2021. The figure depicts the average yields by residual maturity – expressed in years – of ESG and non-ESG instruments and their difference in terms of basis points over the sample period.

Such results can be summarized in a more formal way by running a linear fixed-effects regression of the yield of the debt securities issued by residents in area a at the end of month t on the ESG indicator variable which is equal to one if the security is an ESG one and zero otherwise:

$$y_{a,t,s} = \gamma ESG_{a,t} + \theta_1 M_{a,t} + \theta_2 M_{a,t}^2 + \theta_2 M_{a,t}^3 + \eta_a + \eta_t + \varepsilon_{a,t} \quad (3)$$

where the third degree polynomial in the residual maturity $M_{a,t}$ should capture the functional form of the yield curves we have just estimated through the Nelson and Siegel (1987) approach. The model also includes area and time fixed effects so as to account for, respectively, time-invariant characteristics of the economic areas and common economic shocks and the economic cycle. The model is separately estimated for non-financial and financial corporations (Table 1).

We find that ESG debt securities issued by non-financial corporations are characterized by 8 basis points lower yields than their non-ESG counterparts. The yield spread is a slightly higher for financial corporations (11 basis points). Next we test whether the pandemic shock has increased such spreads with the introduction of the interaction of the ESG indicator variable with a *COVID* indicator variable which is equal to one for all the observations following March 2020. Once we control for the *COVID* shock, we obtain a small reduction of the base ESG effect and at the same time we find an incremental effect of the negative premium. The additional *greenium* is estimated to be 10 basis points for non-financial corporations and 5 basis points for financial corporations. Hence the result obtained with the analysis of the yield curves is again corroborated by a more formal analysis through linear fixed effects regressions.

Determinants of Bond Yields - Yield Curves Samples

Table 1

	Corporations			
	Non-financial	Financial	Non-financial	Financial
ESG	-0.0843*** (0.0002)	-0.1140*** (0.0003)	-0.0554*** (0.0003)	-0.1009*** (0.0003)
ESG x COVID			-0.0998*** (0.0005)	-0.0454*** (0.0006)
MATURITY	-0.1963*** (0.0002)	-0.1949*** (0.0002)	-0.1963*** (0.0002)	-0.1949*** (0.0002)
$MATURITY^2$	-0.0087*** (0.00002)	-0.0084*** (0.00003)	-0.0087*** (0.00002)	-0.0084*** (0.00003)
$MATURITY^3$	-0.0001*** (0.000001)	-0.0001*** (0.000001)	-0.0001*** (0.000001)	-0.0001*** (0.000001)
Area FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
N	10,805,040	10,805,040	10,840,560	10,840,560
adj. R^2	0.9048	0.8622	0.9051	0.8623

[1] This table reports the estimation results of a linear fixed effects model where the outcome variable is the yield to maturity of a security measured at the end of the month. The explanatory variables are the residual maturity of the security in terms of years (M), the indicator variable ESG and the COVID indicator variable being equal to one after February 2020 and zero before.

6.2 Regression Analysis

The estimation of the yield curves, albeit carried out on rather homogeneous cross-section samples of securities, may be subject to some factors we do not control for, as shown by Table A.12 where one can notice that, depending on the particular subsample we are focusing on, ESG bonds are structurally different from conventional ones. ESG securities could be on average more liquid and the lower yields may reflect such feature. We have carefully selected a subsample of the available securities based on their investment grade rating, this nonetheless could be not enough if ESG bonds are characterized by higher ratings even within the investment grade subsample as Figure 3 could seem to suggest. A third factor we have not been considering is the security listing on an exchange market thus leading on principle to higher transparency and to a more reliable observed price. We could easily solve such potential pitfalls by selecting narrower samples of securities for the estimation of the yield curve or we could run our optimization procedures by minimizing a weighted measure of errors accounting for the amount issued of the security. A viable alternative could be a regression analysis based on the data at security level with the following linear fixed effects model specification accounting for all the above-mentioned confounding factors:

$$y_{t,s} = \gamma ESG_{s,t} + \theta^{\mathbf{T}} X_{s,t} + \eta_{i,t} + \eta_{c,t} + \eta_{u,t} + \varepsilon_{s,t} \tag{4}$$

where the yield to maturity of security s at the end of month t is regressed on the ESG indicator variable being equal to zero prior to the Covid-19 shock in March 2020 and equal to one in the following months. Additionally, the model includes a third degree polynomial in the residual maturity $M_{s,t}$ and a vector of time-varying control variables, namely the indicator variable LISTED equal to one if the security is traded on an exchange, the quadratic form of the RATING of the security and the logarithm of the issued amount. The model is saturated with issuer-time fixed effects in order to account for unobserved time-varying characteristics of the issuer such as managerial skills, size of the firm, financial structure, etc... We further saturate the model with country-time fixed effects to account for economy-wide shocks and the financial cycle affecting the dynamics of GDP, real interest rates, government debt. Finally we control for the currency of denomination of the securities which usually coincides with the country but in the case of monetary unions and of international corporations issuing in several currencies could a factor to control for. The model is estimated on three sectors, i.e. non-financial corporations, financial corporations and the government sector. The specification is additionally enriched by the interaction of the ESG indicator variable with a COVID indicator variable being equal to one after March 2020 and zero before. Such interaction should capture the effects of the Covid-19 pandemic on the ESG market yields and isolate them from the base difference.

The estimation results of the model provide a picture which is mostly consistent with our *a priori*. In the baseline model we find that if the bond is traded on an exchange then, as expected, this leads to a lower yield of 4-6 basis points depending on the sector (Table 2). A higher rating determines a lower yield as this incorporates lower risk premia, the larger the amount issued, the lower the yield which is attributable to benefits of securities that are traded in larger volumes and by a larger number of investors. The coefficients of the ESG indicator variable are all statistically significant across the three sectors in the baseline model. The *greenium*, i.e. the difference between the yields on ESG bonds and the yields on their non-ESG counterparts, is estimated to be 10 basis points for the non-financial corporations and is even higher (16 basis points) for financial corporations. On the other hand, the yield spread for debt securities issued by the government sector is half as much as that of the non-financial corporations (5 basis points). On the one hand, such findings are slightly greater than the one found by Zerbib (2019) that on average finds a *greenium* equal to 2 basis points by running a matching estimation on Bloomberg database; then they show that such negative premium is more pronounced for low-rating bonds and when the issuer is a financial institution. On the other hand, our results are lower than those reported by Fatica et al. (2021) who run a regression analysis on a Dealogic DCM and CBI data: by controlling for maturity, currency, rating and bond size they find a large *greenium* for non financial institutions (22 bps) and no significant difference for the financial ones. As for the securities issued by Governments, our results are consistent with anecdotal findings by Banca d'Italia (2021) related the emission the first Italian green bond in March 2021.

Determinants of Bond Yields - Debt Securities Sample

Table 2

	Corporations			Corporations		
	Non-financial	Financial	Government	Non-financial	Financial	Government
ESG	-0.0981***	-0.1574***	-0.0532***	-0.0461***	-0.1280***	-0.0451*
	(0.0093)	(0.0091)	(0.0195)	(0.0131)	(0.0122)	(0.0253)
ESG x COVID				-0.1035***	-0.0663***	-0.0201
				(0.0185)	(0.0182)	(0.0397)
LISTED	-0.0645***	-0.0350***	-0.0367***	-0.0646***	-0.0351***	-0.0367***
	(0.0030)	(0.0038)	(0.0070)	(0.0030)	(0.0038)	(0.0070)
RATING	-0.3750***	-0.2477***	-0.2256***	-0.3749***	-0.2477***	-0.2256***
	(0.0031)	(0.0009)	(0.0025)	(0.0031)	(0.0009)	(0.0025)
AMOUNT	-0.0220***	-0.0935***	-0.0113***	-0.0219***	-0.0935***	-0.0113***
	(0.0008)	(0.0011)	(0.0006)	(0.0008)	(0.0011)	(0.0006)
MATURITY	-0.1237***	-0.1035***	-0.0840***	-0.1239***	-0.1036***	-0.0840***
	(0.0022)	(0.0027)	(0.0050)	(0.0022)	(0.0027)	(0.0050)
$MATURITY^2$	-0.0044***	-0.0059***	-0.0069***	-0.0044***	-0.0059***	-0.0069***
	(0.0003)	(0.0004)	(0.0006)	(0.0003)	(0.0004)	(0.0006)
$MATURITY^3$	-0.0003***	-0.0003***	-0.0004***	-0.0003***	-0.0003***	-0.0004***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Issuer x Time FE	Yes	Yes	No	Yes	Yes	No
Country x Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Currency x Time FE	Yes	Yes	Yes	Yes	Yes	Yes
N	331,134	376,082	97,797	331,134	376,082	97,797
adj. R^2	0.931	0.852	0.896	0.931	0.852	0.896

[1] This table reports the estimation results of a linear fixed effects model where the outcome variable is the yield to maturity of a security measured at the end of the month. The explanatory variables are the residual maturity of the security in terms of years (M), the indicator variable LISTED being equal to one if the security is listed on an exchange, the RATING mapped into a numeric sequence of integers as illustrated in Figure 3, the log amount issued AMOUNT, residual MATURITY, the indicator variable ESG and the COVID indicator variable being equal to one after February 2020 and zero before.

Next, we investigate whether the Covid-19 shock had an effect on the yield spread between ESG securities and conventional counterparts. To this end we introduce an additional indicator variable COVID being equal to one after the shock has occurred in March 2020 and zero before. We interact the COVID indicator variable with the ESG indicator variable in order to estimate the possible additional premium following the Covid-19 outbreak. The magnitude and the significance of all the control variables remain the same as in the baseline model. We find that the base effect of the ESG label on the yield falls to 5 and 13 basis points for non-financial and financial corporations and is unchanged for the government sector, even though with a reduced statistical significance level of 10% for the latter. The pandemic shock has induced an additional negative premium on ESG bonds issued by non-financial and financial corporations (10 and 7 basis points) whereas we do not find evidence of an additional negative premium on those issued by the government sector.

7. Conclusions

ESG bonds are bound to be a key financial instrument to channel financial resources into green, sustainable and social projects. The adoption of such instruments by corporations and governments has rapidly increased in the last five years, with a dramatic expansion of the volumes issued and of the number of issuers. We compiled a comprehensive list of ESG securities, partly web-scraped and partly hand-collected, by exploiting only publicly available information from a wide variety of online sources. Next we merged this list with microdata used for official statistics such as financial accounts, security holdings, banks' and investment funds' balance-sheets.

Based on the integrated data base we show that the euro area, China and the US are three major players in the global supply of ESG bonds. In Europe, Germany and France are by far the countries with the largest share of ESG bond supply especially due to the role of the government sector. The expansion of the ESG instruments supply is mirrored by the increase of their weight especially in financial intermediaries' assets, exceeding 4% in funds' portfolios and 2% for banks and insurance corporations.

Finally, we analyzed the yields of ESG debt securities in order to contribute to the literature debate on the *greenium* puzzle, i.e. the negative premium on ESG bonds when compared to conventional ones with the same characteristics in terms of liquidity, riskiness and maturity. We find evidence for a statistically significant negative premium on ESG bonds with heterogeneity across sectors and over time. The negative premium is estimated to be 5 basis points for the non-financial corporations and government sectors whereas it is higher (13 basis points) for the financial sector. We also find evidence of an additional negative premium following the Covid-19 shock only for the non-financial corporations (10 basis points) and financial sector (7 basis points).

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Appendix

A.1 Information Sources

CBI reports a `**Bond Library'** where provides an overview of new green bond issuers entering the market; moreover, we check for repeated issues by using the `**Market Blogs Archive'** where CBI highlights a summary of the green bond market by reporting the list of the new and repeated issuers as well as the excluded and pending bonds starting from 2018; even if subsequent issues are not reported before 2018, we check for them. This information is strictly linked to the `**Labelled Green Bonds Database'** and the `**Certified Bond Database'** where CBI publishes the full list of latest 3 months new and repeated green bonds and the list of all bonds aligned to the certification scheme under the Climate Bonds Standards, respectively (to meet Climate Bonds Standards securities must be certified by third-party approved verifiers and aligned to more tight criteria ensuring consistency with the goals of the 2015 Paris Agreement to limit warming under 2 Celsius degrees). A similar exercise is carried out by using the daily updated `**EF bond database'** listing the 25 most recent ESG bond issuances (categorized in green, sustainable, sustainability-linked and social bonds) and augmented by using the list of issuer reported by the `Sustainable bonds database' provided and monthly updated by the ICMA.

ESG Bonds – Sources

(euro billions)

Table A.1

Source	Total	GRE	SOC	SUS	CSDB	Volumes
CBI/ICMA/EF	9,221	7,72	794	707	3,871	1,341.6
US Nasdaq	5,556	5,254	270	32	510	130.1
Green indexes	1,963	1,963	0	0	1,718	852.0
Luxembourg Stock Exchange	961	522	74	365	919	475.1
Research institutes	798	481	10	307	727	352.5
Other	437	354	37	46	399	212.4
Euronext	392	362	15	15	378	244.2
Nasdaq Nordic	328	320	3	5	309	27.2
London Stock Exchange	284	210	2	72	274	78.8
Börse Frankfurt	259	259	0	0	255	261.5
Singapore Exchange	222	145	26	51	202	80.7
BIX Malaysia	201	187	0	14	200	1.3
Borsa Italiana	138	71	14	53	134	264.8
Asean Capital Market Forum	125	125	0	0	119	1.9
World Bank	108	108	0	0	29	1.8
Oslo Børs	68	68	0	0	68	7.5
Taipei Exchange	53	49	0	4	52	4.6

[1] This table reports statistics on the number of ESG debt securities broken down by market or information provider. The following classification is applied: `**GRE**': green bonds included those that also are aligned to the social and/or sustainable principles as well as infrastructure green, transition, climate action, climate resilience, climate awareness, environment and blue bonds; `**SOC**': social bonds include infrastructure social, health and microfinance ones; ; `**SUS**': sustainable bonds include infrastructure sustainable, sustainable awareness, SDG-linked and COVID-19 ones; `**CSDB**': number of securities found in the ECB CSDB. **Volumes**: euro billions outstanding amounts.

ESG Bonds Volumes by Purpose of the Proceeds

(euro billions and percentage values) Table A.2

	Outstanding amounts				Share		
Source	Total	GRE	SOC	SUS	GRE	SOC	SUS
CBI/ICMA/EF	1,341.6	975.5	222.6	143.5	72.7	16.6	10.7
US Nasdaq	130.1	109.5	16.8	3.8	84.1	12.9	2.9
Green indexes	852	852	0	0	100	0	0
Luxembourg Stock Exchange	475.1	201.2	111.9	162	42.4	23.6	34.1
Research institutes	352.5	304.9	5.9	41.7	86.5	1.7	11.8
Other	212.4	179.4	5.7	27.3	84.5	2.7	12.9
Euronext	244.2	194.4	42.4	7.4	79.6	17.4	3
Nasdaq Nordic	27.2	26.5	0.4	0.3	97.5	1.4	1.1
London Stock Exchange	78.8	61.5	2.8	14.4	78.1	3.6	18.3
Börse Frankfurt	261.5	261.5	0	0	100	0	0
Singapore Exchange	80.7	54	10.4	16.4	66.9	12.8	20.3
BIX Malaysia	1.3	1.1	0	0.2	82.2	0	17.8
Borsa Italiana	264.8	135.7	66.3	62.7	51.3	25	23.7
Asean Capital Market Forum	1.9	1.9	0	0	100	0	0
World Bank	1.8	1.8	0	0	100	0	0
Oslo Børs	7.5	7.5	0	0	100	0	0
Taipei Exchange	4.6	4.4	0	0.2	95.6	0	4.4

[1] This table reports statistics on the number of ESG debt securities broken down by market or information provider. The following classification is applied: `**GRE**': green bonds included those that also are aligned to the social and/or sustainable principles as well as infrastructure green, transition, climate action, climate resilience, climate awareness, environment and blue bonds; `**SOC**': social bonds include infrastructure social, health and microfinance ones; ; `**SUS**': sustainable bonds include infrastructure sustainable, sustainable awareness, SDG-linked and COVID-19 ones; `**CSDB**': number of securities found in the ECB CSDB. **Volumes**: euro billions outstanding amounts.

ESG Bond Supply Characteristics over Time

Table A.3

Reference date	Total amount	New issues	Number of:		USD share	EUR share	Share of bonds issued by residents in:				
			securities	issuers			U.S.	China	Germany	France	Italy
2015 Q1	192.7	12.7	528	204	4.9	15.5	2.3	55.5	0.7	6.2	0.2
2015 Q2	215.9	23.2	658	236	5.0	18.2	2.2	54.5	1.3	6.0	0.2
2015 Q3	263.5	47.6	760	253	5.0	28.3	2.4	48.2	11.1	5.0	0.1
2015 Q4	283.9	20.4	892	285	6.8	27.7	2.4	48.2	10.8	6.1	0.1
2016 Q1	332.4	48.5	962	310	7.4	33.2	2.5	44.3	18.7	5.2	0.1
2016 Q2	356.9	24.5	1,069	342	8.4	33.4	2.9	43.0	17.9	5.2	0.2
2016 Q3	384.3	27.6	1,157	381	9.5	31.7	2.7	44.1	16.7	4.8	0.2
2016 Q4	424.5	40.7	1,274	427	10.2	30.8	2.8	45.0	15.6	5.2	0.2
2017 Q1	479.4	55.4	1,359	461	10.1	35.3	2.9	41.4	14.2	11.4	0.2
2017 Q2	519.6	40.7	1,488	520	10.5	34.9	3.1	42.0	13.7	10.7	0.2
2017 Q3	566.2	46.9	1,699	592	12.3	33.8	3.4	41.5	12.8	10.4	0.2
2017 Q4	620.2	54.6	1,979	683	13.5	33.8	3.8	40.9	12.2	10.0	0.5
2018 Q1	673.5	53.5	2,17	729	13.5	34.3	3.8	39.6	11.7	9.6	0.4
2018 Q2	723.7	50.6	2,374	798	14.2	34.0	4.3	38.9	11.0	9.1	0.4
2018 Q3	776.5	54.0	2,569	853	15.2	33.5	4.4	38.3	10.4	8.7	0.6
2018 Q4	837.3	65.8	2,79	934	15.3	34.1	4.5	38.0	10.0	8.4	0.6
2019 Q1	901.9	70.9	3,061	1,012	16.0	34.2	5.0	36.2	9.7	8.5	0.7
2019 Q2	1,009.9	110.1	3,401	1,106	17.1	35.3	5.2	33.9	9.4	8.3	0.8
2019 Q3	1,101.8	97.0	3,781	1,196	17.8	34.2	5.2	33.8	9.3	8.0	0.9
2019 Q4	1,171.8	88.8	4,103	1,297	18.9	35.3	5.9	31.0	9.1	8.2	1.0
2020 Q1	1,235.4	73.9	4,32	1,347	19.6	36.0	6.3	28.9	9.0	8.3	1.0
2020 Q2	1,374.8	153.0	4,576	1,394	20.7	38.4	6.6	25.8	10.8	8.5	1.1
2020 Q3	1,518.3	165.2	4,939	1,494	22.6	39.8	7.2	22.4	12.5	9.1	1.2
2020 Q4	1,672.8	175.4	5,364	1,579	23.0	41.9	7.3	19.7	11.6	10.2	1.2
2021 Q1	1,847.6	184.9	5,676	1,647	23.5	43.6	6.8	17.8	10.9	11.2	1.9

[1] This table reports summary statistics on ESG bond market supply between 2015 and 2021. Total outstanding amount and new issues are reported in euro billions.

ESG Bond Supply Characteristics by Issuer Country - March 2021

Table A.4

Country	Total amount	Median amount	Number of securities	Number of issuers	Amount for issuer	Number of sectors	Original maturity	Residual maturity
CN	328.2	0.2	843	372	0.9	11	7.6	4.1
FR	206.8	0.03	393	67	3.1	12	11.4	9.3
DE	202.2	0.03	281	41	4.9	11	8.5	6.9
US	126.4	0.04	654	202	0.6	20	13.3	10.5
NL	109.1	0.5	178	50	2.2	11	11.0	8.9
KR	53.4	0.1	248	49	1.1	10	5.2	4.1
JP	42.5	0.1	321	122	0.3	14	10.1	8.8
ES	42.1	0.2	113	32	1.3	9	8.1	6.3
SE	40.5	0.05	455	84	0.5	11	5.4	3.8
GB	39.7	0.1	188	60	0.7	11	20.3	14.8
IT	34.3	0.5	65	33	1.0	9	8.8	7.1
NZ	32.3	0.1	20	6	5.4	3	9.3	7.0
BE	32.0	0.5	24	13	2.5	8	11.0	9.8
CA	26.3	0.2	80	38	0.7	12	13.7	11.4
HK	19.8	0.4	52	25	0.8	7	7.2	5.7
NO	17.2	0.1	104	40	0.4	9	6.1	4.4
KY	16.1	0.3	48	25	0.6	8	8.0	6.6
LU	16.0	0.3	49	25	0.6	9	8.1	6.5
AU	14.9	0.2	45	26	0.6	11	8.0	6.1
DK	14.6	0.5	30	10	1.5	5	14.6	13.0
CL	13.9	0.4	25	10	1.4	7	19.2	17.5
FI	12.0	0.4	34	16	0.7	8	7.2	5.6
MX	9.9	0.2	24	11	0.9	8	11.2	8.3
IE	9.6	0.2	14	8	1.2	5	8.8	7.8
ID	8.5	0.4	18	8	1.1	5	6.6	4.8
IN	7.7	0.3	34	16	0.5	5	7.6	4.8
MU	6.1	0.4	18	8	0.8	4	5.3	3.0
AT	5.5	0.01	38	15	0.4	7	9.1	7.1
SG	4.8	0.1	26	14	0.3	5	6.9	4.9
VG	4.3	0.2	20	13	0.3	4	7.6	5.9

[1] This table reports summary statistics on ESG bond market supply by domicile country of the issuer at the end of first quarter of 2021. Total, median and per-issuer amounts of the issues are reported in euro billions, original and residual maturity are expressed in terms of years. The sectors considered in the calculation of the number of sectors are the ESA 2010 institutional sectors, i.e. S.11, S.122-S.129, S.13, as reported in Table A.5.

ESG Bond Supply by Country and Sector of the Issuer - March 2021

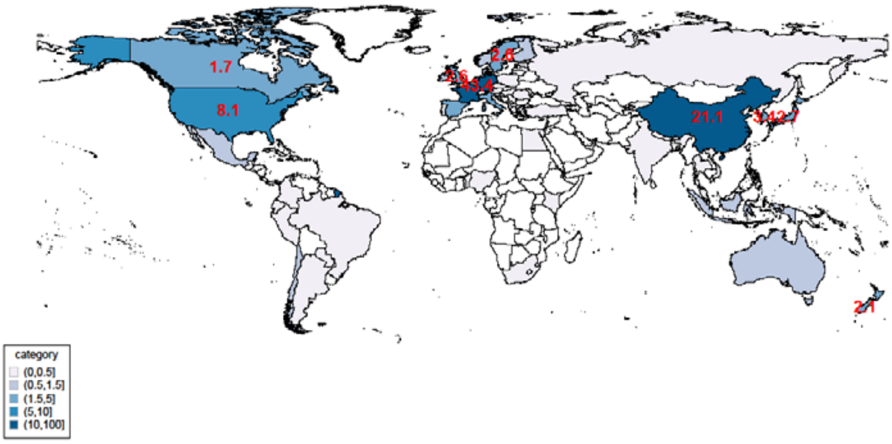
(euro billions) Table A.5

Country	Non-financial corporations	Deposit-taking institutions	OFI	Financial auxiliaries	Captive institutions	Insurance corporations	General government
	S.11	S.122	S.125	S.126	S.127	S.128	S.13
CN	238	43	17.4	10.1	0	0	19.6
FR	35.7	30.6	1	1	0	0.8	137.7
DE	16.5	56.6	0	0.1	0.6	1.2	127.2
US	68	8.4	35.4	6.9	1.2	0.8	5.3
NL	16	42.1	4.7	6.5	29.1	0	10.7
KR	17	17.6	16.7	0.5	0	1.2	0.4
JP	17.9	5.1	12.8	1.2	0.4	0	4.9
ES	15	17.6	0	0	0	0	9.4
SE	18.4	12.9	0	0	0.2	0	9
GB	9.4	8.5	16.3	0.1	4.5	0.3	0.6
IT	14.3	9.1	0	1	0	1.4	8.5
NZ	31.8	0	0	0	0	0	0.5
BE	0.9	0	0.7	1	0	0	16.4
CA	4.3	5.5	6.7	0.2	0	1.2	8.5
HK	1.5	8.9	3.3	0.1	0	0	4.3
NO	4.1	12.2	0.2	0.5	0	0	0.1
KY	7.3	1.8	6.5	0.1	0.5	0	0
LU	0.2	2.8	0.6	0	10.4	0	1.5
AU	0.6	6	1.6	0.5	0	0.2	6
DK	5.4	9.1	0	0	0	0	0
CL	3.8	0.2	0	0.1	0	0	9.9
FI	5.6	5.6	0.7	0	0	0	0.1
MX	0.7	0.6	7.4	0.1	0	0	0.8
IE	0	0	1.3	1	1.2	0	6.2
ID	2.1	0.4	5.9	0	0	0	0.1
IN	3.4	0.2	4	0	0	0	0
MU	0.8	0	4.8	0.6	0	0	0
AT	1.7	3	0	0	0.6	0.2	0
SG	0.8	2.8	0.1	1.1	0	0	0
VG	0	0	4.2	0	0.2	0	0
Total	557.6	325.2	157.2	34.1	51.2	7.9	402.5

[1] This table reports data on the break-down of ESG debt securities by residence country and sector of the issuer excluding supranational institutions. Outstanding amounts are reported in euro billions. Sectors considered in the table are the ESA 2010 institutional sectors whose corresponding codes are reported in the headers.

Figure A.1: Share of ESG Bonds Supply by Country - Amount issued

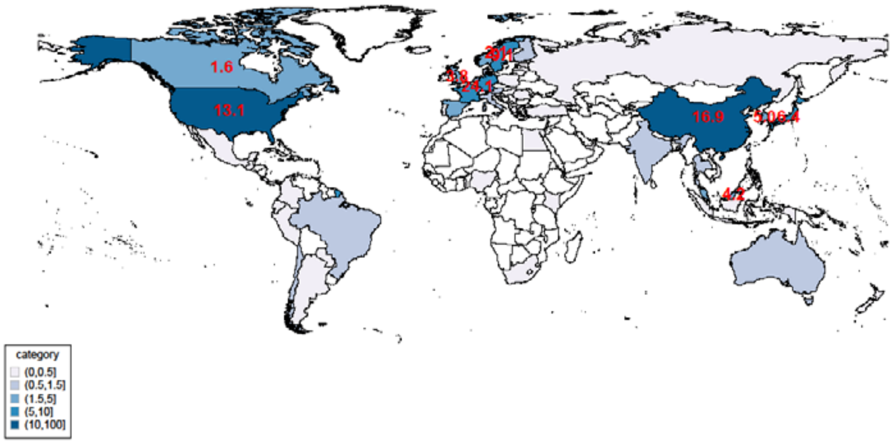
(percentage values)



[1] This figure depicts the world share of the outstanding amount of ESG debt securities by country at the end of March 2021. Data on the outstanding amount of the security and on the country of residence of the issuer are drawn from the ECB Centralised Securities Data Base (CSDB). Supranational entities are excluded from the calculation of the country shares.

Figure A.2: Share of ESG Bonds Supply by Country - Number of securities

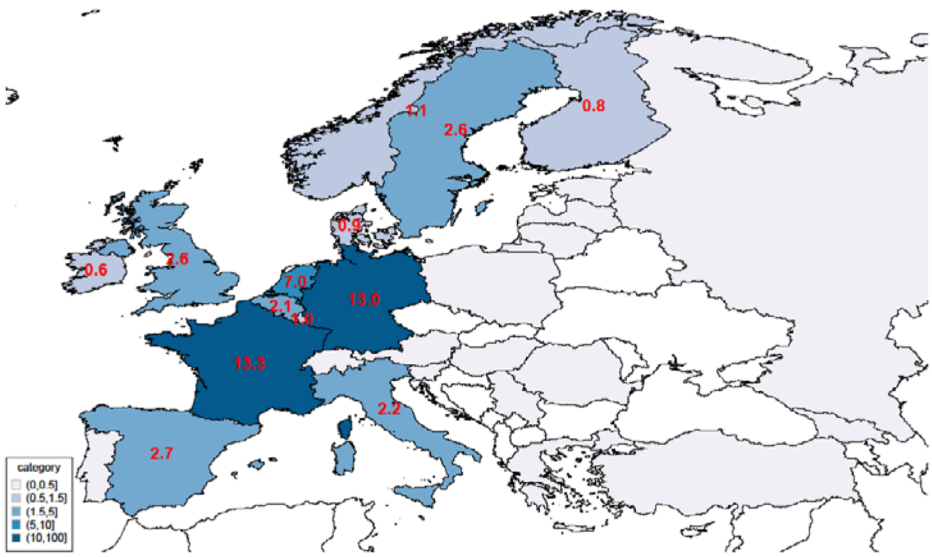
(percentage values)



[1] This figure depicts the world share of the total number of ESG debt securities issued by country at the end of March 2021. Data on the outstanding amount of the security and on the country of residence of the issuer are drawn from the ECB Centralised Securities Data Base (CSDB). Supranational entities are excluded from the calculation of the country shares.

Figure A.3: Share of ESG Bonds Supply by Country in Europe - Amount issued

(percentage values)



[1] This figure depicts the world share of the outstanding amount of ESG debt securities by country at the end of March 2021. Data on the outstanding amount of the security and on the country of residence of the issuer are drawn from the ECB Centralised Securities Data Base (CSDB). Supranational entities are excluded from the calculation of the country shares.

Italian Residents' Holdings of ESG Bonds – Summary Statistics

Table A.6

Reference date	Outstanding amount	Number of: securities	issuers	countries	Maturity original	residual	Currency share EUR	USD	Listed share
2015 Q2	0.8	103	56	25	10.8	8.9	51.6	16.3	87.2
2015 Q3	2.3	116	61	26	11.2	9.3	83.7	6.3	98.8
2015 Q4	2.7	134	68	25	10.5	8.5	85.5	5.6	98.9
2016 Q1	4.0	144	74	27	10.4	8.3	89.6	3.9	99.4
2016 Q2	4.9	164	85	29	10.3	8.2	90.2	4.4	99.4
2016 Q3	6.0	181	89	30	10.3	8.1	91.1	4.1	99.5
2016 Q4	5.7	194	95	31	10.5	8.2	89.6	4.4	99.5
2017 Q1	4.1	211	105	34	10.5	8.4	83.9	6.6	99.4
2017 Q2	5.0	237	120	37	10.0	8.0	84.8	6.8	99.3
2017 Q3	5.1	277	138	42	10.2	8.3	82.9	9.1	98.7
2017 Q4	6.3	318	161	44	9.8	7.9	82.6	10.0	96.0
2018 Q1	6.8	342	173	48	9.3	7.4	83.5	9.4	96.7
2018 Q2	7.0	371	181	47	9.1	7.2	82.2	10.1	95.8
2018 Q3	7.6	389	189	46	9.0	6.9	82.6	10.0	92.9
2018 Q4	8.6	432	211	47	8.9	6.8	82.4	9.8	92.9
2019 Q1	10.9	482	222	48	9.0	6.9	85.2	8.6	90.1
2019 Q2	13.1	535	254	50	8.9	7.0	87.1	7.8	90.2
2019 Q3	14.6	575	269	50	9.3	7.3	87.6	7.5	90.2
2019 Q4	16.6	634	302	54	9.3	7.3	88.5	6.9	90.1
2020 Q1	17.8	700	322	52	9.5	7.5	89.2	6.3	89.6
2020 Q2	20.9	781	349	56	9.6	7.6	89.8	5.8	87.1
2020 Q3	24.5	871	391	58	9.6	7.5	91.2	5.1	87.3
2020 Q4	28.6	958	417	61	9.6	7.6	91.5	4.9	88.0
2021 Q1	37.4	1,090	471	66	12.1	10.1	92.5	4.5	88.4

[1] This tables reports summary statistics on Italian residents' holdings of ESG debt securities between 2015 and March 2021. Data are drawn from the harmonized Securities Holdings Statistics (SHS). The outstanding amount, net of Bank of Italy's holdings, is reported in euro billions, original and residual maturities are expressed in terms of years. Listed share is the percentage proportion of ESG debt securities that are listed and traded on a financial exchange.

Italian Residents' Holdings of ESG Bonds by Issuer Country

Table A.7

Country Institute	Outstanding amount	Amount share	Number of: securities	Number of: issuers	Number of: countries	Maturity: original	Maturity: residual	Currency share: EUR	Currency share: USD	Listed share
IT	11.2	30.1	50	24	8	7.9	6.4	100	0	65.4
FR	6.3	16.8	132	52	8	10.4	8.2	98.1	1.9	98.6
NL	3.5	9.3	120	43	8	8.6	6.7	97.7	1.8	99.5
EU	2.6	7.1	9	1	8	15.0	14.7	100	0	100
DE	2.5	6.7	83	33	8	12.3	10.5	98.0	1.6	96.5
ES	2.5	6.7	55	20	8	7.4	5.7	100	0	96.1
IBRD	1.8	4.7	125	1	8	7.1	4.6	24.3	32.5	94.7
EIB	1.0	2.7	39	1	8	11.6	7.6	51.5	36.5	100
BE	0.5	1.4	13	6	7	12.3	10.7	100	0	100
IE	0.5	1.4	6	5	8	10.4	8.9	98.9	1.0	100
CL	0.5	1.4	9	3	7	22.7	21.3	93.9	5.9	100
GB	0.5	1.3	44	30	8	9.0	6.2	82.9	0.4	99.9
PT	0.4	1.0	4	1	8	49.4	48.3	100	0	100
Other	3.5	9.4	401	251	8	17.5	15.7	83.3	13.4	97.5

[1] This tables reports summary statistics on Italian residents' holdings of ESG debt securities at the end March 2021. Data are drawn from the harmonized Securities Holdings Statistics (SHS). The outstanding amount, net of Bank of Italy's holdings, is reported in euro billions, original and residual maturities are expressed in terms of years. Listed share is the percentage proportion of ESG debt securities that are listed and traded on a financial exchange.

Italian Residents' Holdings of ESG Bonds by Issuer Sector

(euro billions and percentage values) Table A.8

		Resident issuers			Non-resident issuers			
Reference date	Outstanding amounts	Non-financial corp.	Deposit-taking inst.	General government	Non-financial corp.	Deposit-taking inst.	General government	Other
		S.11	S.122	S.13	S.11	S.122	S.13	
2015 Q2	0.8	3.1	0	0	26.8	6.4	3.8	59.9
2015 Q3	2.3	1.1	0	0	8.7	2.1	71.7	16.5
2015 Q4	2.7	1	0	0	7.7	3.8	71.8	15.6
2016 Q1	4.0	2.4	0	0	19	6.8	55.6	16.1
2016 Q2	5.0	6.5	0	0	17.1	5.2	55.9	15.4
2016 Q3	6	5.3	0	0	15.1	4.7	61.4	13.5
2016 Q4	5.7	6.5	0	0	18.6	5	54.4	15.5
2017 Q1	4.1	7.8	0	0	30.3	9.3	25.5	27.2
2017 Q2	5.0	6.4	1	0	25.8	9.3	31.6	25.9
2017 Q3	5.1	7.3	1	0	29	9.9	23.8	29.1
2017 Q4	6.3	10.9	3.5	0	25.3	9.9	20.9	29.5
2018 Q1	6.8	9.9	3.1	0	24.7	8.4	23.3	30.5
2018 Q2	7	9.4	3	0	24.7	11.2	18.7	33
2018 Q3	7.6	11.4	5.8	0	22.9	11.5	16.8	31.7
2018 Q4	8.6	10.7	5.6	0	21.5	12.5	16	33.7
2019 Q1	10.9	12.7	8	0	21.3	10.6	16.3	31.1
2019 Q2	13.1	13.2	9.2	0	20.4	12.1	15.3	29.8
2019 Q3	14.7	15.1	8.7	0	20.3	11.6	15.7	28.3
2019 Q4	16.6	15.6	10.1	0	19.6	11.5	14.2	27.8
2020 Q1	17.8	13.3	11.1	0	19.2	10.8	16.7	28.1
2020 Q2	20.9	12	13.3	0	19.9	10.8	16.8	26.3
2020 Q3	24.5	10.6	13	0	19	11	20.2	24.3
2020 Q4	28.6	9.5	11.2	0	19.8	11.2	18.8	27.6
2021 Q1	37.4	10	10.3	8.3	16.2	9.6	19	25.1

[1] This table reports data on Italian residents' holdings of ESG debt securities, broken down by issuer sector. Outstanding amounts held by Italian residents are reported in euro billions whereas the following columns report the percentage share issued by resident and non-resident institutional sectors according to the ESA 2010 classifications. Bank of Italy's holdings of ESG debt securities are excluded from the total outstanding amount.

Italian Residents' Holdings of ESG Bonds by Holding Sector

(euro billions and percentage values) Table A.9

Reference date	Outstanding amount	Non-financial corp.	Deposit-taking inst.	Investment funds	Insurance corp.	Pension funds	General government	Households and NPISH	Other
		S.11	S.122	S.124	S.128	S.129	S.13	S.14+S.15	
2015 Q2	0.8	3.6	25	12.3	0	5.8	0.8	50.9	1.6
2015 Q3	2.3	1.1	69.4	9.5	0	2.3	0.3	16.7	0.6
2015 Q4	2.7	1.2	65.6	12.4	0	4	0.6	15.3	1
2016 Q1	4.0	0.9	45.2	9.1	26.6	5.6	0.5	11.6	0.4
2016 Q2	5.0	0.8	50.8	8.8	23.1	6	0.5	9.6	0.4
2016 Q3	6	0.7	57.7	8.4	19.5	4.7	0.5	8.1	0.3
2016 Q4	5.7	1.7	50	8.5	24.6	4.9	0.6	9.3	0.4
2017 Q1	4.1	2.6	16.5	12.9	44.7	7	0.7	15	0.6
2017 Q2	5.0	2.2	24.4	13.2	40	5.3	0.7	13.5	0.7
2017 Q3	5.1	2.2	20.5	13.8	42.9	4.9	1	13.8	0.8
2017 Q4	6.3	1.8	22.7	14	41.5	4.6	2.2	12.5	0.6
2018 Q1	6.8	1.7	21.3	13.1	43.6	5	2.2	12.4	0.7
2018 Q2	7	1.7	16.4	12.3	48.4	5.3	2.1	13.2	0.7
2018 Q3	7.6	1.7	17.4	12.4	48.2	5.1	1.9	12.5	0.9
2018 Q4	8.6	1.5	16.2	12.6	50.2	5	1.8	12.1	0.7
2019 Q1	10.9	1.3	21.1	13.2	47.2	4.8	1.5	10.2	0.6
2019 Q2	13.1	0.7	23.4	15.3	43.8	4.9	2.2	9.2	0.5
2019 Q3	14.7	0.6	23.8	16.9	42.7	5	2	8.6	0.5
2019 Q4	16.6	0.8	25.4	15.9	41.5	5.1	1.9	8.6	0.7
2020 Q1	17.8	0.8	28.3	14.2	41.2	5.2	1.7	7.9	0.7
2020 Q2	20.9	0.8	28.9	15.5	40.7	5	1.3	7.1	0.7
2020 Q3	24.5	0.7	29.2	15.6	41.3	5.2	1.2	6.1	0.6
2020 Q4	28.6	0.6	28.6	16.2	42.1	5.4	1.1	5.6	0.5
2021 Q1	37.4	1.8	35.1	15	36.7	4.6	1.1	5.2	0.5

[1] This table reports data on Italian residents' holdings of ESG debt securities, broken down by holding sector. Outstanding amounts are reported in euro billions whereas the following columns report the percentage share held by Italian resident institutional sectors according to the ESA 2010 classifications. Bank of Italy's holdings of ESG debt securities are excluded from the total outstanding amount.

Yields to maturity of Euro-denominated Bonds - Summary statistics

(percentage values) Table A.10

Sector	Instrument	Year	25th	Mean	50th	75th	SD	*N*
Non-financial corp.	Conventional	2017	0.46	0.94	0.88	1.28	0.64	4,379
		2018	0.57	1.13	1.06	1.53	0.77	8,08
		2019	0.27	0.78	0.60	1.09	0.71	8,863
		2020	0.27	0.83	0.61	1.13	0.81	10,561
		2021	0.16	0.52	0.37	0.72	0.57	2,487
	ESG	2017	0.74	1.16	1.06	1.41	0.74	199
		2018	0.87	1.31	1.23	1.65	0.71	405
		2019	0.29	0.75	0.62	1.00	0.66	628
		2020	0.23	0.71	0.48	0.93	0.72	922
		2021	0.19	0.51	0.39	0.63	0.57	290
Financial corp.	Conventional	2017	0.34	1.25	0.75	1.51	1.37	11,972
		2018	0.41	1.33	0.89	1.71	1.31	24,191
		2019	0.25	1.07	0.67	1.42	1.20	23,589
		2020	0.25	1.05	0.67	1.43	1.19	22,652
		2021	0.19	0.86	0.44	0.98	1.24	4,986
	ESG	2017	0.19	0.52	0.39	0.75	0.42	291
		2018	0.30	0.74	0.62	1.18	0.56	711
		2019	0.18	0.55	0.40	0.74	0.54	871
		2020	0.20	0.64	0.44	0.87	0.64	1,176
		2021	0.14	0.44	0.31	0.53	0.48	315
General government	Conventional	2017	0.37	1.13	0.86	1.61	0.96	3,864
		2018	0.39	1.23	0.91	1.75	1.07	6,882
		2019	0.28	1.06	0.71	1.55	1.01	5,262
		2020	0.18	0.80	0.50	1.19	0.85	4,207
		2021	0.16	0.66	0.38	0.81	0.93	881
	ESG	2017	0.30	0.58	0.50	0.76	0.41	100
		2018	0.35	0.68	0.63	0.94	0.43	198
		2019	0.18	0.46	0.38	0.64	0.35	191
		2020	0.09	0.31	0.26	0.43	0.30	217
		2021	0.10	0.29	0.25	0.38	0.27	84

[1] This table reports summary statistics on the yields of the euro-denominated debt securities issued by euro area residents broken down by issuer sector, type of instrument (ESG/non-ESG) and reference year.

Yields to maturity of USD-denominated Bonds - Summary statistics

(percentage values) Table A.11

Sector	Instrument	Year	25th	Mean	50th	75th	SD	*N*
Non-financial corp.	Conventional	2017	2.75	3.29	3.19	3.75	0.84	20,184
		2018	3.52	4.02	3.94	4.41	0.82	37,381
		2019	2.60	3.29	3.12	3.79	0.96	48,904
		2020	1.31	2.27	2.06	2.93	1.33	58,615
		2021	1.03	1.94	1.78	2.66	1.13	15,679
	ESG	2017	3.01	3.41	3.23	3.96	0.61	145
		2018	3.67	4.22	3.99	4.77	0.76	325
		2019	2.61	3.23	3.08	3.69	0.79	642
		2020	1.42	2.29	1.95	2.89	1.32	1,081
		2021	1.31	1.94	1.98	2.54	0.86	361
Financial corp.	Conventional	2017	2.54	3.11	3.03	3.62	0.98	17,402
		2018	3.28	3.80	3.76	4.32	1.04	36,66
		2019	2.50	3.10	3.00	3.59	0.93	49,54
		2020	0.98	1.98	1.81	2.62	1.32	58,421
		2021	0.62	1.50	1.27	2.10	1.13	14,924
	ESG	2017	2.08	2.52	2.55	2.87	0.78	180
		2018	2.94	3.34	3.23	3.74	0.86	481
		2019	2.34	2.78	2.72	3.24	0.75	883
		2020	0.84	1.52	1.24	2.13	1.00	1,292
		2021	0.59	1.17	1.00	1.59	0.75	403
General government	Conventional	2017	2.08	2.73	2.58	3.32	1.07	2,85
		2018	2.77	3.33	3.19	3.92	1.07	5,321
		2019	1.83	2.52	2.37	3.02	1.03	7,117
		2020	0.32	1.37	0.99	2.05	1.30	8,404
		2021	0.30	1.25	0.86	1.91	1.19	2,184
	ESG	2019	1.97	2.01	2.02	2.09	0.14	15
		2020	0.91	1.33	1.15	1.81	0.58	50
		2021	0.91	1.33	1.33	1.76	0.58	35

[1] This table reports summary statistics on the yields of the USD-denominated debt securities issued by non-euro area residents broken down by issuer sector, type of instrument (ESG/non-ESG) and reference year.

Yield Curve Estimation - Sample Characteristics

Table A.12

Area	Issuer sector	ESG	Rating	Number of securities	(log) amount	Residual maturity
Euro area	Non-financial	no	14.4	1,257.3	20.1	7.1
		yes	14.7	64.5	20.1	8.1
	Financial	no	16.2	2,600.3	19.5	7.1
		yes	15.7	85.1	20.2	6.0
	Government	no	15.9	563.2	17.1	9.4
		yes	18.0	11.2	20.6	9.9
Rest of the World (USD)	Non-financial	no	14.4	4,021.9	19.8	7.0
		yes	15.0	51.8	19.8	7.0
	Financial	no	15.5	3,947.7	20.0	5.3
		yes	16.9	56.4	20.0	3.9
	Government	no	18.0	575.8	21.9	6.2
		yes	18.4	2.9	20.3	6.1

[1] This table reports summary statistics on the samples used for the estimation of the yield curves over time. The samples include only securities with rating information and with investment grade characteristics, i.e. those with a BBB or higher rating. The rating class has been mapped into a numeric sequence of integers as illustrated in Figure 3.

Yield Curves Estimation Results

Table A.13

Area	Sector	Instrument	Parameter	25th	Mean	50th	75th	SD	N
Euro area	Non-financial corp.	Conventional	λ	1.80	1.85	1.91	1.97	0.21	11,294
			β_1	1.47	1.79	1.94	2.16	0.48	11,294
			β_2	- 2.13	- 1.61	- 1.87	- 1.28	0.76	11,294
			β_3	- 2.82	- 2.59	- 2.45	- 2.20	0.75	11,294
		ESG	λ	1.82	1.85	1.95	1.99	0.26	11,289
			β_1	1.22	1.67	1.84	2.13	0.57	11,289
			β_2	- 2.08	- 1.51	- 1.78	- 1.10	0.85	11,289
			β_3	- 2.80	- 2.51	- 2.41	- 2.16	0.85	11,289
	Financial corp.	Conventional	λ	1.77	1.81	1.92	1.98	0.28	11,294
			β_1	1.54	1.75	1.80	2.07	0.47	11,294
			β_2	- 1.97	- 1.49	- 1.69	- 1.26	0.84	11,294
			β_3	- 2.78	- 2.53	- 2.42	- 2.17	0.91	11,294
		ESG	λ	1.82	1.87	1.94	1.99	0.20	11,294
			β_1	1.41	1.80	1.83	2.22	0.56	11,294
			β_2	- 2.15	- 1.59	- 1.72	- 1.20	0.84	11,294
			β_3	- 3.02	- 2.76	- 2.65	- 2.29	0.93	11,294
Rest of the World (USD)	Non-financial corp.	Conventional	λ	1.03	1.31	1.30	1.58	0.35	11,295
			β_1	3.08	3.63	3.70	4.19	0.67	11,295
			β_2	- 2.06	- 1.88	- 1.83	- 1.66	0.38	11,295
			β_3	- 2.07	- 1.94	- 1.87	- 1.76	0.33	11,295
		ESG	λ	0.90	1.25	1.29	1.70	0.52	11,143
			β_1	2.86	3.49	3.51	4.05	0.75	11,143
			β_2	- 2.05	- 1.75	- 1.80	- 1.58	0.74	11,143
			β_3	- 2.08	- 1.85	- 1.85	- 1.68	0.65	11,143
	Financial corp.	Conventional	λ	1.00	1.25	1.24	1.51	0.35	11,295
			β_1	3.08	3.64	3.74	4.20	0.70	11,295
			β_2	- 2.09	- 1.85	- 1.80	- 1.60	0.41	11,295
			β_3	- 2.06	- 1.92	- 1.85	- 1.73	0.37	11,295
		ESG	λ	1.07	1.31	1.33	1.57	0.37	11,286
			β_1	2.99	3.43	3.48	3.90	0.64	11,286
			β_2	- 2.11	- 1.75	- 1.80	- 1.50	0.69	11,286
			β_3	- 2.09	- 1.90	- 1.88	- 1.71	0.47	11,286

[1] This table reports the estimated parameters of the Nelson-Siegel yield curve model on a sample of investment grade debt securities issued by non-financial corporations of the euro area and of the rest of the world. Data are referred to the period spanning from June 2017 to December 2020. For each combination of reference area (euro area and rest of the world), instrument type (ESG and non-ESG bonds) and reference date 250 random samples with repetition have been drawn from the available sample of securities as described in Table A.10 and Table A.11.

Everything You Always Wanted to Know About Green Bonds (But Were Afraid to Ask)

D. Liberati, G. Marinelli

Paris, September 14, 2021

Overview

Data base components

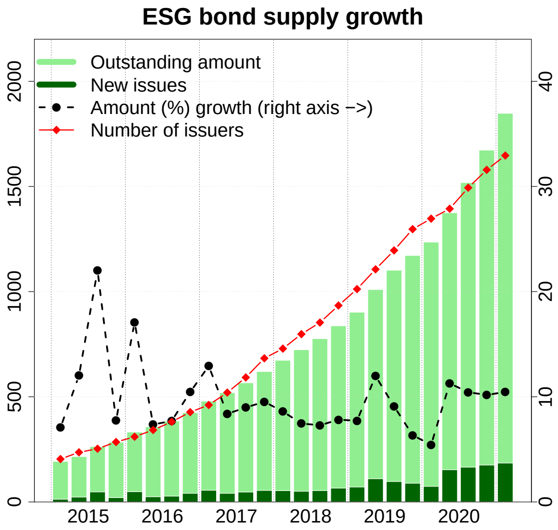
An official register of ESG bonds does not exist. We used three main components for our list:

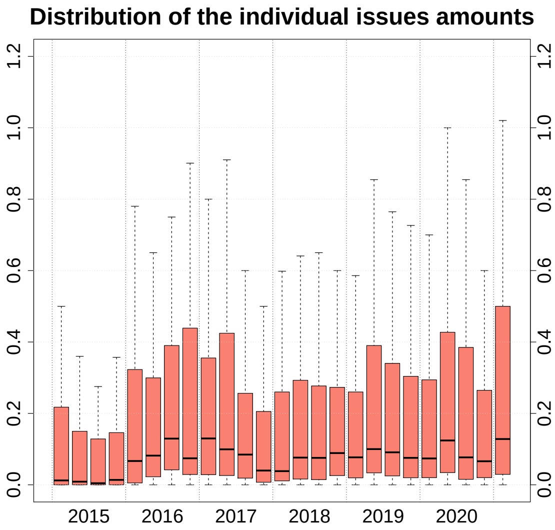
1. ESG debt securities which are quoted on dedicated bond markets ;
2. available information published by providers such as CBI, Environment Finance (EF) and ICMA ;
3. composition of some of the main green indexes and previous reports.

Other components from **official statistics micro-data**:

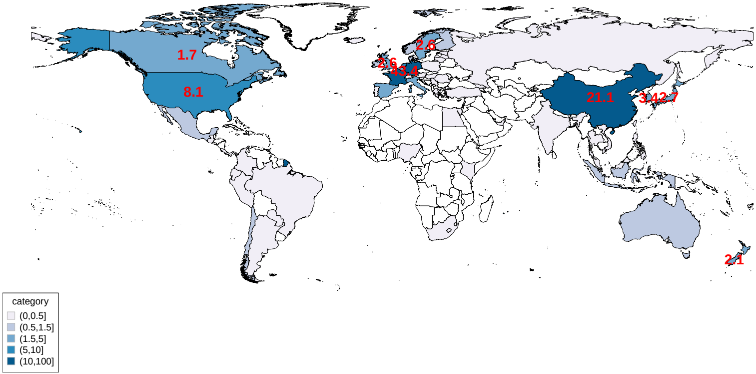
1. Bank of Italy Security Data Base ;
2. Bank of Italy supervisory statistics on individual banks', mutual funds' and insurance corporations balance-sheets;
3. Bank of Italy Security Holdings Statistics (SHS);
4. Harmonized statistics on sectoral financial accounts compiled by the Bank of Italy.

ESG Bond Supply Expansion

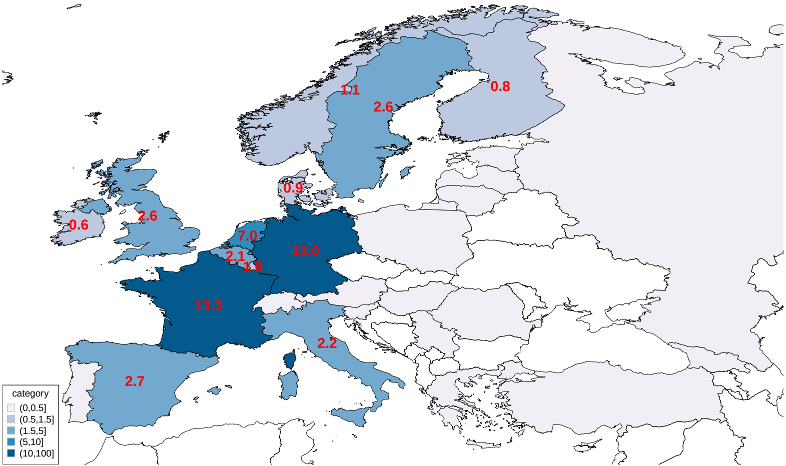




Share of ESG Bonds Supply by Country - Amount issued



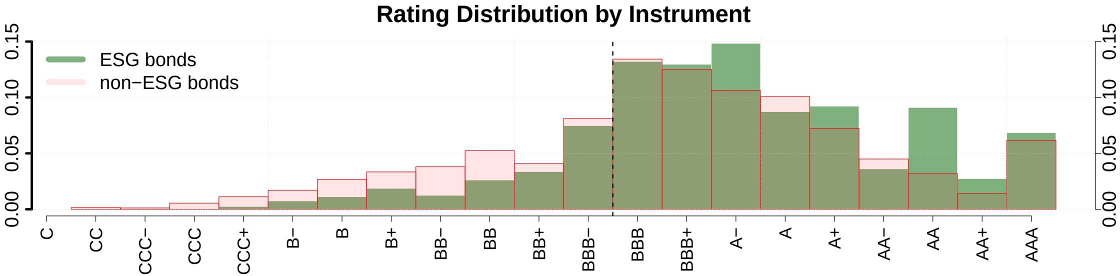
Share of ESG Bonds Supply by Country - Amount issued

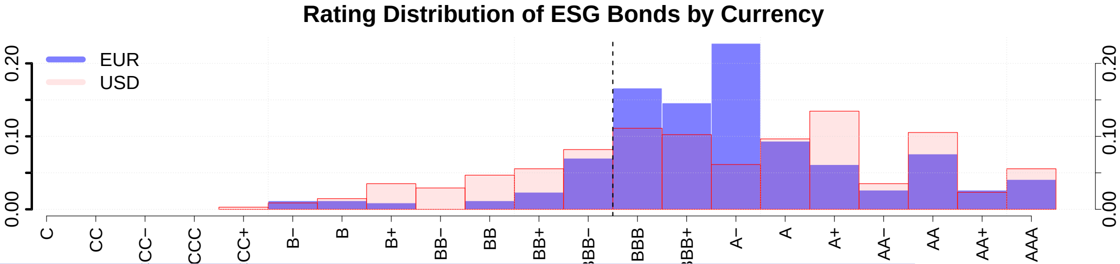


ESG Bond Supply by Country and Sector of the Issuer

Country	Non-financial Corporations S.11	Deposit-taking Institutions S.122	OFI S.125	Financial Auxiliaries S.126	Captive Institutions S.127	Insurance Corporations S.128	General Government S.13
CN	238	43	17.4	10.1	0	0	19.6
FR	35.7	30.6	1	1	0	0.8	137.7
DE	16.5	56.6	0	0.1	0.6	1.2	127.2
US	68	8.4	35.4	6.9	1.2	0.8	5.3
NL	16	42.1	4.7	6.5	29.1	0	10.7
KR	17	17.6	16.7	0.5	0	1.2	0.4
JP	17.9	5.1	12.8	1.2	0.4	0	4.9
ES	15	17.6	0	0	0	0	9.4
SE	18.4	12.9	0	0	0.2	0	9
GB	9.4	8.5	16.3	0.1	4.5	0.3	0.6
IT	14.3	9.1	0	1	0	1.4	8.5

ESG Bonds' Ratings



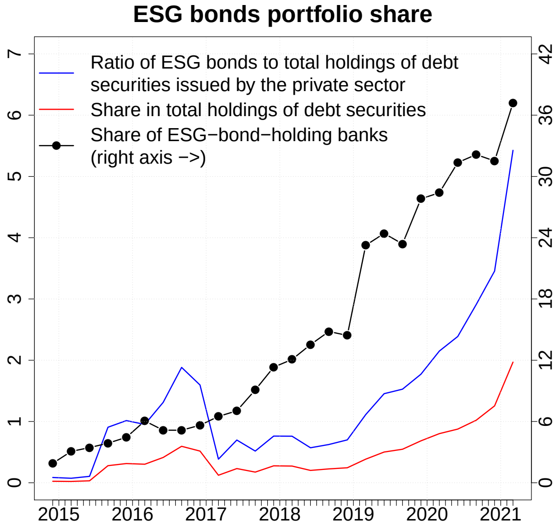


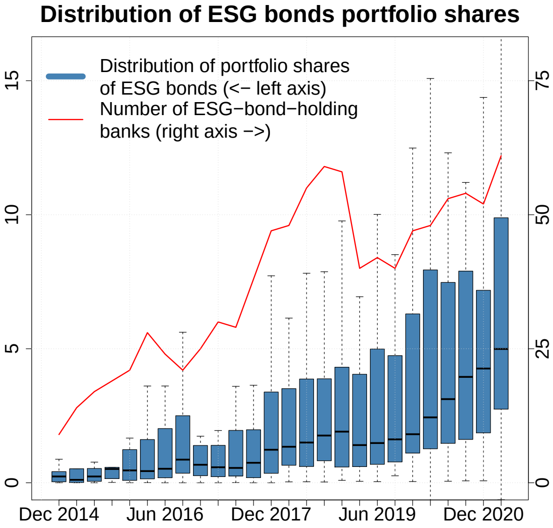
ESG security holdings - Italian residents

Reference date	Outstanding amount	Number of securities	Number of issuers	Number of countries	Maturity original	Maturity residual	Currency share EUR	Currency share USD	Listed share
2015 Q4	2.7	134	68	25	10.5	8.5	85.5	5.6	98.9
2016 Q4	5.7	194	95	31	10.5	8.2	89.6	4.4	99.5
2017 Q4	6.3	318	161	44	9.8	7.9	82.6	10.0	96.0
2018 Q4	8.6	432	211	47	8.9	6.8	82.4	9.8	92.9
2019 Q4	16.6	634	302	54	9.3	7.3	88.5	6.9	90.1
2020 Q1	17.8	700	322	52	9.5	7.5	89.2	6.3	89.6
2020 Q2	20.9	781	349	56	9.6	7.6	89.8	5.8	87.1
2020 Q3	24.5	871	391	58	9.6	7.5	91.2	5.1	87.3
2020 Q4	28.6	958	417	61	9.6	7.6	91.5	4.9	88.0
2021 Q1	37.4	1,090	471	66	12.1	10.1	92.5	4.5	88.4

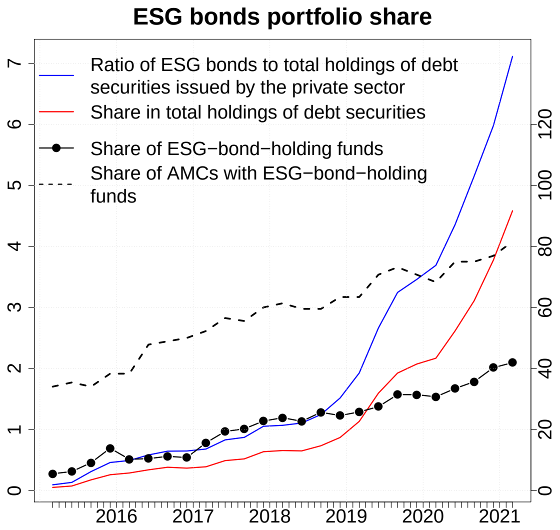
Reference date	Outstanding amount	Non-financial corporations S.11	Deposit-taking institutions S.122	Investment funds S.124	Insurance corporations S.128	Pension funds S.129	General Government S.13	Households and NPISH S.14+S.15	Other
2015 Q4	2.7	1.2	65.6	12.4	0	4	0.6	15.3	1
2016 Q4	5.7	1.7	50	8.5	24.6	4.9	0.6	9.3	0.4
2017 Q4	6.3	1.8	22.7	14	41.5	4.6	2.2	12.5	0.6
2018 Q4	8.6	1.5	16.2	12.6	50.2	5	1.8	12.1	0.7
2019 Q4	16.6	0.8	25.4	15.9	41.5	5.1	1.9	8.6	0.7
2020 Q1	17.8	0.8	28.3	14.2	41.2	5.2	1.7	7.9	0.7
2020 Q2	20.9	0.8	28.9	15.5	40.7	5	1.3	7.1	0.7
2020 Q3	24.5	0.7	29.2	15.6	41.3	5.2	1.2	6.1	0.6
2020 Q4	28.6	0.6	28.6	16.2	42.1	5.4	1.1	5.6	0.5
2021 Q1	37.4	1.8	35.1	15	36.7	4.6	1.1	5.2	0.5

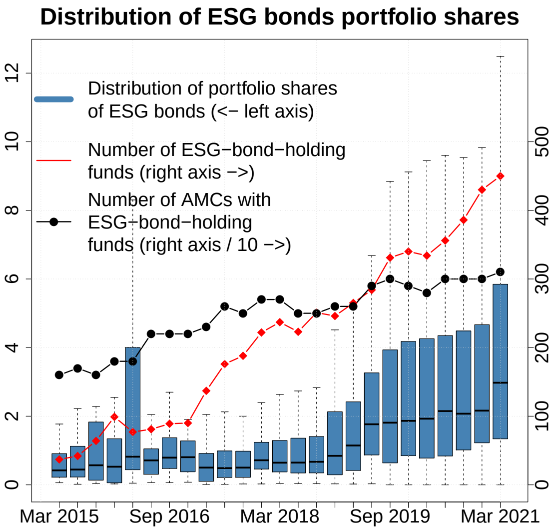
Banks' holdings



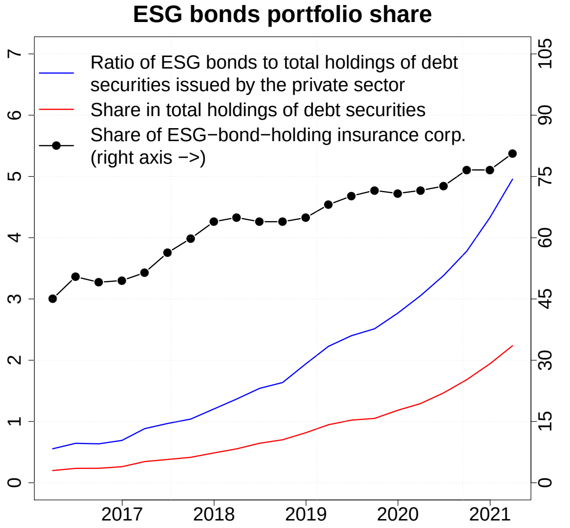


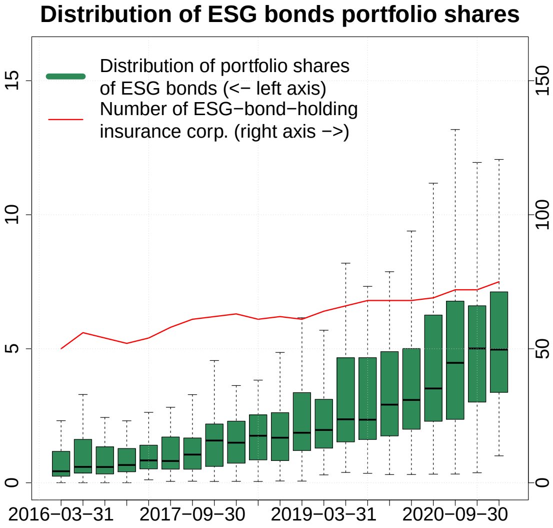
Investment funds' holdings





Insurance corporations' holdings





What is the *greenium*?

Previous findings and anecdotal evidence

- Negative yield spread between ESG and conventional bonds on the primary and secondary market
- Size of the premia ranges between 1 and 69 bps
- A few studies show a positive spread

Possible explanations

- Socially responsible investing → not only portfolio payoffs but tastes for assets as consumption goods (Fama and French 2007).
- Asset pricing theory (Fama, 1998): green bonds with lower risks due to:
  1. regular monitoring → higher transparency
  2. conventional bonds exposed to long-term climate-change risks (carbon tax or physical risks)

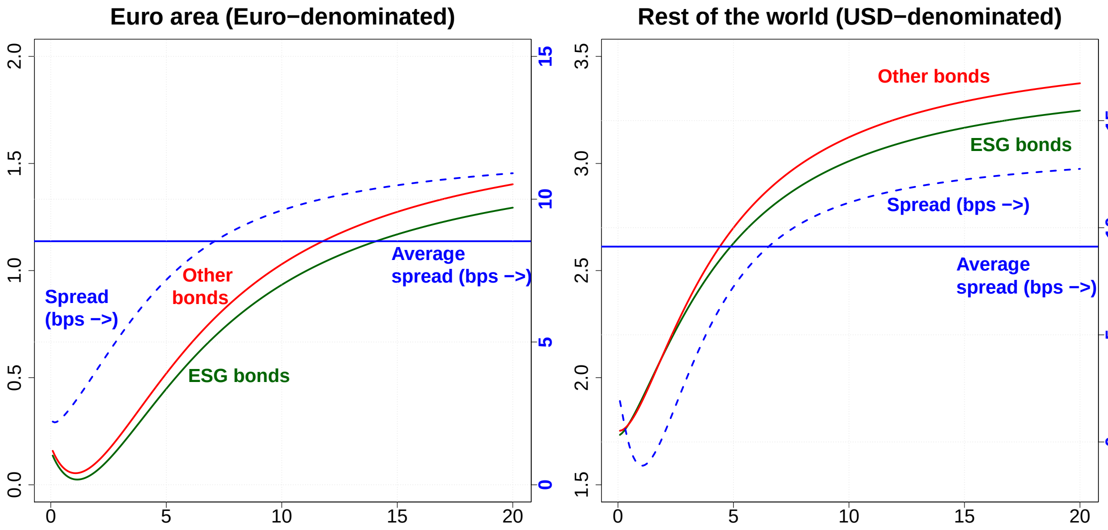
Yield Curve Estimation - Nelson-Siegel (1987) model

$$y_t^{NS}(\tau_s) = \beta_{1,t} - \beta_{2,t}\left[\frac{1 - exp(-\lambda_t\tau_s)}{\lambda_t\tau_s}\right] - \beta_{3,t}\left[\frac{1 - exp(-\lambda_t\tau_s)}{\lambda_t\tau_s} - exp(-\lambda_t\tau_s)\right]$$

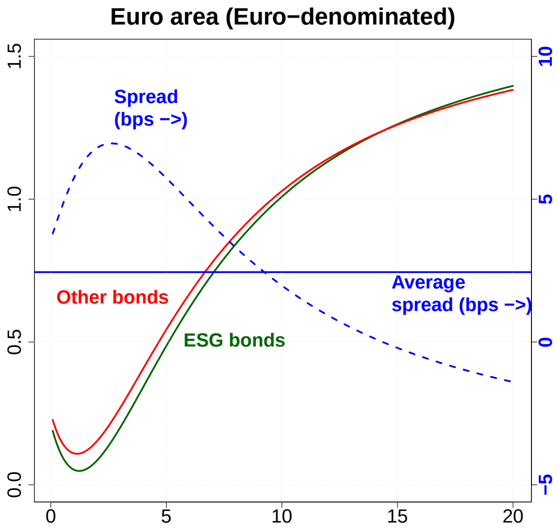
$$\begin{aligned} \underset{\{\beta_{1,t},\beta_{2,t},\beta_{3,t},\lambda_t\}}{\text{minimize}} \quad & Med\left(\left|y_t(\tau_s) - y_t^{NS}(\tau_s)\right|\right) \\ s.t. \quad & \beta_{1,t} > 0 \\ & \beta_{1,t} + \beta_{2,t} > 0 \\ & \lambda_t > 0 \end{aligned}$$

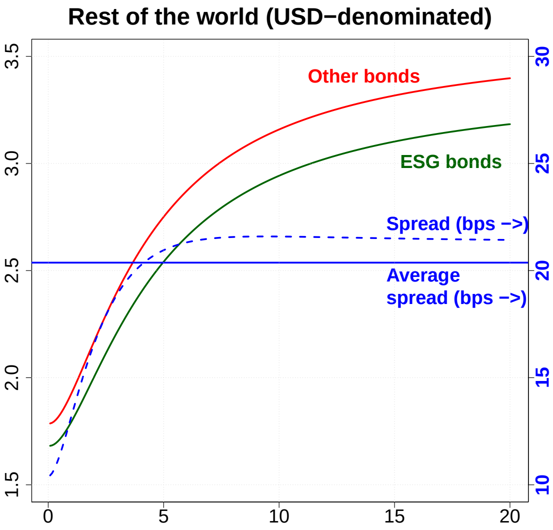
- In each monthly reference date between June 2017 and March 2021 we run the estimation on the original **sample of investment grade securities**
- We subsequently draw **250 samples of securities** belonging to 8 categories based on the disaggregation by ESG/non-ESG, currency of denomination (euro and USD) and institutional sector of the issuer (non-financial and financial corporations).

Yield Curve Analysis - Non-financial corporations



Yield Curve Analysis - Financial sector





Panel Regression

We carefully selected our subsamples for the yield curves estimation but...

- ESG securities could be on average **more liquid** and the lower yields may reflect such feature
- ESG bonds are characterized by **higher ratings** even within the investment grade subsample
- Security listing on an **exchange market**

The yield $y_{s,t}$ of security s in month t is regressed on:

$$y_{s,t} = \gamma ESG_{s,t} + \theta^{\intercal} X_{s,t} + \eta_{i,t} + \eta_{c,t} + \eta_{u,t} + \varepsilon_{s,t}$$

- ESG **indicator variable**
- $X_{s,t}$ vector of time-varying control variables at security level
- $\eta_{i,t}$ issuer-time fixed effects
- $\eta_{c,t}$ country-time fixed effects
- $\eta_{u,t}$ currency-time fixed effects

Securiy-level Estimation Results

	Corporations		Government	Corporations		Government
	Non-financial	Financial		Non-financial	Financial	
ESG	-0.098***	-0.1574***	-0.0532***	-0.0461***	-0.1280***	-0.0451*
	(0.0093)	(0.0091)	(0.0195)	(0.0131)	(0.0122)	(0.0253)
ESG × COVID				-0.1035***	-0.0663***	-0.0201
				(0.0185)	(0.0182)	(0.0397)
LISTED	-0.0645***	-0.0350***	-0.0367***	-0.0646***	-0.0351***	-0.0367***
	(0.0030)	(0.0038)	(0.0070)	(0.0030)	(0.0038)	(0.0070)
RATING	-0.3750***	-0.2477***	-0.2256***	-0.3749***	-0.2477***	-0.2256***
	(0.0031)	(0.0009)	(0.0025)	(0.0031)	(0.0009)	(0.0025)
AMOUNT	-0.0220***	-0.0935***	-0.0113***	-0.0219***	-0.0935***	-0.0113***
	(0.0008)	(0.0011)	(0.0006)	(0.0008)	(0.0011)	(0.0006)
MATURITY	0.1237***	0.1035***	0.0840***	0.1239***	0.1036***	0.0840***
	(0.0022)	(0.0027)	(0.0050)	(0.0022)	(0.0027)	(0.0050)
MATURITY^2	0.0044***	0.0059***	0.0069***	0.0044***	0.0059***	0.0069***
	(0.0003)	(0.0004)	(0.0006)	(0.0003)	(0.0004)	(0.0006)
MATURITY^3	-0.0003***	-0.0003***	-0.0004***	-0.0003***	-0.0003***	-0.0004***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Issuer × Time FE	Yes	Yes	No	Yes	Yes	No
Country × Time FE	Yes	Yes	Yes	Yes	Yes	Yes
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Yes

Conclusions

1. Dramatic **rise of the global supply**
2. Analogous weight increase in Italian residents' portfolios
3. Negative premia $\rightarrow$ **greenium does exist**
4. **Heterogeneity** across sectors
5. Covid-19 pandemic effect (**wake-up call** on climate change risks?)

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BIS

International Conference on "Statistics for Sustainable Finance", co-organised with the Banque de France and the Deutsche Bundesbank

14-15 September 2021, Paris, France, hybrid format

Climate Transition Risk Metrics – Investigating Convergence and Estimation Drivers[1]

Julia Anna Bingler, Swiss Federal Institute of Technology (ETH Zurich);
Chiara Colesanti Senni and Pierre Monnin, Council on Economic Policies

[1] This presentation was prepared for the conference. The views expressed are those of the authors and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

Climate Transition Risk Metrics

Investigating Convergence and Estimation Drivers

Julia Anna Bingler[a], Chiara Colesanti Senni[b], Pierre Monnin[b]

Abstract

Climate risks are now fully recognized as financial risks. Against this background, a rapidly growing number of market participants and financial authorities are exploring which metrics to use to capture climate risks, to what extent the use of different metrics delivers heterogeneous results, and which factors impact the assessment of risk. To shed a light on these questions, we analyse a sample of 69 transition risk metrics, delivered by nine providers, and covering about 1,500 firms worldwide. Our findings show that firms' risk assessments across metrics are relatively heterogeneous but display some degree of convergence. Convergence between metrics is significantly higher for the firms most exposed to transition risk. Our results also highlight that metrics' characteristics – the scenario and methodology they rely on – have an impact on the estimated risks. These findings bear important insight for the practical use of climate risk metrics: they suggest that available metrics provide useful information to risk managers to address high climate risk exposures and that risk managers must understand how metrics are built to choose those most appropriate to their needs.

Keywords: climate risk metrics, transition risk, panel OLS, scenario analysis, risk management

JEL classification: C83, D53, D81, G12, G32, Q54

[a] ETH Zurich.

[b] Council on Economic Policies.

Contents

1. Introduction

Climate risks are financial risks. As such, they must be duly assessed and managed by investors, asset managers and other financial institutions.[1] Financial supervisors and central banks must also diligently monitor and mitigate them to safeguard the stability of individual financial institutions and the financial system as a whole. However, although the materiality of climate-related financial risks is uncontested,[2] there is currently no agreement on how to measure these risks. There is a consensus, however, that traditional backward-looking methods, based on historical data and fitted distributions, are not suited to assess the unprecedented risks of climate change.[3] Against this background, various risk metrics providers have started to develop new forward-looking approaches that can be used by financial market participants to assess and manage climate-related financial risks.

Yet, the methodologies, data and assumptions underpinning these new risk assessment approaches can vary substantially from one metric to another (Bingler and Colesanti Senni 2020). This does not come as a surprise: it reflects the significant complexity and uncertainty in the analysis of climate risks. This heterogeneity can generate divergence in climate risk assessments across metrics and thus requires conscious decisions on which metrics to use by investors and financial institutions, as well as by central banks and financial supervisors.

In this context, previous research shows that forward-looking transition risk metrics display much less heterogeneity for the firms that are most and, to a lesser extent, least exposed to transition risks (Bingler et al., 2020, 2021a). This feature can be used by investors, asset managers, central banks, and financial supervisors to mitigate exposures to high climate-related financial risks. The same research also shows that understanding how metrics characteristics affect their risk assessments is key.

Against this background, in this study, we first check whether the convergence of metrics on firms most exposed to transition risk observed by Bingler et al. (2020, 2021a) for a European sample of firms is also observed globally. For that, we replicate Bingler et al.'s study with additional transition risk metrics and for a larger portfolio that is also covering non-European firms. Second, we explore which metric characteristics are associated with changes in the estimated transition risk exposures. For that, we empirically assess which sub-elements of the metric characteristics (i.e. underlying scenario elements and methodology elements) significantly affect transition risk estimates.

Our results confirm the earlier findings of Binger et al. (2020, 2021a), that is: 1) climate risk metrics display a significant degree of heterogeneity, which reflects the complexity of assessing climate risks, as well as the different methodologies and data

[1] See Monnin (2020).

[2] Central banks and financial supervisors acknowledge the materiality of climate-related financial risks (NGFS, 2018; BCBS, 2020; Bolton et al., 2020; FSOC, 2021), and the scientific literature back this assessment (Caldecott et al., 2016; Gros et al., 2016; Battiston et al., 2017; Stolbova et al., 2018; Roncoroni et al., 2019; Bretschger and Karydas, 2019).

[3] There is also a general recognition that non-linearity, non-stationarity, path-dependencies and endogeneity render climate-related financial risks more challenging to assess than traditional risks (Weitzman, 2011; Chenet et al., 2019; Battiston et al., 2019; Karydas and Xepapadeas, 2019).

underpinning these metrics, and 2) risk assessments across metrics tend to converge on which firms are most exposed to transition risks. In addition, our results show that the assumptions underlying metrics affect the convergence between them: metrics sharing similar transition scenarios tend to have a higher degree of convergence than when they diverge in these dimensions.

We also find strong evidence that the scenario and the methodology underlying a metric affect the estimated transition risk. Our analysis shows that 1) the individual model characteristics are an important driver of the estimated risk. In particular, metrics that include information on firms' climate plans are associated with higher risk estimates than metrics, which do not include such information. Furthermore, we find 2) that the scenario on which a metric is based impacts its estimated risk: lower temperature targets increase risk estimates, longer time horizons also increase the estimated risk, and an orderly transition scenario delivers lower risk estimates than a disorderly transition scenario. Finally, our analysis shows that the majority of metric characteristics are not statistically significantly associated with the shape of the distributions of estimated risks, i.e. the distributions' standard deviation, skewness and kurtosis.

These findings provide important insights for the practical use of climate risk metrics. First, despite the heterogeneity observed across metrics, we find that metrics tend to converge on which firms are the most exposed to transition risks. They thus provide decision-useful information to risk managers to address high transition risk exposures. Second, the scenario and methodology underlying metrics do impact the estimated risk. It is therefore important for risk managers to understand well how metrics are built to choose the ones that are the most appropriate to their needs. Third, firms, which disclose climate risks should also report the underlying methods, data sources and scenario assumptions in addition to the metrics' values.

2. Data

In this study, we focus on the companies included in the MSCI World Index as of 31 January 2021. Moreover, we only consider forward-looking risk metrics that provide an assessment of transition risk at the firm level.

We contacted 25 providers of transition risk metrics and invited them to share with us their estimates of transition risk for the companies in our portfolio. Out of 25 providers, 14 agreed to send us their estimates, of which we removed 5 because their metrics were not providing estimates at the firm level, were not covering at least half of our portfolio, or were not based on forward-looking analysis (e.g., were based on current CO2 emissions only).[4]

Several providers delivered estimates for various temperature targets, time horizons and assumptions about the transition path. We treated each combination of temperature target, time horizon and transition path from the same provider as one specific metric. Overall, this gave us 69 different transition risk metrics from nine

[4] For a detailed description of our data and sample procedure see Bingler et al. (2021b).

providers, all based on different methodologies, horizons, and transition scenarios.[5] This sums up to a dataset of 105’000 transition risk point estimates for the individual firms in our sample.[6]

For metric characteristics, we distinguish between features of the scenario underlying the risk estimation (temperature target, time horizon and shape of transition path) and features related to the methodology underlying the metrics (type of metric delivered, inclusion of information about firms’ climate plans, bottom-up vs top-down approach[7]). These characteristics are detailed in Table 1.

Metrics characteristics

Description Table 1

	Possible values
Scenario	
Temperature target	1.5°C, below 2°C, 2°C, 3°C, NA
Time horizon	2025, 2030, 2040, 2050, 2100, NA
Transition path	Orderly, Disorderly, NA
Methodology	
Type of metric[8]	Income statement, Asset price, Risk score, Alignment
Information on firms’ climate plans	CAPEX, Target, None
Approach	Bottom-up, Top-down, Combination, NA

3. Assessing convergence across risk metrics

To assess the convergence between metrics, we first rank the firms according to their estimated risk exposure for each metric. We then class them in five risk categories – from 1 for the least exposed firms to 5 for the most exposed firms. To assess the degree of convergence between two metrics, we use two indicators:

5 The metrics included in the final sample for the analysis in this paper are from the following providers: ISS ESG, Moody's Corporation, MSCI ESG Research, PwC / The CO-Firm, Planetrics, right. based on science, S&P Global Market Intelligence, Sustainaccount, University of Augsburg.

6 Keeping in mind that some metrics are not available for all the firms in our sample.

7 Top-down approaches are macro-oriented (e.g. overall reduction needed in a sector translated at the firm level), bottom-up approaches have firm level data as starting point.

8 The types of metrics are characterised as follows:

(1) Income statement: metric shows the estimate of climate transition risks as an estimated impact on firms’ costs, revenues or overall profits for a specific timeframe.

(2) Asset price: metric shows the estimated effect of climate transition risks on the equity or bond price of the individual firm.

(3) Risk score: metric assigns a specific climate transition risk score to the individual firm or provides a climate transition risk-adjusted credit risk rating for the individual firm.

(4) Alignment: metric assesses the degree of global climate targets alignment/misalignment of a firms’ operations and climate-related performance.

1. The average difference for a firm's risk category between the two metrics (*Absolute Distance*). The lower the Absolute Distance, the higher the convergence between two metrics.

2. The percentage of firms with identical risk categories in the two metrics (*Agreement Rate*). The higher the Agreement Rate, the higher the convergence between two metrics.

Convergence within providers

Our findings indicate a high degree of convergence between risk assessments when they are delivered by the same provider. However, we observe a significant degree of heterogeneity when the risk assessments are delivered by different providers.

As shown in Table 2 (Specification 1), the degree of convergence increases when two metrics are delivered by the same provider. The degree of convergence, however, differs between providers: it is almost perfect for some and lower for others (see Table 2, Specification 2). This suggests that, for some providers, the ranking of firms is not significantly influenced by the scenario and methodology underlying the different metrics of the provider. For other providers, these dimensions have an impact on firms' ranking.

Convergence within providers

OLS regression

Table 2

	Specification 1		Specification 2	
	Absolute Distance	Agreement Rate	Absolute Distance	Agreement Rate
Intercept	1.45**	0.245**	1.45**	0.245**
Same provider	-1.07**	0.478**		
Provider A			-1.35**	0.655**
Provider B			-0.88**	0.352**
Provider C			-0.77**	0.305**
Provider D			-1.34**	0.689**
Provider E			-1.12**	0.445**
Provider F			-0.94**	0.354**

* (**) means statistically significant with a 5% (1%) confidence interval.

Convergence across providers

Our results in Table 2 also indicate that, when two metrics are delivered by two different providers, a significantly lower degree of convergence is observed between them. This result confirms the heterogeneity in risk assessments delivered by different providers that we observed in our previous study (Bingler *et al*. 2020, 2021a). The heterogeneity in risk assessments that we find does not come as a surprise: it reflects the significant complexity and uncertainty in the analysis of climate risks.

However, some degree of convergence exists between providers. Our regression results in Table 2 show that the Agreement Rate between two metrics stemming from two different providers is about 25%, that is 20% more frequently than if the two metrics were perfectly heterogeneous.

To highlight the drivers of the convergence between two metrics from different providers, we assess whether the characteristics of each provider's methodology impact the convergence between two metrics. To this end, we assess whether the convergence between two metrics increases when they are based on similar scenarios,[9] metric type, and methodologies.[10] The results are presented in Table 3.

Convergence by similar metrics features

OLS Regression Table 3

	Absolute Distance	Agreement Rate
Intercept	1.56**	0.208**
Same Time Horizon	-0.02	0.007*
Same Temperature Target	-0.07**	0.012**
Same Transition Path	-0.06**	0.018**
Same Metric Type[1]	-0.03	0.010
Same Approach[2]	0.02	0.005
Both with information on firms' climate plans	-0.02*	-0.001

[1] Impact on income statement, impact on asset price, risk score or alignment with transition.

[2] Top-down, bottom-up or combined approach.

* (**) means statistically significant with a 5% (1%) confidence interval.

Our results show that metrics sharing similar scenario characteristics like similar horizon, temperature target and assumptions on the path of the transition display higher convergence, both when measured by the Absolute Distance (decrease in the Absolute Distance) and the Agreement Rate (increase in the Agreement Rate). Evidence on the impact of the type of methodology is less univocal: delivering the same metric type or being both based on information including firms' climate plans significantly increases convergence only according to one of our two statistics: The Agreement Rate when metrics have the same type of metric, and the Absolute Distance when metrics are both based on information including firms' climate plans. Note, however, that, although statistically significant, the impact of similar scenarios

[9] Concretely, we divide metrics between those with an assessment horizon between 2025 and 2040, and those with a longer horizon; between the metrics with a temperature target of 2°C or below and those above 2°C; and between metrics that model an orderly or a disorderly transition.

[10] We distinguish between types of output delivered by the metrics – financial indicators (e.g. future earnings, value-at-risk, stock price change) vs. other indicators (e.g. risk score, alignment measure) – and whether metrics include information of firms' climate plans (CAPEX or climate targets).

and methodologies only moderately improves the convergence between two metrics: the heterogeneity between them remains pronounced even when two metrics are based on similar scenarios and methodologies.

Convergence on firms with high exposure

We confirm another important result of Bingler et al. (2020, 2021a): metrics from different providers tend to converge more for firms that are assessed as most exposed to transition risk. For that, we estimate the excess frequency of observing a combination of assessments for the same firm in our sample, compared to the frequency that would occur if assessments were fully heterogeneous. To reflect the fact that characteristics of metrics might impact the convergence between metrics (see previous section), we only compare the pairs of assessments for metrics that have similar horizons, temperature targets, assumptions on the path of the transition and output indicators. The results are presented in Table 4.

Convergence between firm's risk assessment pairs

Observed excess frequency (in %) Table 4

Difference between risk assessments in the pair	0	30
	1	6
	2	-8
	3	-27
	4	-20

A positive (negative) number indicates that the difference between two risk assessments for the same firm is observed more (less) frequently than if the two metrics where not correlated

Table 5 shows that pairs of assessments in which two metrics agree – i.e., two metrics rank a firm in the same quintile – occur more often than with an independent distribution. This indicates that risk metrics tend to agree relatively more often than they disagree on the risk exposure of the same firm.

We find that the highest excess frequency is observed for the pairs where both assessments fall into the fifth quintile. This indicates that convergence in assessments between metrics is more pronounced for firms with the highest estimated exposure to transition risks. Bingler *et al.* (2020, 2021a) find the same results on a sample of European firms.

Convergence between firm's risk assessment pairs per quintiles

Observed excess frequency (in %) Table 5

Highest quintile						
	1	6				
	2	-6	13			
	3	-2	40	34		
	4	-11	22	3	-8	
	5	-20	-42	-45	-15	105
		1	2	3	4	5
		Lowest quintile				

A positive (negative) number indicates that the difference between two risk assessments for the same firm is observed more (less) frequently than if the two metrics where not correlated

4. Understanding the drivers of risk assessments

In order to better understand the individual risk assessments, we explore which characteristics of a metric can be associated with the estimated value of firms' transition risk. Unfortunately, the providers in our dataset deliver estimated transition risks in different units (e.g., change in stock price, value-at-risk, credit score, etc.), which makes a direct comparison between metric values impossible. To cope with this issue, we use two different rescaling methods for the metrics for our analyses across firms and providers, each presented in the next two subsections. In addition, in a third subsection, we explore whether the characteristics of a metric impact how estimated risks are distributed across firms – i.e., whether metrics' characteristics modify the shape of the metrics' estimated risk distribution.

Impact of metrics characteristics on firms' risk assessments

We first rescale each risk assessments according to

$$y_{i,j}^{*} = \frac{y_{i,j} - \min_{i}(y_{i,j})}{\max_{i}(y_{i,j}) - \min_{i}(y_{i,j})}$$

where $y_{i,j}$ is the estimated transition risk exposure for firm i with metric j. The rescaling produces a new vector of risk assessments for each metric, with values ranging between 0 and 1. Clearly, with this rescaling, we lose information about the level and the range of the estimated transition risk for a metric compared to other metrics. However, we keep important information on the level of transition risks for a firm relative to other firms provided by one metric.

We use this rescaling to assess whether metric characteristics are associated with changes in the estimated relative level of transition risk for a firm across all metrics. For that, we estimate a heteroskedasticity-robust panel OLS regression with firm-fixed effects to control for unobservable variables at the firm level. We choose an estimation method which is robust to outliers[11] and we compute our model for cluster-robust standard errors, where the clustering is given by the provider.

The results are presented in Table 6. The coefficients are our estimation of the impact of using different temperature targets, time horizons, metric types, climate plan considerations and metric approach, all compared to our baseline. The baseline is a metric using a 1.5°C temperature target, a time horizon of 2025, estimating transition risks for firms' income statement, not including any information about firms' climate plans and using a bottom-up approach.

Impact of metrics characteristics on firm's risk assessment

Robust Panel OLS Regression — Table 6

	Estimated coefficient	Standard error
Intercept		
Scenario		
Temperature target (Baseline: 1.5°C)		
Below 2°C	-0.129	0.199
2°C	-0.124	0.241
3°C	-0.149	0.176
Not applicable	0.228	0.215
Time horizon (Baseline: 2025)		
2030	0.042	0.032
2040	0.109	0.064
2050	0.019	0.107
2100	-0.060	0.109
Not applicable	-0.400**	0.123
Methodology		
Type of metrics (Baseline: Income statement)		
Asset price	0.559	0.315
Alignment	0.578**	0.139
Risk score	0.281**	0.057
Information on firm's climate plans (baseline: no information)		
Firm's targets	0.303**	0.085
Firm's CAPEX	0.565**	0.089
Approach (baseline: Bottom-up)		
Combined	-0.322**	0.054
Top-down	0.096	0.155

* (**) means statistically significant with a 5% (1%) confidence interval.

Panel with fixed effects for firms.

[11] We use the iterated re-weighted least squares (IRLS). There are several weighting functions that can be used for IRLS. In our specification we use Huber weights.

We find that the type of metric used, the inclusion of a firm's climate plans and the approach underlying the metric are associated with a significant change in the estimated level of transition risk for a firm, relative to how this firm is assessed by a metric when using the baseline specification. On average, using an alignment indicator or a risk score produces higher relative estimated risks for a firm than using an income statement indicator. Similarly, including information on a firm's climate plans, either by considering a firm's climate targets or its CAPEX, induce a higher relative estimated transition risk than when the metric does not include information about a firm's climate plans. This could suggest that metrics reflect that there are only a few companies with climate plans aligned with the transition requirements and global or national climate targets, and most companies with climate plan not aligned with it. In such a situation, relative risk assessments for metrics that consider climate plans could be higher than risk assessments for metrics that do not take information about plans into account. Finally, we find that metrics based on a combination of top-down and bottom-up approach produce different relative estimated risks than metrics based solely on a top-down or a bottom-up approach. This result, however, should be interpreted with caution, as our dataset only contains a limited number of metrics using a combination of top-down and bottom-up approach.

Finally, we do not find that different temperature targets and time horizons affect the relative estimated risk for a firm. This, however, does not mean that scenarios have no impact on estimated risks. It might rather show that the average level of risk is influenced by scenarios, but that through our rescaling, we lose information about this level for a metric compared to other metrics. In the next subsection, we take advantage of the fact that some providers delivered several metrics in the same unit, but with different temperature targets and time horizons, to assess this case.

Impact of scenarios on risk level assessments

In this subsection, we take advantage of the fact that five providers deliver risk estimations for several scenarios, to assess whether different scenarios impact the level of transition risks estimated by a specific metric. For that, we use a slightly different rescaling, i.e.

$$y_{i,j}^{+} = \frac{y_{i,j} - \min_{i,j \in P}(y_{i,j})}{\max_{i,j \in P}(y_{i,j}) - \min_{i,j \in P}(y_{i,j})}$$

where P is the set of all metrics delivered by a specific provider. Since all the metrics provided by a specific provider are expressed in the same unit, we can rescale them all on the interval between the lowest and the highest value observed in the different scenarios delivered by the provider. This allows us to assess how scenario characteristics impact the estimated level of transition risks.[12]

[12] Note that using this rescaling, we lose the information contained in metrics delivered by providers that do not estimate transition risks for multiple temperature targets and time horizons. Therefore, it was not a useful approach to assess the impact of the metrics' method on the estimated risks.

For each provider, we perform a heteroskedasticity-robust panel OLS regression with firm fixed effects. Note that the number of metrics and of explanatory variables varies across providers. Our results are reported in Table 7. Each column represents one provider, with the regression results for the metrics from this specific provider.

Our results, presented in Table 7, show that both, temperature targets and time horizon, have an impact on the estimated transition risk level. The impact of temperature targets is significant for all our providers. As expected, the lower the temperature target, the higher the estimated transition risk – i.e., a transition to 1.5°C is associated with higher risk estimates for firms than a transition to 3°C (which is commonly considered as business as usual). Results for different time horizons are similar: with the exception of Provider 2, for which the time horizon does not impact the risk level, increasing the horizon significantly increases the estimated risks. Finally, results for Provider 2 show that risks decrease when firms adapt to the transition, compared to the case in which they are inactive facing the transition. Results for Provider 5 indicate that an immediate transition entails less risk than a delayed transition, whereas Provider 3 does not find a significant difference for these two transition pathways.

Impact of temperature targets and time horizon on risk assessment

Robust OLS Regression — Table 7

	Provider 1	Provider 2	Provider 3	Provider 4	Provider 5
Intercept	-0.355**	0.269**	0.289**	-0.467**	-0.525**
Temperature target					
1.5°C			Baseline	Baseline	
Below 2°C	0.006**	0.004**		-0.021**	
2°C	Baseline	Baseline	-0.001**	-0.026**	
3°C		-0.002**	-0.003**		
Time horizon (baseline: 2025)					
2030		-0.001	0.000	0.006**	0.003**
2040		0.000	0.002**	0.008**	0.007**
2050		0.000	0.003**	0.011**	0.009**
Specific metrics assumption					
Firms adapt to transition		-0.011**			
Immediate transition			0.000		-0.002**

* (**) means statistically significant with a 5% (1%) confidence interval.

Impact of metrics characteristics on the shape of distributions

Finally, we assess whether metrics' characteristics significantly impact the shape of the distribution of the estimated risk, beyond their impact on the estimated mean, as shown in the previous sections. For that, for each metric, we compute three statistics summarizing the shape of the distribution of firms' estimated risks: the standard deviation, the skewness, and the kurtosis. The standard deviation shows how close estimated risks are from the metrics' average estimated risk.[13] The skewness is a measure of the symmetry of a distribution.[14] The kurtosis indicates how flat a distribution is.[15]

We then regress these statistics on provider characteristics. Note that since we compute each statistic per metric, we get 69 observations to regress on 17 metrics characteristics. This is potentially not enough observations to get robust estimated coefficients. To cope with this problem, we use a LASSO-reduced OLS regression. The LASSO methodology selects only the variables that have the most impact on the dependent variables, and then estimate a regression with this restricted set of regressors, to obtain a more robust estimation. Our results are presented in Table 8.

Overall, our results show that metrics' characteristics do not significantly alter the shape of the distribution of the estimated risks for firms beyond the metric distributions' means, i.e. the distributions' standard deviation, skewness and kurtosis. Some of them – metrics assessing risk in terms of impact on firms' asset prices, considering firms' climate plans by using information about firms' CAPEX, or adopting a combined bottom-up and top-down approach – reduce the spread of risks around the average (shown via the standard deviation estimates), while metrics assessing a risk score increase it. None of them affect the symmetry of the distribution (shown via the skewness estimates), while metrics assessing risk scores flatten the distribution (shown via the kurtosis estimates).

13 A high standard deviation indicates that the estimated risks are spread out over a large range of values.

14 A positive value means that the right tail of the distribution is longer than the left, a negative value that the left tail is longer than the right.

15 A negative kurtosis indicates that the distribution is flatter than a normal distribution – i.e. with "fat tails".

Impact of metrics characteristics on shape of distribution

LASSO-Reduced OLS Regression Table 8

	Standard deviation	Skewness	Kurtosis
Intercept	0.163**	2.084	45.475**
Temperature target (Baseline: 1.5°C)			
Below 2°C	--	--	--
2°C	-0.017	--	--
3°C	-0.041	--	-17.049
Not applicable	--	--	--
Time horizon (Baseline: 2025)			
2030	--	--	--
2040	--	--	--
2050	--	--	--
2100	--	--	--
Not applicable	--	--	--
Type of metrics (Baseline: Income statement)			
Asset price	-0.073**	--	--
Alignment	--	--	--
Risk score	0.128**	--	-31.986**
Information on firm's climate plans (baseline: no information)			
Firm's targets	--	-2.001	--
Firm's CAPEX	-0.063**	-2.689	--
Approach (baseline: Bottom-up)			
Combined	-0.108**	--	--
Top-down	--	--	--

* (**) means statistically significant with a 5% (1%) confidence interval.

-- indicates that the variable is not selected by the LASSO procedure

5. Conclusion

Our results confirm the early findings of Binger et al (2020, 2021a), that is: 1) climate risk metrics display a significant degree of heterogeneity, which reflects the complexity of assessing climate risks, as well as the different methodologies and data underpinning these metrics, and 2) risk assessments across metrics tend to converge on which firms are most exposed to transition risks. In addition, our results show that 1) metrics from the same provider but based on different scenarios display a higher degree of homogeneity than metrics from different providers, and 2) the scenarios and the methodology underlying a metric affect the convergence between two metrics from different providers: metrics sharing similar time horizons, temperature targets and assumptions about the shape of the transition (i.e., orderly vs disorderly) tend to have a higher degree of convergence than when they diverge in these dimensions.

Turning to the drivers of the risk estimates, we find strong evidence that metric characteristics impact the estimated level of transition risk. Our results show that both the methodology underlying a metric and the scenario it relies on significantly affect the estimated risk for a firm. The across-tools analysis shows 1) that the individual model characteristics are an important driver of the estimated risk relative to another metric. In particular, metrics that include information on firms' climate plans seem to deliver higher relative risk estimates than metrics which do not include such information. Furthermore, our within-tool analysis shows that 2) the scenario on which a metric is based impacts the estimated risks: lower temperature targets increase risk estimates, longer time horizons also increase the estimated risk, and an orderly transition scenario delivers lower risk estimates than a disorderly transition scenario. Finally, our analysis shows that metrics' characteristics do not significantly impact the shape of the distribution of estimated risks beyond the metric distributions' means, i.e. do not impact the standard deviation, skewness and kurtosis.

These findings provide important insights for the practical use of climate risk metrics. First, despite the heterogeneity observed across metrics, we find that metrics tend to converge on which firms are assessed as most exposed to transition risks. They thus provide useful information to risk managers to address high transition risk exposures. Second, the scenario and methodology underlying the metrics impact the estimated risk. It is therefore important for risk managers to understand well how metrics are built and to choose the ones that are the most appropriate to their needs. Third, firms, which disclose climate risks should also report the underlying methods, data sources and scenario assumptions in addition to the metrics' values.

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Climate risk metrics: Convergence, divergence and metrics characteristics

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Contribution

- Climate risks are financial risks
  - assessed, monitored and controlled
  - integrated in financial supervision and monetary policy operations

(1) Do different climate risk metrics lead to a different risk assessment for the same firm?

(2) Do the scenario and the methodology underlying a metrics impact on the estimation of transition risk?

Data and variables

- 1543 firms, components of MSCI World Index as of 31 January 2020
- 9 providers of forward-looking climate risk or alignment metrics
- More than 105'000 observations from 69 transition risk metrics
- For each metric, 6 variables describing the underlying scenario and methodology

Convergence analysis

- For each metric, firms are classified in 5 risk categories (1 = lowest risk, 5 = highest risk)

- Two indicators of coherence between metrics:
  (1) **Absolute distance**: average risk category difference across firms
  (2) **Agreement rate**: percentage of firms in same risk category

- Coherence within providers

	Specification 1		*Specification 2*	
	Absolute Distance	Agreement Rate	Absolute Distance	Agreement rate
Intercept	1.45***	0.245***	1.45***	0.245***
Same Provider	-1.07***	0.478***		
Provider 1			-1.35***	0.655***
Provider 2			-0.88***	0.352***
Provider 3			-0.77***	0.305***
Provider 4			-1.34***	0.689***
Provider 5			-1.12***	0.445***
Provider 6			-0.94***	0.354***

*p<0.1; **p<0.05; ***p<0.01

Convergence across providers

- Scenario and methodology matter for coherence across providers

	Absolute Distance	Agreement Rate
Intercept	1.56***	0.208***
Same Horizon	-0.02*	0.007**
Same Temperature	-0.07***	0.012***
Same Shape	-0.07***	0.018***
Same Output	-0.01	0.015***

*p<0.1; **p<0.05; ***p<0.01

- Higher coherence for firms highly exposed to transition risk

Excess frequency of observed risk assessments pairs vs. independent metrics (in %)

(a) Difference in pairs

0	30
1	6
2	-8
3	-27
4	-20

(b) Per quintile pairs

Highest quintile \ Lowest quintile	1	2	3	4	5
1	6				
2	-6	13			
3	-2	40	34		
4	-11	22	3	-8	
5	-20	-42	-45	-15	105

Metrics characteristics

- Indep. variable: Risk assessments (min-max normalization)
  (1) Across-metrics panel OLS
    - Dep. variables: Temperature target, time horizon, output type, firm targets, CAPEX, approach
    - Heteroskedasticity- and cluster-robust SE
  (2) Within-metric OLS
    - Dep. variables: Temperature target, time horizon, transition path
    - Heteroskedasticity-robust SE
- Robust to outliers specification

Across-metrics panel OLS

	Dependent variable: Risk assessment		
temp_target_b2	-0.129	output_finmetric	0.559*
	(0.199)		(0.315)
temp_target_2	-0.124	output_gap	0.578***
	(0.241)		(0.139)
temp_target_3	-0.149	output_riskscore	0.281***
	(0.176)		(0.057)
temp_target_na	0.228	firm_target_1	0.303***
	(0.215)		(0.085)
time_horizon_2030	0.042	capex_1	0.565***
	(0.032)		(0.089)
time_horizon_2040	0.109*	approach_comb	-0.322***
	(0.064)		(0.054)
time_horizon_2050	0.119	approach_topdown	0.096
	(0.107)		(0.155)
time_horizon_2100	-0.060	Constant	-0.509**
	(0.109)		(0.222)
time_horizon_na	-0.400***		
	(0.123)		

*p<0.1; **p<0.05; ***p<0.01

Across-metrics panel OLS

	Dependent variable: Risk assessment		
temp_target_b2	-0.129	output_finmetric	0.559*
	(0.199)		(0.315)
temp_target_2	-0.124	output_gap	0.578***
	(0.241)		(0.139)
temp_target_3	-0.149	output_riskscore	0.281***
	(0.176)		(0.057)
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	(0.064)		(0.054)
time_horizon_2050	0.119	approach_topdown	0.096
	(0.107)		(0.155)
time_horizon_2100	-0.060	Constant	-0.509**
	(0.109)		(0.222)
time_horizon_na	-0.400***		
	(0.123)		

modelling approach

*p<0.1; **p<0.05; ***p<0.01

Across-metrics panel OLS

	Dependent variable: Risk assessment		
temp_target_b2	-0.129	output_finmetric	0.559*
	(0.199)		(0.315)
temp_target_2	-0.124	output_gap	0.578***
	(0.241)		(0.139)
temp_target_3	-0.149	output_riskscore	0.281***
	(0.176)		(0.057)
temp_target_na	0.228	firm_target_1	0.303***
	(0.215)		(0.085)
time_horizon_2030	0.042	capex_1	0.565***
	(0.032)		(0.089)
time_horizon_2040	0.109*	approach_comb	-0.322***
	(0.064)		(0.054)
time_horizon_2050	0.119	approach_topdown	0.096
	(0.107)		(0.155)
time_horizon_2100	-0.060	Constant	-0.509**
	(0.109)		(0.222)
time_horizon_na	-0.400***		
	(0.123)		

modelling approach

forward-looking

$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Within-metric analysis

- 5 providers: different assumptions about temperature target, time horizon and transition path
- Robust to outliers, but no panel dimension, no cluster-robust SE and different normalization
- Temperature target, time horizon and transition path matter for the risk assessment

Conclusion

- Metrics based on similar scenario and methodology deliver more similar risk assessments
- Metrics converge more for firms highly exposed to transition risk
- Metrics methodology is associated with changes in the estimation of transition risk
- Scenarios are also associated with changes in the level of risk within tools

Thank you!

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Appendix

Data providers

Table: Data provider

Provider	Type	Tool name	Metric name	Output type
2 Degrees Investing Initiative & Asset Resolution	Think tank	PACTA		alignment gap
ClimateWise from CISL	Academia	Transition Risk Framework	Transition Risk Exposure Matrix	risk score
Entelligent	Financial services			risk score
ESG+	Financial services			risk score
ISS-ESG	Financial services	Portfolio Climate Impact	Carbon Risk Rating Climate VaR Climate Margin	risk score financial metric financial metric
Moody's / Vigeo Eiris	Financial services			financial metric
MSCI / CarbonDelta	Financial services		Climate VaR Warming potential	financial metric alignment gap
PWC / The CO-Firm	Financial Services	Climate Excellence	EBITDA change	balance sheet effect
right. based on science	Think tank	XDC model		alignment gap
S&P Global Market Intelligence	Financial Services	S&P Global Corporate Sustainability Assessment (CSA)	Climate Strategy Metric	risk score
Sustainaccount	Financial Services	ESG Enterprise Suite		balance sheet effect
University of Augsburg	Academia	Carima	Carbon Beta	risk score
Planetrics	Think tank	Climate Risk Metric Toolkit	Profit impairment	financial metric alignment gap
Zero-carbon 2030	Think tank			risk score

Explanatory variables

Table: Descriptive overview explanatory variables

Explanatory variable	Categories	Shares
Temperature target	1.5°C	0.12
	below 2°C	0.42
	2°C	0.2
	3°C	0.23
	na	0.29
Time horizon	2025	0.22
	2030	0.22
	2040	0.23
	2050	0.26
	2100	0.01
	na	0.01
Output type	balance sheet effect	0.52
	financial metric	0.35
	gap	0.03
	risk score	0.1
Firm targets	included	0.58
	not included	0.42
CAPEX plans	included	0.58
	not included	0.42
Approach	bottom-up	0.93
	combined	0.04
	top-down	0.03

Double LASSO - Risk assessments I

- Prediction: LASSO + robust OLS on reduced model
- 16 dummified variables, only 1 dropped (bottom-up approach)
- Same direction of impacts but different significance
  - Non significance of the type of output
  - Non significance of including of firm targets

Double LASSO - Risk assessments II

	Dependent variable: Risk assessment		
temp_target_b2	-0.143	output_finmetric	0.356*
	(0.150)		(0.202)
temp_target_2	-0.124	output_gap	0.193
	(0.163)		(0.148)
temp_target_3	-0.115	output_riskscore	0.082
	(0.150)		(0.088)
temp_target_na	0.198	firm_target_1	0.203
	(0.181)		(0.137)
time_horizon_2030	0.042**	capex_1	0.447***
	(0.018)		(0.109)
time_horizon_2040	0.094**	approach_topdown	0.217***
	(0.039)		(0.076)
time_horizon_2050	0.087	Constant	-0.352*
	(0.055)		(0.202)
time_horizon_2100	-0.133		
	(0.146)		
time_horizon_na	-0.223		
	(0.169)		

*p<0.1; **p<0.05; ***p<0.01

Within-metric OLS

	Dependent variable: risk assessment				
	Metrics 5-6	Metrics 7-30	Metrics 31-46	Metrics 53-64	Metrics 66-73
temp_target_b2	0.006*** (0.002)	0.004*** (0.0003)		-0.021*** (0.001)	
temp_target_2			-0.001*** (0.0003)	-0.026*** (0.001)	
temp_target_3		-0.002*** (0.0003)	-0.003*** (0.0005)		
time_horizon_2030		-0.001* (0.0003)	0.0003 (0.0003)	0.006*** (0.001)	0.003*** (0.001)
time_horizon_2040		-0.0003 (0.0003)	0.002*** (0.0003)	0.008*** (0.001)	0.007*** (0.001)
time_horizon_2050		-0.0001 (0.0004)	0.003*** (0.0003)	0.011*** (0.001)	0.009*** (0.001)
ass_mainstream		-0.011*** (0.0002)			
ass_immediate			0.00004 (0.0003)		-0.002*** (0.0004)
Constant	-0.355*** (0.001)	0.296*** (0.0003)	0.289*** (0.0004)	-0.467*** (0.001)	-0.525*** (0.0004)

*p<0.1; **p<0.05; ***p<0.01

Within-metric double LASSO

	Dependent variable: Risk assessment				
	Metrics 5-6	Metrics 6-30	Metrics 31-46	Metrics 53-64	Metrics 66-73
time_horizon_2030				0.010***	
				(0.001)	
temp_target_2			-0.002**	-0.056***	
			(0.001)	(0.001)	
temp_target_3		-0.005***	-0.004***		
		(0.001)	(0.001)		
temp_target_b2	0.007***	0.005***		-0.049***	
	(0.003)	(0.0005)		(0.001)	
time_horizon_2040		-0.002***	0.002***	0.013***	0.008***
		(0.0005)	(0.0005)	(0.001)	(0.001)
time_horizon_2050		-0.004***	0.005***	0.019***	0.016***
		(0.001)	(0.001)	(0.001)	(0.001)
ass_mainstream		-0.019***			
		(0.0004)			
ass_immediate			-0.0001		-0.007***
			(0.001)		(0.001)
Constant	-0.343***	0.271***	0.288***	-0.440***	-0.522***
	(0.002)	(0.0004)	(0.001)	(0.001)	(0.001)

*p<0.1; **p<0.05; ***p<0.01

Moments of the distribution

- Mean, standard deviation, skewness and kurtosis
- Higher temperature target associated with lower kurtosis
- Financial/gap/risk scores metrics associated with higher mean, lower skewness, mixed standard deviation
- CAPEX/firm targets associated with larger mean and lower skewness
- Combined/top-down approach associated with lower standard deviation

Moments of the distributions OLS

	Dependent variable: Distribution of risk assessment			
	Mean	Standard deviation	Skewness	Kurtosis
temp_target_b2	-0.094	0.007	1.425	-4.777***
	(0.292)	(0.006)	(6.108)	(1.111)
temp_target_2	-0.085	0.003	1.275	-2.647
	(0.307)	(0.006)	(5.990)	(2.426)
temp_target_3	-0.135	-0.006	1.989	-4.659*
	(0.354)	(0.005)	(6.404)	(2.387)
temp_target_na	0.269	-0.122***	-3.246	6.019
	(0.275)	(0.011)	(6.204)	(7.451)
time_horizon_2030	0.036	0.003	-0.695	-6.263
	(0.074)	(0.006)	(1.750)	(3.993)
time_horizon_2040	0.103	0.005	-1.144	-6.761**
	(0.138)	(0.010)	(2.256)	(2.864)
time_horizon_2050	0.116	0.004	-0.880	-4.213
	(0.144)	(0.015)	(2.195)	(6.832)
time_horizon_2100	-0.007	0.037***	-3.253	13.204
	(0.155)	(0.012)	(2.274)	(9.653)
time_horizon_na	-0.403***	0.056*	5.500**	-28.462
	(0.098)	(0.033)	(2.613)	(19.133)
output_finmetric	0.596*	-0.125***	-6.618	46.254***
	(0.339)	(0.020)	(4.364)	(11.599)
output_gap	0.587***	0.082**	-8.110***	23.243
	(0.086)	(0.035)	(1.990)	(20.924)
output_riskscore	0.269***	0.262***	-2.721***	-2.500
	(0.030)	(0.015)	(0.627)	(7.897)
firm_target_1	0.322***	-0.029	-4.885***	14.183
	(0.054)	(0.018)	(1.146)	(10.251)
capex_1	0.562***	-0.102***	-6.166***	20.486**
	(0.097)	(0.014)	(1.308)	(9.688)
approach_comb	-0.333***	-0.196***	4.313***	5.653
	(0.046)	(0.011)	(0.808)	(6.442)
approach_topdown	0.109	-0.258***	-0.261	0.598
	(0.137)	(0.014)	(1.601)	(7.830)
Constant	-0.091	0.185***	6.763	2.446
	(0.203)	(0.015)	(4.942)	(9.722)

*p<0.1; **p<0.05; ***p<0.01

Moments of the distributions double LASSO

	Dependent variable: Distribution of risk assessment			
	Mean	Standard deviation	Skewness	Kurtosis
temp_target_2		-0.017 (0.013)		
temp_target_3		-0.041 (0.025)		-17.049 (18.737)
output_finmetric		-0.073*** (0.020)		
output_riskscore		0.128*** (0.046)		-31.986*** (9.578)
firm_target_1			-2.001 (2.735)	
capex_1	0.241* (0.130)	-0.063*** (0.020)	-2.689* (1.593)	
approach_comb		-0.108*** (0.038)		
Constant	0.354*** (0.130)	0.163*** (0.008)	2.084 (2.052)	45.475*** (14.808)

*p<0.1; **p<0.05; ***p<0.01

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Making real financial sustainability through formal and informal indicators assessment[1]

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[1] This presentation was prepared for the conference. The views expressed are those of the author and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

Making real financial sustainability through formal and informal indicators assessment

María Lidón Lara Ortiz[1]

Abstract

This paper aims to offer an outlook which will allow the determination of the sustainability rating indicators for being useful to analyse the degree of achievement of the Sustainable Development Goals through the financial system. More sustainability is feasible since theirs analysis could lead us to get to know the weaker points of the whole issue. In these sense, it is possible to distinguish two kinds of items: the formal and the informal ones. The former ones are determined through financial regulations, and the latest ones are extracted from other sources, but all of them are useful.

Keywords: Sustainable Development Goals, financial regulation, financial globalization, green finance, measuring indicators.

JEL classification: K22, K23, F30.

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Contents

1. Introduction.

Achieving sustainable development at a global level has multidisciplinary implications since its scope encloses environmental, economic, social, and governance aspects. The financial system can decisively contribute to the achievement of a more sustainable world through sustainable finances that are already being promoted. But, it is a must to standardize the indicators to measure the accomplishment degree of the sustainability targets and the exchange of data collected in this scope, which are issues currently evolving slowly (Bese Goksu, E. and Tissot B. (2018)).

The indicators about data that allow statistically rating the degree of sustainable development achieved are essential to promote more sustainability in the more depressed scopes, because they will highlight the weaker points. Statistical analysis of data can strongly contribute to a further sustainability, showing the real situation (Sánchez Almaraz J. (2021)). The indicators could be extracted from two types of sources: the formal and the informal ones.

Thus, a first group of indicators that we could name formal indicators, are those that can be identified as sustainability milestones and actions in favour of sustainability, being the result of the traditional sources of analysis such as legal or regulatory requirements. The accomplishment of these indicators can be known through analysis of the data publicized by the transparency imposed on the public sector or on the financial entities. An example of this, in the financial field, is the obligation of disseminating information that results from the Regulation (EU) 2019/2088 of the European Parliament and of the Council of November 27, 2019 on the disclosure of information related to sustainability in the financial services sector.

A second group of indicators are informal in nature, but no less relevant since they are expanding. This second group includes some international guidelines and other documents, as reports, that label different kinds of tools as sustainable products and mechanisms, and the indicators related to the data that make possible to rate compliance with the social responsibility of the administrations -in the public sphere-, and of corporate social responsibility -in the private scope-. As an example, we can quote the 18/2018 Act, of July 13, of the Valencian Government, for the promotion of social responsibility in the public sector, which is a regional regulation applicable to a part of the Spanish territory, from which we can extract different elements as data indicators of environmental, economic, governance, and social sustainability.

Finally, the purpose of this paper is offer a template with an initial scheme of the indicators that could be useful to rate de sustainability achievement in a holistic sense. The template offered in the epigraph “proposed template for rating sustainable impact of the financial activities” is a first approach to the useful indicators to rate the sustainability development through the financial sector, which could be enhanced and amended considering future financial regulations in a global scale.

2. The evolution of the concept of "sustainability" and the effectiveness of the regulations on its defence.

It is needed to start by clarifying the current concept of "sustainability" at a global scale. It leads us to determine the extent of the concept for rating the accomplishment of the whole scope of it, and it evidences the main material indicators.

The most widespread definition of sustainability was coined decades ago in the report "Our Common Future", issued by the United Nations World Commission on Environment and Development, and which has also been called the 1987 Brundtland Report. This Commission coined the concept of sustainable development as the one that satisfies current needs without endangering the ability of future generations to meet their own needs (United Nations (1987)). Although it is true that the interest of the international community on sustainability has been increasing since the end of the eighties, it is also true that one of the biggest problems to achieve effective results has been the legal implementation of measures with enforcement, so that all states could be obliged to effectively regulate mechanisms in defense of the sustainability. The lack of legally binding nature of the former international agreements, and the existence of some conflicts of interest of economic nature, have generated, for years, a situation of recurrent regulatory ineffectiveness at the international level, since the guidelines that we found in this area are considered the kind of rules of *soft law* (Nava Escudero C. (2018)). Thus, the main drawback in making any initiative enforceable has long resided in the voluntary nature of its compliance (García Sánchez I.J. (2013)). Given state sovereignty, the will of each state is decisive to ensure international guidelines in its own territory (Chicharro A., (2013); Mazuelos Bellido A. (2004); Alarcón García G. (2010); Abbot K.W. and Snidal D. (2000)). As we will see, this disadvantage can be supplied, to a certain extent, with citizens' awareness, which needs to be useful that the citizens have been properly informed regarding sustainable actions, and they have been formed on financial culture, when sustainability is related to the financial market. In this sense, the values of transparency and public or corporate social responsibility are essential.

Despite all, this feature is changing since the Paris Agreement of December 12, 2015, was signed (United Nations, 2015), because it leads us to the "2030 Agenda" proposed by the United Nations General Assembly, as a new global framework for sustainable development, that has been described as the first universal and legally binding agreement in this area (Linares P. (2018); Moreno J.M. (2016)). This agreement determines the goals of sustainability as a common target of international relevance, with a real commitment from the signatory States to apply specific and particular means in each nation. So, the current extension of the concept of sustainability is defined by the targets included in each and every one of the seventeen Sustainable Development Goals (hereinafter, SDG) included in the 2030 Agenda, considered as a binding agreement. Precisely, unfolding the targets of these SDGs, a complete framework of indicators have been elaborated according with the Resolution adopted by the General Assembly on 29 January 2014 of the United Nations about *Fundamental Principles of Official Statistics* (United Nations (2014)). The official document that identifies these indicators is the *Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development of United Nations* (United Nations (2021a)), which includes 169 targets (United Nations (2021b)), and, as a consequence, all of them are indicators of sustainability. Thus they have been included in the "proposed template to rate sustainable impact of financial activities", despite some of them are related to rate the national achievement in every State through others activities, so, we must considerer that in these cases the assessment of the proposed template must be understood as how the activity of any financial entity assessed are contributing to achieve every national target on material sustainability.

3. Formal indicators of sustainability.

Indicators based on material goals

The SDGs encompass goals to achieve sustainability in the social, economic, environmental, and governance dimensions, so the SDGs allow a reinterpretation of the concept of sustainability, giving due relevance to all the dimensions of sustainability included in the 2030 Agenda. From a holistic point of view, they all will ease to size the degree of compliance of sustainability in those areas determined by the 2030 Agenda, as social, economic, environmental and governance goals, and which should be considered indicators to measure the degree of inherent sustainability in activities considered sustainable finance. We will consider the goals of the 2030 Agenda as formal indicators, since international treaties are formal legal instruments, and as they determine the content of the current concept of sustainability, they should be considered as material sustainability objectives. According with it, we are including them in the "proposed template to rate sustainable impact of financial activities".

Also, the requirements contained in current regulations to feature some financial products as "green finance" could be considered as formal indicators of sustainability too, because they are elements that contribute to achieve sustainability in any of its areas. But there are some difficulties for outlining a complete sample of international impact indicators as formal ones, due to the fact that the initiatives undertaken at this level are merely soft law actions, which means that in some cases we should include them as informal indicators, being treated in the next section. However, there are indicators that can be extracted from formal sources and that have a transnational character, mainly in the recent regulation of the European Union in relation to sustainable finance. The "sustainable finances" are defined as those that allow the financing of institutional and market arrangements that contribute to the achievement of strong, sustainable, balanced and inclusive growth, through direct and indirect support to the framework of the Goals of Sustainable Development (European Banking Authority, 2020). It is noteworthy that both direct and indirect actions that impact on the achievement of the SDGs are included.

When we analyze the current regulation on sustainable finance, we see that despite the conceptual expansion of sustainability, the environmental aspect is the one that is generating a more wide regulatory reply, which not only exceeds other aspects of social, governance, or economic sustainability, but also it has a greater enforcement capacity than in previous phases. This is due to the fact that there is currently a well-founded concern about the fight against climate change, included in the "2030 Agenda" as SDG-13 (Climate Action), and which is closely related to the SDG-14 (Underwater life) and SDG-15 (Life of terrestrial ecosystems). Environmental protection and more specifically the fight against climate change, is more encouraged than other facets of sustainability through the regulation of "sustainable finance", precisely because some of the effects that have been manifesting lately as derived from climate change are already serious[2], and because there is a direct relationship between the stability of the international financial system and the risks linked to climate change (Roldán T., García Pascual A. and Rey P. (2020)).

In this context, the G20 defines sustainable finance or green finance as the financing of investments that provide environmental benefits in the broader context of environmental sustainable development. Indeed, sustainable finance includes efforts to internalize environmental externalities and adjust perceived risk in order to encourage environmentally friendly investments and reduce the harmful ones. With this approach, measures to internalize environmental externalities should be valued as sustainable, and finances that affect transition risks should also be valued as sustainable, through the promotion of investments that are favourable to the environment. But, this concept is incomplete because it is focused exclusively on environmental sustainability, forgetting the social, economic and governance dimensions of it.

Indicators based on actions emerged in the green finance scope. Direct and indirect sustainable actions.

Sustainable finances affect a wide range of institutions and financial assets, both public and private ones, and they involve the effective management of environmental risks through the financial system (G20 (2016)). Therefore, sustainable finances are useful to control the risks directly liked to climate change, and have the potential to give rise to an immense boost forward sustainability as an inserted value in all types of businesses, due to the fact that it will be valued positively by consumers in general, regarding any kind of products financed through sustainable financial instruments. This value is an incentive for private companies, as a competitive advantage (Rivas L.A., Matellán A., and Garcimartín C. (2021)), and also it is for the public sector. Including sustainability in all kind of products and services, could suppose obtaining greater acceptance -when it is referred to financial products-, or obtaining more financing facilities -when it is referred to other types of products for whose production financing is required-.

The connection between the risks associated with climate change and a subsequent hypothetical instability of the world wide economy as a consequence of climate imbalances, has already been considered by the Advisory Scientific Committee of the European Systemic Risk Board -hereinafter, ESRB- (Belando Garín B. (2021)), as a cause that could seriously affect the stability of the global financial system, and that, therefore, should be considered as a systemic risk. For this reason, the ESRB has stated that the resilience of the financial system to the challenges raised from climate change is a priority for the European institutions, including the ESRB itself. The ESRB has noticed that climate change creates physical risks, such as extreme weather events, and transition risks evolving the real economy towards a more sustainable production (European Systemic Risk Board (2020)). In this sense, climate change is considered a systemic, global and urgent risk for the financial system (Tapia Sánchez M. R. (2020)). The global character of the hazard is a consequence of the fact

[2] In this sense: the extreme snowfalls that occurred on January 2021, in Spain (Portillo, G. (2021)), the floods that occurred on July 2021, in Germany, Belgium, and Austria (Informativos Telecinco-Europa Press (2021)), and in addition, the outbreak of new viruses capable of jeopardizing health global security (Gascueña D. (2020)). All they reflect how the phenomenon of change climate has a potential impact on global economic stability as a consequence of these disasters.

that financial operations are manifested on a global scale, and therefore, the harmonization to face these global risks must follow the lines marked from international instances (Belando Garín B. (2021)), giving rise to a global response that avoids the fragmentation of the markets. However, at this level we still find difficulties for international guidelines to be effectively applied, as indicated above.

The European Central Bank (hereinafter, ECB) differentiates physical and transition risks (ECB (2019)). The physical risks are those associated directly with the climate change process (Aguilar P., González B., and Hurtado S. (2021)), and transition risks are those related to initiatives to slow down the climate change process (Belando Garín B. (2021)). Thus, it can be stated that the European Union differentiates as well two kind of actions included in the concept of sustainable finance: one kind are those actions that seek to alleviate physical risks or disasters, and the second kind of actions are those that seek to alleviate transition risks with an indirect impact on the process towards sustainability. This distinction offers us new categories of indicators to measure the impact on the sustainability of financial activities: those directly linked to sustainability, and those indirectly linked to sustainability. These categories should also be included in the template proposal that we will formulate later.

Regarding the question of how to include its assessment, it must be considered that on the financial regulation of the European Union there is a tendency to appreciate sustainability as an element that must be controlled in a prudential sense (García Álvarez G. (2018)), related to the macroprudential and microprudential aspects, as it is a factor that can generate risks to the financial stability because it has the potential to generate illiquidity or insolvency (NGFS (2019); and Banque de France (2020)), which are classic risks that must be controlled, and which are always the core of financial regulations (Laguna de Paz J.C. (2014); and Lara Ortiz M.L. (2018)). The regulation on sustainable finance by the European Union tries to mitigate the risks derived from climate change related to microprudential and macroprudential aspects through the EU own powers that had been unfold in the reform implemented in the last decade. These powers on financial regulations related to banking activity reside on the ECB who exercises them with the cooperation of the Competent National Authorities[3]. The securities and insurance and pensions sectors in the new European supervisory system are also influenced by EU regulation, but in these sectors the character is much more harmonizing than in the credit sector (Lara Ortiz M.L. (2018)), unless there are implications in the banking sector stability due to the existence of systemic risks, which is possible as a consequence of climate risk.

In order to determine the indicators for measuring the promotion of sustainability extracted from European regulations, we must analyze some instruments of different regulatory scope. Thus, in 2016 a Group of European Experts on Sustainable Finance was created, and the European Commission presented its Commission Action Plan for a greener and cleaner economy, on March 8, 2018 in which it was proposed to integrate non-financial statements values in the accounts of financial market agents: banking, stock market and insurance (Belando Garín B. (2021)). This initiative is consistent with the European Green Deal, of December 11, 2019 (COM (2019 640 final)), through which the European Commission aimed to integrate the perspective of sustainability into all its public policies. It is followed by the proposal for a Regulation of the European Parliament and of the Council

[3] As it results from the legal framework of de Single Supervisory Mechanism. Especially, in accordance with Regulation (EU) 1024/2013, October 15; and Regulation (EU) 468/2014, April 16.

establishing the framework to achieve climate neutrality and amending Regulation (EU) 218/1999, "European Climate Act", on March 4, 2020. With regard to sustainable finance more specifically, the Regulation (EU) 2019/2088 of the European Parliament and of the Council of November 27, 2019, on the disclosure of information related to sustainability in the sector of financial services, in force from March 10, 2021, has been amended and complemented with Regulation (EU) 2020/852 of the European Parliament and of the Council of June 18, 2020, on the establishment of a framework to facilitate sustainable investments. It follows that "sustainable investments" are investments in those economic activities that actively contribute to an environmental objective, or that passively, do not significantly harm any of the environmental or social objectives set out on Regulation (EU) 2019/2088. Therefore, this leads us to include both positive and negative indicators, because a so-called sustainable action will not be sustainable indeed if it also damages the same or other material goals of the 2030 Agenda (as shown in the epigraph "proposed template to rate sustainable impact of financial activities").

On February 2, 2021, the three authorities of the European System of Financial Supervisors -the European Banking Authority, the European Securities and Markets Authority, and the European Insurance and Occupational Pensions Authority- presented the *Final Report on Regulatory Technical Standards* that complements the former regulations, by developing their content, methodologies and transparency requirements, especially those required on Regulation (EU) 2019/2088. The documents are grounded on the rationale that the promotion of financial products pursuing environmentally sustainable objectives is an effective way to channel private investment towards sustainable activities, and also on the rationale that the risks linked to climate change can affect the European financial system stability.

With all, some types of sustainable finance indicators can be identified as actions to face direct risks, and actions to face transition risks. The first ones are actions to alleviate climate change consequences or improve the environment with a clear effect on the fight against climate change. The second ones are referred to any other indicator referred to any other goal included in the 2030 Agenda as target of the SDGs. Furthermore, in any one of both categories must be size the positive and the potential negative effect that could neutralize the sustainable effect of the actions. This question is something that is very specified in the rules on taxonomy of the European Union, that are relevant to specify when an action is sustainable or not and when it can be detrimental in terms of sustainability.

Direct indicators of sustainable finance result from regulations on prudential supervision. Particularly, they result from Regulation (EU) 575/2013, of the European Parliament and of the Council, of June 26, on the prudential requirements of credit institutions and investment companies, which has been modified and now include the contribution to sustainability as a prudential requirement. Mainly, it is required that large entities that issue securities traded on a regulated market should disclose prudential information on environmental, social and governance risks, including physical risks and transition risks (Belando Garín B. (2021)). In addition, pursuant article 501 bis, letter o), numbers i) and ii) it is provided an adjustment of entities' funds requirements for dealing with credit risk exposures, applying a correction factor of 0.75, when the assets issued by them contribute to enhance environmental objectives, specifically when contributing to mitigate climate change and to facilitate the adaptation to climate change. With this measure, it is being boosted the contribution for fighting against climate change, but there is no reference to other SGDs.

Similarly, Delegated Regulation (EU) 2021/1256 of the Commission, on April 21, 2021, aims to integrate sustainability risks in the management of insurance and reinsurance, in accordance with other international initiatives that seek to publicize the information on the environmental impact in the prudential aspect, as the *Application Paper on the Supervision of Climate-related Risks in the Insurance Sector*, of October 13, 2020, of the International Association of Insurance Supervisors (IAIS).

Regarding the investment entities the consideration of sustainability has been introduced through the Directive (EU) 2019/2034 of the European Parliament and the Council of November 27, 2019, related to the prudential supervision of the investment services. In relation with investment entities must be highlighted that Regulation (EU) 2019/2033 has changed the concept of credit entity to extend it to the enterprises of investment services. In this scope, the sustainability is considered in relation with the environmental, social and governance risks, on prudential issues and improving transparency to ease citizens' control.

Consequently, from the former regulations we can extract positive indicators of sustainability, from a prudential point of view, as the dissemination of information on the fulfillment of sustainable objectives, and, where appropriate, the adaptation of capital requirements when contributing to environmental objectives.

In the other hand, indicators of actions in the fight against transition risks are, above all, those that reflect the promotion of investment in sustainability. In this area, the issuance of so-called green bonds is often used, such as debt securities issued to obtain capital for the financing of projects related to the climate or the environment, and which can be issued by international financial organizations, large companies, banks and even national governments and municipalities, allowing to facilitate investment in sustainability to a multitude of agents. They are currently being promoted through the *Proposal of the European Commission to the European Parliament and the Council for the Regulation of European Green Bonds*, of July 6, 2021, COM (2021) 391 final, and also through informal sources of international nature. This proposal is worthy as it aims to improve investors' ability to identify and trust high-quality green bonds, facilitate their issuance by clarifying the definitions of green economic activities, and reducing potential reputational risks for the issuers of the bonds, and standardize the practice of external review, as well as improve trust in external reviewers by introducing a voluntary registration and oversight regime (Belando Garín B. (2021)). Although at the moment, it is only a proposal, its content is very important, and it should be supported by the transparency of the financial system and the taxonomy regulation that are briefly analyzed below.

Transparency and financial culture as sustainability indicators.

Transparency is essential for the proper functioning of the financial system; it not only favors the control deployed by regulators and authorities of the system, but also gives investors and depositors a certain power of control. The role of investors, depositors and, in general, consumers of financial products is very important, because through supply-demand processes they can enhance the preferential consumption of those products based on sustainability. For that, two elements are essential. The first one is that investors and depositors ought to have access to financial information, especially the one referred to the prudential aspect of entities and referred to their sustainable investments. Both aspects are related to the Sustainable Finance Action Plan, issued by the European Commission on July 6, 2021 (European Commission(2021)), following the recommendations of the European Banking Authority in this regard (European Banking Authority (2021)). The second one is that investors and depositors should have the ability to understand the information provided to them, for which the promotion of financial culture is essential. Financial culture has been the target of financial regulators during years, but some authors consider that it is still insufficient (Humbert F. (2019)).

Regulation (EU) 2019/2088, on its article 4, includes the obligation to disseminate information on due diligence of financial institutions through their websites, as a transparency measure that facilitates the control of sustainability by investors and depositors. The obligation of financial advisers is also imposed to disseminate in the pre-contractual information provided theirs clients and investors the information about the sustainability risks associated with investment products that they trade, pursuant articles 3, 8 and 9. Regulation (EU) 2020/852 is consistent with this, since it defines on its articles 5 to 8, the conditions to consider that the obligations of transparency and disclosure of pre-contractual information and periodic reports have been fulfilled in relation to: environmentally sustainable investments, products that promote environmental features, other financial products, and corporate transparency in non-financial statements. The transparency obligations are not closed on the provisions of Regulation (EU) 2020/852, since it, in its recital 37, makes express mention of the need for further development on this point through regulation techniques as guidelines, so that the currently existing regulation, foreseeably, will be the object of further development.

In this sense, the consideration of compliance with transparency obligations and the deployment of actions to promote financial culture should be two indicators of financial sustainability inasmuch as they are actions that favor its control by regulators and by citizens. Especially, it eases control by consumers of financial products, and even indirectly, of other products of the same issuing entities. It should not be ignored that, in addition, the promotion of transparency and the financial culture are aligned with the fulfillment of the SDG-12 -responsible production and consumption-, for which, without a doubt, they contribute to generate awareness for a more sustainable consumption and production. As such, they have been included in the epigraph "proposed template to rate sustainable impact of financial activities".

Universal taxonomy regulation

For determining how to extract indicators of one kind or another, it is essential to apply a universal taxonomic system that defines what is sustainable and what is harmful for sustainability. The European Commission stated that it was necessary to specify indicators that would make possible to measure the effectiveness of the so-called sustainable finance, whatever their form was. And this is because the lack of a standardized list of indicators (European Commission (2020)), and of uniformity of concepts to facilitate the measurement of risks, and the degree of development or the impact of the activities that favor sustainability, could make the set of projected sustainable initiatives fail, and, in addition, could avoid the acknowledgment of the impact of sustainable-friendly actions. This fact could generate a lack of confidence regarding the achievement of the SDGs (Gómez Expósito A. (2020)). For the moment, we have some transnational regulations on taxonomy in the Eurozone, being convenient to stablish some international criteria following the same or similar scheme.

So, Regulation (EU) 2020/852 of the European Parliament and of the Council of June 18, 2020 regarding the establishment of a framework to facilitate sustainable investments, was approved to establish the criteria for determining whether an economic activity is considered environmentally sustainable, with the effect of setting the degree of environmental sustainability of regulatory actions and investments, pursuant its article 1.1. Taxonomy in the Eurozone seeks to avoid market fragmentation on this issue (Romo González L.A. (2021)), looking for the application of a common language between investors, legislators and companies (Tapia Sánchez M. R. (2020)). The Regulation defines the relevant concepts to identify any type of instrument or mechanism with a sustainable financial element, and therefore, contains definitions about the elements that must be considered to stablish an international taxonomy system, if possible. In this sense, article 2 and article 9 are relevant, as they refer to the environmental objectives as target of sustainable finance, including the following: a) mitigation of climate change; b) adaptation to climate change; c) sustainable use and protection of water and marine resources; d) transition to a circular economy; e) pollution prevention and control; f) protection and recovery of biodiversity and ecosystems. These criteria can be included as clear indicators of the achievement of SDG-13, SDG-14, and SDG-15, which are related one with another and, to some extent, they are related with the SDG-12 too. They are formal indicators and they have a material nature. In consequence, they could be included in the "proposed template to rate sustainable impact of financial activities", in the crossed information of material objectives and actions taken, as a specification of sustainable actions that could be implemented.

Regulation (EU) 2020/852 introduces on its articles 3 and 4 the criteria applicable to environmentally sustainable economic activities, and rules for the application of the criteria that determine environmentally sustainable economic activities through public measures, standards and labels. It also clarifies on its articles 10 to 15 what is considered a substantial contribution to the mitigation of climate change, to adaptation to climate change, to the sustainable use and protection of water and marine resources, to the transition towards a circular economy, to the prevention and control of pollution, and to the protection and restoration of biodiversity and ecosystems. In addition, on its article 16 it specifies the activities that are considered easers to achieve environmental objectives. These standards are very useful to clarify the interpretation of each one of the objectives included as indicators, and should be taken into account when carrying out the analysis of the sustainability referred to a financial entity through its activity.

As the reverse of all, it is also defined on article 17, what is considered significant damage to environmental objectives, under the hypothesis that through any instrument or mechanism classified as sustainable finance that caused positive effect for the achievement of the environmental sustainable objectives, it might also be caused one or more adverse effects that counteracts the favorable effects on sustainability. For this reason, it is essential to include in the "proposed template to rate sustainable impact of financial activities" a column that indicates whether a product is harmful to any of the sustainability goals. This will allow us to assess the final sustainable impact of the financial activity, being possible to classify it as positive or negative, and to rate the entity assessed with more or less points.

These criteria must be extended not only to the environmentally sustainable effects indicated on Regulation (EU) 2020/852, but also to all material sustainability indicators included on the 2030 Agenda, so it could be possible to size the real impact of the activity on the social, economic, environmental an governing sustainable targets. In these sense, it would be wishful to stablish some international criteria on taxonomy that follow the path opened by the European Union regulations on this issue, but that improve this regulation including definitions about favorable and harmful financial sustainable actions regarding all the SDG of the 2030 Agenda.

4. Informal indicators of sustainability. International reports, international standardization, and corporate social responsibility.

Informal indicators to measure sustainability are all those that result from other non-regulatory initiatives, or that, although they arise from them, have an eminently voluntary nature in terms of compliance, or cannot be qualified as regulatory requirements to determine that we are facing a sustainable activity but have an impact on it. Informal indicators can be obtained too from other initiatives that can be assessed within the framework of what we know as corporate social responsibility or social responsibility of public administrations, depending on whether the agent is private or public.

These informal indicators are relevant since there are some difficulties at the international scope to impose regulatory rules with the character of hard law, because they could supply de weaknesses of the international guidelines. In this sense, we find some relevant international documents that have defined which tools or mechanisms can be identified as favorable for sustainability, considering them sustainable finance. The number of mechanisms of this type is quite huge, so entities and countries could introduce sustainability through different sustainable actions. As such, they can be included as indicators in one of these two sections of the "proposed template to rate sustainable impact of financial activities": 1. Issuance of products classified as sustainable finance, or 2. Investment in products classified as sustainable finance.

In this regard, the mechanisms included in the report *Financing the 2030 Agenda, An Introductory Guidebook for UNDP Country Offices* of the United Nations Development Program, of January 2018, are financial instruments and innovative mechanisms applicable in this sector, valuable for their advantages (United Nations (2018)), and that would be useful for facing transition risks related to climate change. This report includes combined finances or blended finances as sustainable-friendly mechanisms. They are the strategic combination of financing flows for public and private development, with other public or private capital to improve resources for investment in key areas such as infrastructure that can involve public and private financial partnerships. These mechanisms combine different financial products to achieve greater profitability of the sustainable actions. Other mechanisms include facilities for improving access to credit and guarantees for development, impact investments, which use different traditional investment instruments such as private equity debt issuance or fixed income securities, issued with the purpose of generating a social or environmental return. The "Funds for company challenges" or "Enterprise Challenge Funds" are also used, as a mechanism that can also serve to promote a systemic change in favor of sustainability. Similarly, "Social and Development Impact Bonds", although are not bonds in the traditional sense, offer a fixed rate of return and repayment of principal at maturity, or respectively, repayment by an outcome funder only if the specific social outcomes to which they refer are improved. "Crowdfunding" and "debt-for-nature swaps" (DNS) are also used for investing in local conservation efforts, based on the debt-equity swap model in which the discounted debt is exchanged for investments in the assets of an indebted country (United Nations (2018)).

Among all the mechanisms, the "green bonds" stand out. They are financial instruments that link the product issued as a bond to environment-friendly investments. The issuers of these bonds can be private entities, supranational institutions (such as multilateral banks), and public entities, both state and regional entities. The largest issuer of green bonds is, at the moment, the European Investment Bank, which, by issuing the "Climate Awareness Bonds", favors financing in support of energy projects, especially in high-income economies. Following the same line, the World Bank reported that, by the end of 2015, it had carried out around a hundred of transactions in eighteen different currencies to support about seventy climate adaptation projects in developing countries (United Nations (2018)). The issuance of green bonds is being carried out by several Central Banks nationwide throughout the world, and the G20 has also referred to them in its *Green finance synthesis report* issued by the Green Finance Study Group of the G20, on September 2016. The same report proposes the voluntary adoption at the national level of different strategic mechanisms to mobilize capital towards environmentally sustainable investment, including (G20 (2016)):

- The adoption of clear strategic policies for environmental investment.
- The promotion of voluntary compliance principles to assess progress in sustainable banking, responsible investing, and other key areas for sustainable finance.
- The expansion of knowledge-based networks on sustainable finance, such as the Sustainable Banking Network (SBN), or the UN-backed Principles for Responsible Investment (PRI).
- The inclusion of mechanisms for supporting the local or regional development of green bond markets.
- The promotion of international collaboration to facilitate international investments in green bonds.
- The promotion of the dissemination of knowledge on environmental and financial risk.
- And the improvement of activities on sustainable finance and its impact.

Despite all the former actions, regulation on sustainable finance must overcome some difficulties that affect its efficiency. In this sense, the main challenges have been highlighted regarding the environmental aspects on sustainability, and they are related to the difficulties to internalize environmental externalities and asymmetries in the information accessed by investors and recipients, as well as to the inadequacy of the analytical capacity related to the lack of clarity in definitions of what is environmentally sustainable. The current regulation of the European Union is dealing with all these challenges, as indicated, but the drawbacks of it are the character of no-international, but transnational of the regulation, and the partiality of the material scope of the regulation, because it is only focused on environmental sustainability. So, the guidelines that could be stated at the international scope should try to overcome all this cons.

Another source of informal indicators can be found through the normalization or standardization of quality that puts in value sustainability actions, but with the limitation of their voluntariness. The measurement of these indicators allows gauging those initiatives that are out of a real commitment to initiate actions favorable for sustainability. Notwithstanding, the not-compulsory feature of standardization, it is interesting for entities to accomplish the standards because it allows them to offer an improved corporate image to gain good public opinion. So, the rules of standardization or normalization related to environmental quality intend to reflect an enhancement of the public image of the company or public administration. Anyhow, the important thing is the result or impact on sustainability as a result of the accomplishment of standards, and for this reason it must be included as an indicator in the "proposed template to rate sustainable impact of financial activities". In this area, we can highlight the ISO-14001, as an international standard for environmental quality management, and the ISO-50001 that establishes the requirements of an Energy Management System, in order to carry out systematic and continuous improvements to the energy performance of both public and private organizations. These initiatives are voluntary and, for the moment, only allow improving the public image within the framework of social responsibility. For a much more accurate rating of the sustainable effects of standardization, it would be desirable the development of a more detail framework on international standards about the different sustainable material indicators, it is, about all the targets of SDGs.

Other initiatives from which indicators can be obtained are related to corporate social responsibility of the entities or the social responsibility of the public sector. There are different nationwide or region-wide initiatives regarding this issue but not yet an international unification in this area. However, we can refer, as an example, the 18/2017 Act, of July 13, of the Generalitat Valenciana (a Regional Government in Spain), for the promotion of social responsibility in the public scope, which on its articles 17 and 18 refer to the Valencian Social Responsibility Plan and the Annual Report of social responsibility, as a tools that show the achievement of the aims on social responsibility. Particularly, this Act includes that the Plan and the Annual Report must mention the actions undertaken in defense of the environment in compliance with the article 9 of the same Act, that states: "Public administrations will promote measures, actions and practices to minimize the environmental impact of its decisions and its activity, in order to reduce the effects of climate change and promote respect for biodiversity and the preservation of Valencian ecosystems, landscape and cultural and historical heritage. In decision-making, and beyond compliance with legal requirements, they will adopt complementary measures that are respectful with the environment and that promote, among others, aspects such as energy saving, waste reduction, radiation reduction, emission control, renewable energies, programmed obsolescence control, recycling and the consumption of certified ecological products". Moreover, on article 9.2 it is stated too that "Public administrations will encourage private entities and economic sectors of the Valencian Community to carry out actions or measures to save energy and water, reduce waste and emissions, promote of the circular economy, the use of renewable energies and the protection of biodiversity". Consequently, the actions taken in the public or public-private scope must have a reflection as indicators to size de degree of accomplishment of the SDGs. The indicators could be obtained through the results of the social responsibility plan and the annual report on social responsibility (in the case of the Valencian Act), that are publicized pursuant the Spanish Transparency Act of 2013, in accordance with the Transparency Act and Good Governance of the Valencian Community of 2015. But this could be applied regarding others plans and reports on social responsibility (corporate or public ones) all over the world.

The good results on corporate social responsibility in the public and in the private spheres are useful for the promotion of sustainability as transversal mechanisms. Precisely, in the field of public procurement, the promotion of sustainability is expressly made positive through "green nudge", which is identified as acting in favor of sustainable actions, in a transversal or horizontal way, but directly, for example, including certain conditions for sustainability in public procurement tenders, or including sustainable clauses in procurement documents (Terrón Santos D. (2019)). This kind of actions can be considered as positive indicators when evaluating public financial entities, and for this reason, we have also included it in the "proposed template to rate sustainable impact of financial activities".

Finally, it should be noted that corporate social responsibility in the private sphere also has regulations throughout the world (Friedman M. (1970); Kramer M.R. and Porter. M.E. (2007)), which allow more indicators to be identified, since corporate social responsibility includes the environmental, social and governance dimensions (Esteban Ríos, J. (2021)), which are coincident with part of the SDGs that we have considered material indicators of sustainability and on which there is international consensus. But in the social responsibility scope some standardization framework is needed (Reyes Reina F.E. (2021)), to ease the statistical task.

Specifically, in the field of financial entities, the concept of corporate social responsibility has also emerged and established itself, being included as a value to be implemented by several documents of financial regulators. In Spain, for example, it has been the *Comisión Nacional del Mercado de Valores* who has referred to its application to listed companies (CNMV (2020)). In the field of the credit market, European regulatory advances to improve corporate social responsibility are focused on the aspect of the governance of entities as part of sustainability, in alignment with the SDG-16 (Peace, justice and strong institutions). All this is because after the financial crisis of 2008, weaknesses related to the banking corporate governance structures (Esteban Ríos, J. (2021)), were considered as an aspect included under the prudential control of regulators (Lara Ortiz, M.L. (2016)). In this sense, the existence of controls about the compliance of some goals of corporate social responsibility may be included as positive indicators of sustainability in relation to the accomplishment of prudential regulations that we have already considered when dealing with the formal indicators in the "proposed template to rate sustainable impact of financial activities". However, in territories where there is no similar regulation in force, it is possible to also include the existence of controls on corporate social responsibility as an indicator of informal nature for favoring sustainability, at least, because it is useful to the achievement of the SDG-16.

5. Results. Proposed template to rate sustainable impact of financial activities.

As result of the previous sections, we offer below an initial proposal for a template useful to assess the impact on sustainability of the activities carried out by public or private financial institutions. It could be applicable to assess each entity periodically by crossing data about sustainable actions taken and the material indicators on SDGs determined by UN (these last ones included in the left column), which are referred in some cases to the national situation of each country or territory in where the entity assessed has developed its actions by having there its registered main office. The official data of each whole country, in relation with all activities, are publicized periodically by State authorities (for example, in Spain, by the Instituto Nacional de Estadística, that has determined 232 indicators for monitoring the 2030 Agenda accomplishment in Spain[4]) and could be compared with the results of the actions of the assessed entity in relation with each target, in the same period, to analyze the degree of contribution of its actions on sustainability.

This template could be completed and improved for a better determination of the achievement of sustainability values through sustainable finance and on formal or informal indicators, including more future indicators. For determining them, in the international scope, it is needed enhancing financial inclusion on sustainable finances through definitions or taxonomy, Central Banks contributions, internal coordination, data collection, international cooperation, and international data-sharing (Tissot B. and Gadanecz B. (2018)).

The template we propose could be as follows:

Assessment on sustainable finances						
Sustainable finance actions						
Positive effects						**Harmful effects**
	Direct actions on sustainability –Against direct risks-		Indirect actions on sustainability –Against transition risks-		Other actions	
	Prudential requirements accomplishment	*Transparency requirements accomplish-ment and financial culture promotion*	*Sustainable finance issuance (green finance and others)*	*Sustainable finance investment (green finance and others)*	*According with informal indicators*	
Material indicators of sustainability						
Social Goals						
Goal 1. End of poverty in all its forms everywhere						

[4] As it is shown on the website INEbase (2021): *Indicadores de la Agenda 2030 para el Desarrollo Sostenible*, Instituto Nacional de Estadística (Spain), available in https://www.ine.es/dyngs/ODS/es/index.htm

1.1.1 Proportion of the population living below the international poverty line by sex, age, employment status and geographic location (urban/rural) 1.2.1 Proportion of population living below the national poverty line, by sex and age 1.2.2 Proportion of men, women and children of all ages living in poverty in all its dimensions according to national definitions 1.3.1 Proportion of population covered by social protection floors/systems, by sex, distinguishing children, unemployed persons, older persons, persons with disabilities, pregnant women, newborns, work-injury victims and the poor and the vulnerable 1.4.1 Proportion of population living in households with access to basic services 1.4.2 Proportion of total adult population with secure tenure rights to land, (*a*) with legally recognized documentation, and (*b*) who perceive their rights to land as secure, by sex and type of tenure 1.5.1 Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population 1.5.2 Direct economic loss attributed to disasters in relation to global gross domestic product (GDP) 1.5.3 Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030 1.5.4 Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies 1.a.1 Total official development assistance grants from all donors that focus on poverty reduction as a share of the recipient country's gross national income 1.a.2 Proportion of total government spending on essential services (education, health and social protection) 1.b.1 Pro-poor public social spending		***Through:*** ○Blended finances ○Credit and guarantees fo development, ○Impact investments, a private equity debt issuance or fixed income securities ○"Funds for company challenges" or "Enterprise Challenge Funds" ○"Social and Developmen Impact Bonds" ○"Crowdfunding" and "debt-for-nature swaps" (DNS)	***Through:*** ○Blended finances ○Credit and guarantees for development, ○Impact investments, as private equity debt issuance or fixed income securities ○Funds for company challenges" or "Enterprise Challenge Funds" ○Social and Development Impact Bonds" ○Crowdfunding" and "debt-for-nature swaps" (DNS)	○Quality standards accomplishment ○Existence and accomplishment of Social Responsibility Plan ○ Existence and issuance of periodical Report on social responsibility accomplishment ○"Green nudge" or "sustainable nudge"
Goal 2. End hunger, achieve food security and improve nutrition, and promote sustainable agriculture 2.1.1 Prevalence of undernourishment 2.1.2 Prevalence of moderate or severe food insecurity in the population, based on the Food Insecurity Experience Scale (FIES) 2.2.1 Prevalence of stunting (height for age <-2 standard deviation from the median of the World Health Organization (WHO) Child Growth Standards) among children under 5 years of age 2.2.2 Prevalence of malnutrition (weight for height >+2 or <-2 standard deviation from the median of the WHO Child Growth Standards) among children under 5 years of age, by type (wasting and overweight) 2.2.3 Prevalence of anaemia in women aged 15 to 49 years, by pregnancy status (percentage) 2.3.1 Volume of production per labour unit by classes of farming/pastoral/forestry enterprise size 2.3.2 Average income of small-scale food producers, by sex and indigenous status 2.4.1 Proportion of agricultural area under productive and sustainable agriculture 2.5.1 Number of (*a*) plant and (*b*) animal genetic resources for food and agriculture secured in either medium- or long-term conservation facilities 2.5.2 Proportion of local breeds classified as being at risk of extinction 2.a.1 The agriculture orientation index for government expenditures 2.a.2 Total official flows (official development assistance plus other official flows) to the agriculture sector 2.b.1 Agricultural export subsidies 2.c.1 Indicator of food price anomalies		***Through:*** ○Blended finances ○Credit and guarantees fo development, ○Impact investments, a private equity debt issuance or fixed income securities ○"Funds for company challenges" or "Enterprise Challenge Funds" ○"Social and Developmen Impact Bonds" ○"Crowdfunding" and "debt-for-nature swaps" (DNS)	***Through:*** ○Blended finances ○Credit and guarantees for development, ○Impact investments, as private equity debt issuance or fixed income securities ○Funds for company challenges" or "Enterprise Challenge Funds" ○Social and Development Impact Bonds" ○Crowdfunding" and "debt-for-nature swaps" (DNS)	○Quality standards accomplishment ○Existence and accomplishment of Social Responsibility Plan ○ Existence and issuance of periodical Report on social responsibility accomplishment ○"Green nudge" or "sustainable nudge"
Goal 3. Ensure healthy life and promote well-being for all at all ages 3.1.1 Maternal mortality ratio 3.1.2 Proportion of births attended by skilled health personnel 3.2.1 Under-5 mortality rate 3.2.2 Neonatal mortality rate		***Through:*** ○Blended finances ○Credit and guarantees fo development, ○Impact investments, a private equity debt issuance or fixed income securities	***Through:*** ○Blended finances ○Credit and guarantees for development, ○Impact investments, as private equity debt issuance or fixed income securities	○Quality standards accomplishment ○Existence and accomplishment of Social Responsibility Plan ○ Existence and issuance of periodical Report on social responsibility accomplishment

3.3.1 Number of new HIV infections per 1,000 uninfected population, by sex, age and key populations 3.3.2 Tuberculosis incidence per 100,000 population 3.3.3 Malaria incidence per 1,000 population 3.3.4 Hepatitis B incidence per 100,000 population 3.3.5 Number of people requiring interventions against neglected tropical diseases 3.4.1 Mortality rate attributed to cardiovascular disease, cancer, diabetes or chronic respiratory disease 3.4.2 Suicide mortality rate 3.5.1 Coverage of treatment interventions (pharmacological, psychosocial and rehabilitation and aftercare services) for substance use disorders 3.5.2 Alcohol per capita consumption (aged 15 years and older) within a calendar year in litres of pure alcohol 3.6.1 Death rate due to road traffic injuries 3.7.1 Proportion of women of reproductive age (aged 15–49 years) who have their need for family planning satisfied with modern methods 3.7.2 Adolescent birth rate (aged 10–14 years; aged 15–19 years) per 1,000 women in that age group 3.8.1 Coverage of essential health services 3.8.2 Proportion of population with large household expenditures on health as a share of total household expenditure or income 3.9.1 Mortality rate attributed to household and ambient air pollution 3.9.2 Mortality rate attributed to unsafe water, unsafe sanitation and lack of hygiene (exposure to unsafe Water, Sanitation and Hygiene for All (WASH) services) 3.9.3 Mortality rate attributed to unintentional poisoning 3.a.1 Age-standardized prevalence of current tobacco use among persons aged 15 years and older 3.b.1 Proportion of the target population covered by all vaccines included in their national programme 3.b.2 Total net official development assistance to medical research and basic health sectors 3.b.3 Proportion of health facilities that have a core set of relevant essential medicines available and affordable on a sustainable basis 3.c.1 Health worker density and distribution 3.d.1 International Health Regulations (IHR) capacity and health emergency preparedness 3.d.2 Percentage of bloodstream infections due to selected antimicrobial-resistant organisms		“Funds for company challenges" or “Enterprise Challenge Funds” “Social and Development Impact Bonds” “Crowdfunding” and “debt-for-nature swaps” (DNS)	Funds for company challenges" or “Enterprise Challenge Funds” Social and Development Impact Bonds” Crowdfunding” and “debt-for-nature swaps” (DNS)	“Green nudge” or “sustainable nudge”	
Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all 4.1.1 Proportion of children and young people (*a*) in grades 2/3; (*b*) at the end of primary; and (*c*) at the end of lower secondary achieving at least a minimum proficiency level in (i) reading and (ii) mathematics, by sex 4.1.2 Completion rate (primary education, lower secondary education, upper secondary education) 4.2.1 Proportion of children aged 24–59 months who are developmentally on track in health, learning and psychosocial well-being, by sex 4.2.2 Participation rate in organized learning (one year before the official primary entry age), by sex 4.3.1 Participation rate of youth and adults in formal and non-formal education and training in the previous 12 months, by sex 4.4.1 Proportion of youth and adults with information and communications technology (ICT) skills, by type of skill 4.5.1 Parity indices (female/male, rural/urban, bottom/top wealth quintile and others such as disability status, indigenous peoples and conflict-affected, as data become available) for all education indicators on this list that can be disaggregated 4.6.1 Proportion of population in a given age group achieving at least a fixed level of proficiency in functional (*a*) literacy and (*b*) numeracy skills, by sex 4.7.1 Extent to which (i) global citizenship education and (ii) education for sustainable development are mainstreamed in (*a*) national education policies; (*b*) curricula; (*c*) teacher education; and (*d*) student assessment 4.a.1 Proportion of schools offering basic services, by type of service 4.b.1 Volume of official development assistance flows for scholarships by sector and type of study 4.c.1 Proportion of teachers with the minimum required qualifications, by education level		***Through:*** Blended finances Credit and guarantees for development, Impact investments, as private equity debt issuance or fixed income securities “Funds for company challenges" or “Enterprise Challenge Funds” “Social and Development Impact Bonds” “Crowdfunding” and “debt-for-nature swaps” (DNS)	***Through:*** Blended finances Credit and guarantees for development, Impact investments, as private equity debt issuance or fixed income securities Funds for company challenges" or “Enterprise Challenge Funds” Social and Development Impact Bonds” Crowdfunding” and “debt-for-nature swaps” (DNS)	Quality standards accomplishment Existence and accomplishment of Social Responsibility Plan Existence and issuance of periodical Report on social responsibility accomplishment “Green nudge” or “sustainable nudge”	

Goal 5. Achieve gender equality and empower all women and girls. 5.1.1 Whether or not legal frameworks are in place to promote, enforce and monitor equality and non-discrimination on the basis of sex 5.2.1 Proportion of ever-partnered women and girls aged 15 years and older subjected to physical, sexual or psychological violence by a current or former intimate partner in the previous 12 months, by form of violence and by age 5.2.2 Proportion of women and girls aged 15 years and older subjected to sexual violence by persons other than an intimate partner in the previous 12 months, by age and place of occurrence 5.3.1 Proportion of women aged 20–24 years who were married or in a union before age 15 and before age 18 5.3.2 Proportion of girls and women aged 15–49 years who have undergone female genital mutilation/cutting, by age 5.4.1 Proportion of time spent on unpaid domestic and care work, by sex, age and location 5.5.1 Proportion of seats held by women in (*a*) national parliaments and (*b*) local governments 5.5.2 Proportion of women in managerial positions 5.6.1 Proportion of women aged 15–49 years who make their own informed decisions regarding sexual relations, contraceptive use and reproductive health care 5.6.2 Number of countries with laws and regulations that guarantee full and equal access to women and men aged 15 years and older to sexual and reproductive health care, information and education 5.a.1 (*a*) Proportion of total agricultural population with ownership or secure rights over agricultural land, by sex; and (*b*) share of women among owners or rights-bearers of agricultural land, by type of tenure 5.a.2 Proportion of countries where the legal framework (including customary law) guarantees women's equal rights to land ownership and/or control 5.b.1 Proportion of individuals who own a mobile telephone, by sex 5.c.1 Proportion of countries with systems to track and make public allocations for gender equality and women's empowerment		***Through:*** Blended finances Credit and guarantees fo development, Impact investments, a private equity debt issuance or fixed income securities "Funds for company challenges" or "Enterprise Challenge Funds" "Social and Developmen Impact Bonds" "Crowdfunding" and "debt-for-nature swaps" (DNS)	***Through:*** Blended finances Credit and guarantees for development, Impact investments, as private equity debt issuance or fixed income securities Funds for company challenges" or "Enterprise Challenge Funds" Social and Development Impact Bonds" Crowdfunding" and "debt-for-nature swaps" (DNS)	Quality standards accomplishment Existence and accomplishment of Social Responsibility Plan Existence and issuance of periodical Report on social responsibility accomplishment "Green nudge" or "sustainable nudge"
Goal 6. Ensure availability and sustainable management of water and sanitation for all 6.1.1 Proportion of population using safely managed drinking water services 6.2.1 Proportion of population using (*a*) safely managed sanitation services and (*b*) a hand-washing facility with soap and water 6.3.1 Proportion of domestic and industrial wastewater flows safely treated 6.3.2 Proportion of bodies of water with good ambient water quality 6.4.1 Change in water-use efficiency over time 6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources 6.5.1 Degree of integrated water resources management 6.5.2 Proportion of transboundary basin area with an operational arrangement for water cooperation 6.6.1 Change in the extent of water-related ecosystems over time 6.a.1 Amount of water- and sanitation-related official development assistance that is part of a government-coordinated spending plan 6.b.1 Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management		***Through:*** Blended finances Credit and guarantees fo development, Impact investments, a private equity debt issuance or fixed income securities "Funds for company challenges" or "Enterprise Challenge Funds" "Social and Developmen Impact Bonds" "Crowdfunding" and "debt-for-nature swaps" (DNS)	***Through:*** Blended finances Credit and guarantees for development, Impact investments, as private equity debt issuance or fixed income securities Funds for company challenges" or "Enterprise Challenge Funds" Social and Development Impact Bonds" Crowdfunding" and "debt-for-nature swaps" (DNS)	Quality standards accomplishment Existence and accomplishment of Social Responsibility Plan Existence and issuance of periodical Report on social responsibility accomplishment "Green nudge" or "sustainable nudge"
Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all		***Through:*** Blended finances Credit and guarantees fo development, Impact investments, a private equity debt issuance or fixed income securities	***Through:*** Blended finances Credit and guarantees for development, Impact investments, as private equity debt issuance or fixed income securities	Quality standards accomplishment Existence and accomplishment of Social Responsibility Plan Existence and issuance of periodical Report on social responsibility accomplishment "Green nudge" or "sustainable nudge"

7.1.1 Proportion of population with access to electricity 7.1.2 Proportion of population with primary reliance on clean fuels and technology 7.2.1 Renewable energy share in the total final energy consumption 7.3.1 Energy intensity measured in terms of primary energy and GDP 7.a.1 International financial flows to developing countries in support of clean energy research and development and renewable energy production, including in hybrid systems 7.b.1 Installed renewable energy-generating capacity in developing countries (in watts per capita)		"Funds for company challenges" or "Enterprise Challenge Funds" "Social and Development Impact Bonds" "Crowdfunding" and "debt-for-nature swaps" (DNS)	"Funds for company challenges" or "Enterprise Challenge Funds" "Social and Development Impact Bonds" "Crowdfunding" and "debt-for-nature swaps" (DNS)		
Economic Goals					
Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all 8.1.1 Annual growth rate of real GDP per capita 8.2.1 Annual growth rate of real GDP per employed person 8.3.1 Proportion of informal employment in total employment, by sector and sex 8.4.1 Material footprint, material footprint per capita, and material footprint per GDP 8.4.2 Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP 8.5.1 Average hourly earnings of employees, by sex, age, occupation and persons with disabilities 8.5.2 Unemployment rate, by sex, age and persons with disabilities 8.6.1 Proportion of youth (aged 15–24 years) not in education, employment or training 8.7.1 Proportion and number of children aged 5–17 years engaged in child labour, by sex and age 8.8.1 Fatal and non-fatal occupational injuries per 100,000 workers, by sex and migrant status 8.8.2 Level of national compliance with labour rights (freedom of association and collective bargaining) based on International Labour Organization (ILO) textual sources and national legislation, by sex and migrant status 8.9.1 Tourism direct GDP as a proportion of total GDP and in growth rate 8.10.1 (*a*) Number of commercial bank branches per 100,000 adults and (*b*) number of automated teller machines (ATMs) per 100,000 adults 8.10.2 Proportion of adults (15 years and older) with an account at a bank or other financial institution or with a mobile-money-service provider 8.a.1 Aid for Trade commitments and disbursements 8.b.1 Existence of a developed and operationalized national strategy for youth employment, as a distinct strategy or as part of a national employment strategy		***Through:*** Blended finances Credit and guarantees for development, Impact investments, as private equity debt issuance or fixed income securities "Funds for company challenges" or "Enterprise Challenge Funds" "Social and Development Impact Bonds" "Crowdfunding" and "debt-for-nature swaps" (DNS)	***Through:*** Blended finances Credit and guarantees for development, Impact investments, as private equity debt issuance or fixed income securities "Funds for company challenges" or "Enterprise Challenge Funds" "Social and Development Impact Bonds" "Crowdfunding" and "debt-for-nature swaps" (DNS)	Quality standards accomplishment Existence and accomplishment of Social Responsibility Plan Existence and issuance of periodical Report on social responsibility accomplishment "Green nudge" or "sustainable nudge"	
Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation 9.1.1 Proportion of the rural population who live within 2 km of an all-season road 9.1.2 Passenger and freight volumes, by mode of transport 9.2.1 Manufacturing value added as a proportion of GDP and per capita 9.2.2 Manufacturing employment as a proportion of total employment 9.3.1 Proportion of small-scale industries in total industry value added 9.3.2 Proportion of small-scale industries with a loan or line of credit 9.4.1 CO_2 emission per unit of value added		***Through:*** Blended finances Credit and guarantees for development, Impact investments, as private equity debt issuance or fixed income securities "Funds for company challenges" or "Enterprise Challenge Funds" "Social and Development Impact Bonds" "Crowdfunding" and "debt-for-nature swaps" (DNS)	***Through:*** Blended finances Credit and guarantees for development, Impact investments, as private equity debt issuance or fixed income securities "Funds for company challenges" or "Enterprise Challenge Funds" "Social and Development Impact Bonds" "Crowdfunding" and "debt-for-nature swaps" (DNS)	Quality standards accomplishment Existence and accomplishment of Social Responsibility Plan Existence and issuance of periodical Report on social responsibility accomplishment "Green nudge" or "sustainable nudge"	

9.5.1 Research and development expenditure as a proportion of GDP 9.5.2 Researchers (in full-time equivalent) per million inhabitants 9.a.1 Total official international support (official development assistance plus other official flows) to infrastructure 9.b.1 Proportion of medium and high-tech industry value added in total value added 9.c.1 Proportion of population covered by a mobile network, by technology					
Goal 10. Reduce inequality within and among countries 10.1.1 Growth rates of household expenditure or income per capita among the bottom 40 per cent of the population and the total population 10.2.1 Proportion of people living below 50 per cent of median income, by sex, age and persons with disabilities 10.3.1 Proportion of population reporting having personally felt discriminated against or harassed in the previous 12 months on the basis of a ground of discrimination prohibited under international human rights law 10.4.1 Labour share of GDP 10.4.2 Redistributive impact of fiscal policy[2] 10.5.1 Financial Soundness Indicators 10.6.1 Proportion of members and voting rights of developing countries in international organizations 10.7.1 Recruitment cost borne by employee as a proportion of monthly income earned in country of destination 10.7.2 Number of countries with migration policies that facilitate orderly, safe, regular and responsible migration and mobility of people 10.7.3 Number of people who died or disappeared in the process of migration towards an international destination 10.7.4 Proportion of the population who are refugees, by country of origin 10.a.1 Proportion of tariff lines applied to imports from least developed countries and developing countries with zero-tariff 10.b.1 Total resource flows for development, by recipient and donor countries and type of flow (e.g. official development assistance, foreign direct investment and other flows) 10.c.1 Remittance costs as a proportion of the amount remitted		***Through:*** Blended finances Credit and guarantees fo development, Impact investments, a private equity debt issuance or fixed income securities "Funds for company challenges" or “Enterprise Challenge Funds” “Social and Developmen Impact Bonds” “Crowdfunding” and “debt-for-nature swaps” (DNS)	***Through:*** Blended finances Credit and guarantees for development, Impact investments, as private equity debt issuance or fixed income securities Funds for company challenges" or “Enterprise Challenge Funds” Social and Development Impact Bonds” Crowdfunding” and “debt-for-nature swaps” (DNS)	Quality standards accomplishment Existence and accomplishment of Social Responsibility Plan Existence and issuance of periodical Report on social responsibility accomplishment “Green nudge” or “sustainable nudge”	
Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable 11.1.1 Proportion of urban population living in slums, informal settlements or inadequate housing 11.2.1 Proportion of population that has convenient access to public transport, by sex, age and persons with disabilities 11.3.1 Ratio of land consumption rate to population growth rate 11.3.2 Proportion of cities with a direct participation structure of civil society in urban planning and management that operate regularly and democratically 11.4.1 Total per capita expenditure on the preservation, protection and conservation of all cultural and natural heritage, by source of funding (public, private), type of heritage (cultural, natural) and level of government (national, regional, and local/municipal) 11.5.1 Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population 11.5.2 Direct economic loss in relation to global GDP, damage to critical infrastructure and number of disruptions to basic services, attributed to disasters 11.6.1 Proportion of municipal solid waste collected and managed in controlled facilities out of total municipal waste generated, by cities 11.6.2 Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted) 11.7.1 Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities 11.7.2 Proportion of persons victim of physical or sexual harassment, by sex, age, disability status and place of occurrence, in the previous 12 months		***Through:*** Blended finances Credit and guarantees fo development, Impact investments, a private equity debt issuance or fixed income securities "Funds for company challenges" or “Enterprise Challenge Funds” “Social and Developmen Impact Bonds” “Crowdfunding” and “debt-for-nature swaps” (DNS)	***Through:*** Blended finances Credit and guarantees for development, Impact investments, as private equity debt issuance or fixed income securities Funds for company challenges" or “Enterprise Challenge Funds” Social and Development Impact Bonds” Crowdfunding” and “debt-for-nature swaps” (DNS)	Quality standards accomplishment Existence and accomplishment of Social Responsibility Plan Existence and issuance of periodical Report on social responsibility accomplishment “Green nudge” or “sustainable nudge”	

11.a.1 Number of countries that have national urban policies or regional development plans that (*a*) respond to population dynamics; (*b*) ensure balanced territorial development; and (*c*) increase local fiscal space 11.b.1 Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030 11.b.2 Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies 11.c Support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilizing local materials					
Goal 12. Ensure sustainable consumption and production patterns 12.1.1 Number of countries developing, adopting or implementing policy instruments aimed at supporting the shift to sustainable consumption and production 12.2.1 Material footprint, material footprint per capita, and material footprint per GDP 12.2.2 Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP 12.3.1 (*a*) Food loss index and (*b*) food waste index 12.4.1 Number of parties to international multilateral environmental agreements on hazardous waste, and other chemicals that meet their commitments and obligations in transmitting information as required by each relevant agreement 12.4.2 (*a*) Hazardous waste generated per capita; and (*b*) proportion of hazardous waste treated, by type of treatment 12.5.1 National recycling rate, tons of material recycled 12.6.1 Number of companies publishing sustainability reports 12.7.1 Degree of sustainable public procurement policies and action plan implementation 12.8.1 Extent to which (i) global citizenship education and (ii) education for sustainable development are mainstreamed in (*a*) national education policies; (*b*) curricula; (*c*) teacher education; and (*d*) student assessment 12.a.1 Installed renewable energy-generating capacity in developing countries (in watts per capita) 12.b.1 Implementation of standard accounting tools to monitor the economic and environmental aspects of tourism sustainability 12.c.1 Amount of fossil-fuel subsidies (production and consumption) per unit of GDP		***Through:*** Blended finances Credit and guarantees fo development, Impact investments, a private equity debt issuance or fixed income securities "Funds for compan challenges" or "Enterprise Challenge Funds" "Social and Developmen Impact Bonds" "Crowdfunding" and "debt-for-nature swaps" (DNS) ***Action with the purpose of…*** a) mitigation of climate change; b) adaptation to climate change; c) sustainable use and protection of water and marine resources; d) transition to a circular economy; e) pollution prevention and control; f) protection and recovery of biodiversity and ecosystems g)Other purposes	***Through:*** Blended finances Credit and guarantees for development, Impact investments, as private equity debt issuance or fixed income securities Funds for company challenges" or "Enterprise Challenge Funds" Social and Development Impact Bonds" Crowdfunding" and "debt-for-nature swaps" (DNS) ***Action with the purpose of…*** a) mitigation of climate change; b) adaptation to climate change; c) sustainable use and protection of water and marine resources; d) transition to a circular economy; e) pollution prevention and control; f) protection and recovery of biodiversity and ecosystems g)Other purposes	Quality standards accomplishment Existence and accomplishment of Social Responsibility Plan Existence and issuance of periodical Report on social responsibility accomplishment "Green nudge" or "sustainable nudge"	
Environmental Goals					
Goal 13. Take urgent action to combat climate change and its impacts 13.1.1 Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population 13.1.2 Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030 13.1.3 Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies 13.2.1 Number of countries with nationally determined contributions, long-term strategies, national adaptation plans and adaptation communications, as reported to the secretariat of the United Nations Framework Convention on Climate Change 13.2.2 Total greenhouse gas emissions per year 13.3.1 Extent to which (i) global citizenship education and (ii) education for sustainable development are mainstreamed in (*a*) national education policies; (*b*) curricula; (*c*) teacher education; and (*d*) student assessment 13.a.1 Amounts provided and mobilized in United States dollars per year in relation to the continued existing collective mobilization goal of the $100 billion commitment through to 2025		***Through:*** Blended finances Credit and guarantees fo development, Impact investments, a private equity debt issuance or fixed income securities "Funds for compan challenges" or "Enterprise Challenge Funds" "Social and Developmen Impact Bonds" "Crowdfunding" and "debt-for-nature swaps" (DNS) ***Action with the purpose of…***	***Through:*** Blended finances Credit and guarantees for development, Impact investments, as private equity debt issuance or fixed income securities Funds for company challenges" or "Enterprise Challenge Funds" Social and Development Impact Bonds" Crowdfunding" and "debt-for-nature swaps" (DNS) ***Action with the purpose of…***	Quality standards accomplishment Existence and accomplishment of Social Responsibility Plan Existence and issuance of periodical Report on social responsibility accomplishment "Green nudge" or "sustainable nudge"	

13.b.1 Number of least developed countries and small island developing States with nationally determined contributions, long-term strategies, national adaptation plans and adaptation communications, as reported to the secretariat of the United Nations Framework Convention on Climate Change		a) mitigation of climate change; b) adaptation to climate change; c) sustainable use and protection of water and marine resources; d) transition to a circular economy; e) pollution prevention and control; f) protection and recovery of biodiversity and ecosystems g)Other connected purposes	a) mitigation of climate change; b) adaptation to climate change; c) sustainable use and protection of water and marine resources; d) transition to a circular economy; e) pollution prevention and control; f) protection and recovery of biodiversity and ecosystems g)Other connected purposes		
Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development 14.1.1 (*a*) Index of coastal eutrophication; and (*b*) plastic debris density 14.2.1 Number of countries using ecosystem-based approaches to managing marine areas 14.3.1 Average marine acidity (pH) measured at agreed suite of representative sampling stations 14.4.1 Proportion of fish stocks within biologically sustainable levels 14.5.1 Coverage of protected areas in relation to marine areas 14.6.1 Degree of implementation of international instruments aiming to combat illegal, unreported and unregulated fishing 14.7.1 Sustainable fisheries as a proportion of GDP in small island developing States, least developed countries and all countries 14.a.1 Proportion of total research budget allocated to research in the field of marine technology 14.b.1 Degree of application of a legal/regulatory/ policy/institutional framework which recognizes and protects access rights for small-scale fisheries 14.c.1 Number of countries making progress in ratifying, accepting and implementing through legal, policy and institutional frameworks, ocean-related instruments that implement international law, as reflected in the United Nations Convention on the Law of the Sea, for the conservation and sustainable use of the oceans and their resources		***Through:*** Blended finances Credit and guarantees fo development, Impact investments, a private equity debt issuance or fixed income securities 'Funds for company challenges" or "Enterprise Challenge Funds" 'Social and Developmen Impact Bonds" "Crowdfunding" and "debt-for-nature swaps" (DNS) ***Action with the purpose of***... a) mitigation of climate change; b) adaptation to climate change; c) sustainable use and protection of water and marine resources; d) transition to a circular economy; e) pollution prevention and control; f) protection and recovery of biodiversity and ecosystems g)Other connected purposes	***Through:*** Blended finances Credit and guarantees for development, Impact investments, as private equity debt issuance or fixed income securities Funds for company challenges" or "Enterprise Challenge Funds" Social and Development Impact Bonds" Crowdfunding" and "debt-for-nature swaps" (DNS) ***Action with the purpose of***... a) mitigation of climate change; b) adaptation to climate change; c) sustainable use and protection of water and marine resources; d) transition to a circular economy; e) pollution prevention and control; f) protection and recovery of biodiversity and ecosystems g)Other connected purposes	Quality standards accomplishment Existence and accomplishment of Social Responsibility Plan Existence and issuance of periodical Report on social responsibility accomplishment "Green nudge" or "sustainable nudge"	
Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss 15.1.1 Forest area as a proportion of total land area 15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type 15.2.1 Progress towards sustainable forest management 15.3.1 Proportion of land that is degraded over total land area		***Through:*** Blended finances Credit and guarantees fo development, Impact investments, a private equity debt issuance or fixed income securities 'Funds for company challenges" or "Enterprise Challenge Funds"	***Through:*** Blended finances Credit and guarantees for development, Impact investments, as private equity debt issuance or fixed income securities Funds for company challenges" or "Enterprise Challenge Funds"	Quality standards accomplishment Existence and accomplishment of Social Responsibility Plan Existence and issuance of periodical Report on social responsibility accomplishment "Green nudge" or "sustainable nudge"	

15.4.1 Coverage by protected areas of important sites for mountain biodiversity 15.4.2 Mountain Green Cover Index 15.5.1 Red List Index 15.6.1 Number of countries that have adopted legislative, administrative and policy frameworks to ensure fair and equitable sharing of benefits 15.7.1 Proportion of traded wildlife that was poached or illicitly trafficked 15.8.1 Proportion of countries adopting relevant national legislation and adequately resourcing the prevention or control of invasive alien species 15.9.1 (*a*) Number of countries that have established national targets in accordance with or similar to Aichi Biodiversity Target 2 of the Strategic Plan for Biodiversity 2011–2020 in their national biodiversity strategy and action plans and the progress reported towards these targets; and (*b*) integration of biodiversity into national accounting and reporting systems, defined as implementation of the System of Environmental-Economic Accounting 15.a.1 (*a*) Official development assistance on conservation and sustainable use of biodiversity; and (*b*) revenue generated and finance mobilized from biodiversity-relevant economic instruments 15.b.1 (*a*) Official development assistance on conservation and sustainable use of biodiversity; and (*b*) revenue generated and finance mobilized from biodiversity-relevant economic instruments 15.c.1 Proportion of traded wildlife that was poached or illicitly trafficked		“Social and Development Impact Bonds” “Crowdfunding” and “debt-for-nature swaps” (DNS) ***Action with the purpose of***... a) mitigation of climate change; b) adaptation to climate change; c) sustainable use and protection of water and marine resources; d) transition to a circular economy; e) pollution prevention and control; f) protection and recovery of biodiversity and ecosystems g)Other connected purposes	“Social and Development Impact Bonds” “Crowdfunding” and “debt-for-nature swaps” (DNS) ***Action with the purpose of***... a) mitigation of climate change; b) adaptation to climate change; c) sustainable use and protection of water and marine resources; d) transition to a circular economy; e) pollution prevention and control; f) protection and recovery of biodiversity and ecosystems g)Other connected purposes		
Governance Goals					
Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels 16.1.1 Number of victims of intentional homicide per 100,000 population, by sex and age 16.1.2 Conflict-related deaths per 100,000 population, by sex, age and cause 16.1.3 Proportion of population subjected to (*a*) physical violence, (*b*) psychological violence and (*c*) sexual violence in the previous 12 months 16.1.4 Proportion of population that feel safe walking alone around the area they live 16.2.1 Proportion of children aged 1–17 years who experienced any physical punishment and/or psychological aggression by caregivers in the past month 16.2.2 Number of victims of human trafficking per 100,000 population, by sex, age and form of exploitation 16.2.3 Proportion of young women and men aged 18–29 years who experienced sexual violence by age 18 16.3.1 Proportion of victims of violence in the previous 12 months who reported their victimization to competent authorities or other officially recognized conflict resolution mechanisms 16.3.2 Unsentenced detainees as a proportion of overall prison population 16.3.3 Proportion of the population who have experienced a dispute in the past two years and who accessed a formal or informal dispute resolution mechanism, by type of mechanism 16.4.1 Total value of inward and outward illicit financial flows (in current United States dollars) 16.4.2 Proportion of seized, found or surrendered arms whose illicit origin or context has been traced or established by a competent authority in line with international instruments		***Through:*** Blended finances Credit and guarantees for development, Impact investments, as private equity debt issuance or fixed income securities "Funds for company challenges" or “Enterprise Challenge Funds” “Social and Development Impact Bonds” “Crowdfunding” and “debt-for-nature swaps” (DNS)	***Through:*** Blended finances Credit and guarantees for development, Impact investments, as private equity debt issuance or fixed income securities "Funds for company challenges" or “Enterprise Challenge Funds” “Social and Development Impact Bonds” “Crowdfunding” and “debt-for-nature swaps” (DNS)	Quality standards accomplishment Existence and accomplishment of Social Responsibility Plan Existence and issuance of periodical Report on social responsibility accomplishment “Green nudge” or “sustainable nudge”	

16.5.1 Proportion of persons who had at least one contact with a public official and who paid a bribe to a public official, or were asked for a bribe by those public officials, during the previous 12 months 16.5.2 Proportion of businesses that had at least one contact with a public official and that paid a bribe to a public official, or were asked for a bribe by those public officials during the previous 12 months 16.6.1 Primary government expenditures as a proportion of original approved budget, by sector (or by budget codes or similar) 16.6.2 Proportion of population satisfied with their last experience of public services 16.7.1 Proportions of positions in national and local institutions, including (*a*) the legislatures; (*b*) the public service; and (*c*) the judiciary, compared to national distributions, by sex, age, persons with disabilities and population groups 16.7.2 Proportion of population who believe decision-making is inclusive and responsive, by sex, age, disability and population group 16.8.1 Proportion of members and voting rights of developing countries in international organizations 16.9.1 Proportion of children under 5 years of age whose births have been registered with a civil authority, by age 16.10.1 Number of verified cases of killing, kidnapping, enforced disappearance, arbitrary detention and torture of journalists, associated media personnel, trade unionists and human rights advocates in the previous 12 months 16.10.2 Number of countries that adopt and implement constitutional, statutory and/or policy guarantees for public access to information 16.a.1 Existence of independent national human rights institutions in compliance with the Paris Principles 16.b.1 Proportion of population reporting having personally felt discriminated against or harassed in the previous 12 months on the basis of a ground of discrimination prohibited under international human rights law					
Goal 17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development 17.1.1 Total government revenue as a proportion of GDP, by source 17.1.2 Proportion of domestic budget funded by domestic taxes 17.2.1 Net official development assistance, total and to least developed countries, as a proportion of the Organization for Economic Cooperation and Development (OECD) Development Assistance Committee donors' gross national income (GNI) 17.3.1 Foreign direct investment, official development assistance and South-South cooperation as a proportion of gross national income 17.3.2 Volume of remittances (in United States dollars) as a proportion of total GDP 17.4.1 Debt service as a proportion of exports of goods and services 17.5.1 Number of countries that adopt and implement investment promotion regimes for developing countries, including the least developed countries 17.6.1 Fixed Internet broadband subscriptions per 100 inhabitants, by speed[5] 17.7.1 Total amount of funding for developing countries to promote the development, transfer, dissemination and diffusion of environmentally sound technologies 17.8.1 Proportion of individuals using the Internet 17.9.1 Dollar value of financial and technical assistance (including through North South, South South and triangular cooperation) committed to developing countries 17.10.1 Worldwide weighted tariff-average 17.11.1 Developing countries' and least developed countries' share of global exports 17.12.1 Weighted average tariffs faced by developing countries, least developed countries and small island developing States 17.13.1 Macroeconomic Dashboard 17.14.1 Number of countries with mechanisms in place to enhance policy coherence of sustainable development 17.15.1 Extent of use of country-owned results frameworks and planning tools by providers of development cooperation 17.16.1 Number of countries reporting progress in multi-stakeholder development effectiveness monitoring frameworks that support the achievement of the Sustainable Development Goals		***Through:*** • Blended finances • Credit and guarantees for development, • Impact investments, as private equity debt issuance or fixed income securities • "Funds for company challenges" or "Enterprise Challenge Funds" • "Social and Development Impact Bonds" • "Crowdfunding" and "debt-for-nature swaps" (DNS)	***Through:*** • Blended finances • Credit and guarantees for development, • Impact investments, as private equity debt issuance or fixed income securities • "Funds for company challenges" or "Enterprise Challenge Funds" • "Social and Development Impact Bonds" • "Crowdfunding" and "debt-for-nature swaps" (DNS)	• Quality standards accomplishment • Existence and accomplishment of Social Responsibility Plan • Existence and issuance of periodical Report on social responsibility accomplishment • "Green nudge" or "sustainable nudge"	

17.17.1 Amount in United States dollars committed to public-private partnerships for infrastructure 17.18.1 Statistical capacity indicator for Sustainable Development Goal monitoring 17.18.2 Number of countries that have national statistical legislation that complies with the Fundamental Principles of Official Statistics 17.18.3 Number of countries with a national statistical plan that is fully funded and under implementation, by source of funding 17.19.1 Dollar value of all resources made available to strengthen statistical capacity in developing countries 17.19.2 Proportion of countries that (*a*) have conducted at least one population and housing census in the last 10 years; and (*b*) have achieved 100 per cent birth registration and 80 per cent death registration						
Final Assessment Impact quantification of the sustainability achieved	Sum:	Sum:	Sum:	Sum:	Sum:	Sum:
TOTAL RESULT*:						
**Include the difference between the favorable effects and the harmful effects, which must be positive to be considered sustainable finance actions*						

Sources: Performed by the author, María Lidón Lara Ortiz, 2021. Considering the indicators formerly quote in the paper, especially the *Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development of United Nations*[5], regarding the material indicators.

[5] United Nations, Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development -Global indicator framework adopted by the General Assembly in A/RES/71/313 (Annex), annual refinements contained in E/CN.3/2018/2 (Annex II), E/CN.3/2019/2 (Annex II), 2020 Comprehensive Review changes (Annex II) and annual refinements (Annex III) contained in E/CN.3/2020/2 and annual refinements (Annex) contained in E/CN.3/2021/2-, available in: https://unstats.un.org/sdgs/indicators/Global%20Indicator%20Framework%20after%202021%20refinement_Eng.pdf (last access on August 20, 2021).

6. Conclusions.

Sustainable finances are fundamental instruments to achieve international sustainability. There are some difficulties for implementing an international financial system accompanied by mandatory homogeneous regulation, and at this level, there is a certain degree of voluntary compliance. However, the determination of the indicators to measure the degree of sustainability of financial instruments and actions of all kinds can be obtained by extracting formal indicators from the existing regulations, among which the European Union stands out due to its transnational nature and because it has several in force or projected regulatory initiatives on this issue. In the other hand, informal indicators can be obtained as well from other sources that are voluntarily applied. All of them are equally valuable for making a template that collects indicators to assess the degree of sustainability of financial institutions, as indicated. Indeed, the informal indicators analyzed are applicable to all the targets of the SDGs while the formal ones are mainly focused on the environmental targets. So, it would be desirable to unfold more formal indicators by enhancing regulations regarding all the SDGs, because it will ensure the compulsory accomplishment of all the targets included on the 2030 Agenda, and not only the environmental ones.

The proposed template can be improved and completed, but it is a first approach of what should be evaluated to determine the sustainability degree achieved and the contribution extent of each financial entity to achieve the 2030 Agenda. This last one, undoubtedly, provides us with valuable information to determine the material indicators of sustainability in all areas. The indicators provided by the 2030 Agenda should be crossed with those indicators obtained by actions on sustainable finances, which will yield a result after quantifying the number of actions implemented and their positive or harmful impact on sustainability. The result must always be positive for a financial entity or action to be considered sustainable.

This first approach needs to be supported by a universal regulation or guidelines on taxonomy that provides clarity on the assessed concepts, following the path initiated by the European Union. With this and with the development of future standards and guidelines on sustainable finance, this proposal for an assessment template would evolve and be improved, becoming a tool for making real financial sustainability in a forthcoming future.

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MAKING REAL FINANCIAL SUSTAINABILITY THROUGH FORMAL AND INFORMAL INDICATORS ASSESSMENT

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4. Informal indicators of sustainability. International reports, international standardization, and corporate social responsibility.

5. Results. Proposed template to rate sustainable impact of financial activities.

6. Conclusions.

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1. INTRODUCTION

- Achieving sustainable development at a global level has multidisciplinary implications since its scope encloses environmental, economic, social, and governance aspects.

- The financial system can decisively contribute to the achievement of a more sustainable world through sustainable finances that are already being promoted.

- But, it is a must to standardize the indicators to measure the accomplishment degree of the sustainability targets and the exchange of data collected in this scope.

- These indicators are essential to promote more sustainability in the more depressed scopes, because they will show the weaker points.

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2. THE EVOLUTION OF THE CONCEPT OF "SUSTAINABILITY" AND THE EFFECTIVENESS OF THE REGULATIONS ON ITS DEFENSE

- "Our Common Future" report or 1987 Brundtland Report (United Nations (1987)). → Concept of sustainable development as the one that satisfies current needs without endangering the ability of future generations to meet their own needs.

- The lack of legally binding nature of the former international agreements have generated, for years, a situation of recurrent regulatory ineffectiveness at the international level, because the mail rules were considered *soft law.*

- This feature is changing since the Paris Agreement of September 25, 2015, was signed, because it leads us to the "2030 Agenda" proposed by the United Nations General Assembly. It is a new global framework for sustainable development, that has been described as the first universal and legally binding agreement on this area.

- This agreement determines the goals of sustainability as a common target of international relevance. And developing it → the *Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development of United Nations* includes 169 targets, that are indicators of sustainability.

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3. FORMAL INDICATORS OF SUSTAINABILITY.

Formal indicators → are those that can be identified as sustainability milestones and actions in favour of sustainability, being the result of the traditional sources of analysis such as binding international agreements, and legal or regulatory requirements.

Indicators based on material goals

Source: www.un.org

Indicators based on actions of the green finances scope

- **Direct sustainable actions**

  → To deal with direct risks (related to climate change)

  - Prudential requirements accomplishment
  - Transparency requirements accomplishment and financial culture promotion

- **Indirect sustainable actions**

  → To deal with transition risks (related to climate change)

  - Sustainable finance issuance (green finance and others)
  - Sustainable finance investment (green finance and others)

- Transparency and financial culture as sustainability indicators

- Universal taxonomy regulation + DEFINITION OF HARMFUL EFFECTS

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4. INFORMAL INDICATORS OF SUSTAINABILITY.

Informal indicators → Are those that could be extracted from some international guidelines and other documents, as reports, that label different kinds of tools as sustainable products and mechanisms, and the indicators related to the data that make possible to rate compliance with the social responsibility of the administrations -in the public sphere-, and of corporate social responsibility -in the private scope-.

International reports indicators	International standardization	Corporate social responsibility / Public social responsibility
• Blended finances • Credit and guarantees for development • Impact investments, as private equity debt issuance or fixed income securities • "Funds for company challenges" or “Enterprise Challenge Funds” • “Social and Development Impact Bonds” • “Crowdfunding” and “debt-for-nature swaps” (DNS)	• ISO-14001, as an international standard for environmental quality management- • ISO-50001 that establishes the requirements of an Energy Management System, in order to carry out systematic and continuous improvements to the energy performance of both public and private organizations. • Many others in accordance to other targets related to the SDGs	• Quality standards accomplishment • Existence and accomplishment of Social Responsibility Plan • Existence and issuance of periodical Report on social responsibility accomplishment • “Green nudge” or “sustainable nudge”.

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5. RESULTS

As result of the previous sections, we offer below an initial proposal of a template useful to assess the impact on sustainability of the activities carried out by public or private financial institutions.

It could be applicable to assess each financial entity periodically by crossing data about sustainable actions performed and the material indicators on SDGs determined by UN (these last ones showed in the left column) –*see paper for more detail*-, which are referred in some cases to the national situation of each country or territory in where the entity assessed has developed its actions by having there its registered main office.

This template could be completed and improved for a better determination of the achievement of sustainability values through sustainable finance and on formal or informal indicators, including more future indicators.

Assessment on sustainable finances						
Sustainable finance actions						
	Positive effects					Harmful effects
	Direct actions on sustainability –Against direct risks-		Indirect actions on sustainability –Against transition risks-		Other actions	
	Prudential requirements accomplishment	*Transparency requirements accomplish-ment and financial culture promotion*	*Sustainable finance issuance (green finance and others)*	*Sustainable finance investment (green finance and others)*	*According with informal indicators*	
Material indicators of sustainability						
*In this column are included the indicators formerly quote in the paper, especially the *Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development of united Nations*, regarding the material indicators. *See paper for more detail.*			***Through:*** Blended finances Credit and guarantees for development, Impact investments, as private equity debt issuance or fixed income securities "Funds for company challenges" or "Enterprise Challenge Funds" "Social and Development Impact Bonds" "Crowdfunding" and "debt-for-nature swaps" (DNS)	***Through:*** Blended finances Credit and guarantees for development, Impact investments, as private equity debt issuance or fixed income securities "Funds for company challenges" or "Enterprise Challenge Funds" "Social and Development Impact Bonds" "Crowdfunding" and "debt-for-nature swaps" (DNS)	Quality standards accomplishment Existence and accomplishment of Social Responsibility Plan Existence and issuance of periodical Report on social responsibility accomplishment "Green nudge" or "sustainable nudge"	

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5. RESULTS

			Action with the purpose of... a) mitigation of climate change; b) adaptation to climate change; c) sustainable use and protection of water and marine resources; d) transition to a circular economy; e) pollution prevention and control; f) protection and recovery of biodiversity and ecosystems g)Other connected purposes	***Action with the purpose of...*** a) mitigation of climate change; b) adaptation to climate change; c) sustainable use and protection of water and marine resources; d) transition to a circular economy; e) pollution prevention and control; f) protection and recovery of biodiversity and ecosystems g)Other connected purposes		
Final Assessment Impact quantification of the sustainability achieved	Sum:	Sum:	Sum:	Sum:	Sum:	Sum:

TOTAL RESULT*:	

*Include the difference between the favourable effects and the harmful effects, which must be positive to be considered sustainable finance actions

6. CONCLUSIONS

- The determination of the indicators to measure the degree of sustainability of financial instruments and other financial actions can be obtained by extracting formal indicators from the existing regulations, and informal indicators from other sources that are voluntarily applied.

- All of them are equally valuable for making a template that collects indicators to assess the degree of sustainability of financial institutions, as indicated. Indeed, the informal indicators analyzed are applicable to all the targets of the SDGs while the formal ones are mainly focused on the environmental targets. So, it would be desirable to unfold more formal indicators regarding all the SDGs.

- The material indicators provided by the 2030 Agenda should be crossed with those indicators obtained by actions on sustainable finances, which will yield a result after quantifying the number of actions implemented and their positive or harmful impact on sustainability. The result must always be positive for a financial entity or action to be considered sustainable.

- This first approach needs to be supported by a universal regulation or guidelines on taxonomy, that provides clarity on the concepts to be evaluated, following the path initiated by the European Union. With this and with the development of future standards and guidelines on sustainable finance, this proposal for an assessment template would evolve and be improved, becoming a tool for making real financial sustainability in a forthcoming future.

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THANK YOU VERY MUCH

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UNIVERSITAT JAUME I

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Measuring the development of French labelled funds and their contribution to sustainable financing of the economy[1]

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[1] This presentation was prepared for the conference. The views expressed are those of the author and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

Measuring the development of French labeled funds and their contribution to sustainable financing of the economy

David Nefzi, Banque de France[1]

Abstract

The paper describes the development of labeled mutual funds in France. Our approach consists in taking an overview of the French market, based on data from the two main French public labels for investment funds (*Greenfin* and *ISR*). After a presentation of indicators for monitoring this market (subscription rate, performance), we develop a sectoral indicator to estimate the carbon footprint of the labeled funds compared to two other category of funds (ESG self-declared and non-ESG) and we provide a comparative analysis of their portfolio structures. Ultimately, we assess the "green content" of the funds by using a proxy: the share of economic activities covered by the technical screening criteria of the European Union green taxonomy and the share of green bonds in funds' portfolios. Finally, using econometric methods, we estimate a "label effect".

Keywords: Sustainable investment funds, green finance, socially responsible investment

JEL classification: G10, G11, G20, G23

[1] The views expressed in this paper do not represent the opinion of the Banque de France or the Eurosystem. For their help, their comments and discussions, I thank Emilie Candus, Corinne Devillers, François Mouriaux, Franck Sedillot and Pierre Bui Quang.

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Introduction

For several years, climate change mitigation has been the subject of targeted and crosscutting public policies. The Grantham Research Institute at London School of Economics and the Sabin Center at Columbia Law School have built a database covering climate and climate-related laws, as well as laws and policies promoting low carbon transitions[2]. The database lists 2,319 laws and policies in more than 164 countries. In parallel, the World Bank Group has built a dashboard on carbon pricing initiatives[3] – emissions trading systems and carbon taxes. It shows that in 2021, 64 carbon-pricing initiatives, covering 45 national jurisdictions and representing about 22% of global greenhouse gas emissions (GHG), have been implemented.

Aside from general legislation and carbon pricing initiatives, climate change mitigation policies can rely on targeted measures such as labelling rules and requirements for consumer products, including on financial products. In theory, a label aims to promote environmental excellence in a category of products and/or services. This label will therefore be awarded to products and services meeting high environmental standards.

Sustainable finance standards and labels are part of this approach. In 2019, Novethic (2019) published a study listing sustainable finance standards and labels available in Europe. The study shows that, between 2004 and 2019, about 10 specialized, public and private, labels have been created across Europe. The labels serve as a guarantee to investors regarding the allocation of assets in the portfolios. So far, the existing European labels cover a wide range of practices and methods ranging from the integration of ESG criteria in the asset management strategy to thematic green finance funds.

The development of these labels suggests that sustainable investment strategy is more-and-more a criterion for individual investors (AMF, 2019). It is also to meet this increased demand that the supply of investment vehicles has developed accordingly.

Incorporating sustainable criteria into investment strategies takes multiple forms:

- The *opt-out approach* consists of excluding a list of companies or sectors deemed incompatible with sustainable development;
- The *best in class or best in universe approach* consists of evaluating companies according to Environmental, Social and Governance (ESG) criteria and to invest only in those which have obtained the best evaluation within their class of activity;
- It can also take the form of thematic funds.

Of course, these criteria can be more or less weighted within the investment strategy of the funds. In some cases, the ESG approach implemented by funds' managers has a limited or even very limited impact on the investment strategy, and could lead to ESG-washing or greenwashing.

[2] https://climate-laws.org/

[3] https://carbonpricingdashboard.worldbank.org/

Given the integration of robust extra-financial criteria in the investment strategies of labeled funds, sometimes verified through a preliminary audit and an annual review carried out by independent third-party organizations, in theory labeled funds should have better environmental performances than self-declared ESG funds and, a fortiori, non-ESG funds. This paper aims to assess this assumption based on French labeled funds.

The paper is organized as follows: section 1 provide a quick overview of the French labeled funds market. Section 2 presents the data. Section 3 is dedicated, on the one hand, to the construction of a sectoral carbon intensity indicator and, on the other hand, it aims at estimating the carbon footprint of different categories of French mutual funds. Section 4 measures the share of securities issued by NACE sectors covered by the technical screening criteria established by European Commission green taxonomy (TEG, 2020). Section 5 measures the share of Green Bonds (GB) in the different categories of mutual funds' portfolios. Section 6 estimates a potential label effect. Section 7 concludes.

1. The French labeled funds market

In order to allow French savers to identify mutual funds incorporating robust extra-financial criteria in their investment strategies, quality standards, via labelling procedure, have gradually been established. In 1997, the *Finansol* label was created with the aim of promoting solidarity savings products. The trend accelerated from 2015 with the creation of two new labels:

- The *Investissement Socialement Responsable* (*ISR*) label, created in January 2016, supported by the Ministry of the Economy and Finance, and
- The *Greenfin* label, created in December 2015, supported by the Ministry of Ecological Transition.

In March 2021, the assets under management of 564 *ISR* labeled funds was about 383 billion euros. The assets under management was about 16 billion euros for 26 *Greenfin* labeled funds (Novethic, 2021).

Candus & Le Goff (2020) suggest that the labels attract numerous investors. One way to assess the investors' appetite for sustainable investment is to look at the subscription rates of labeled funds compare to the average market subscription rates.

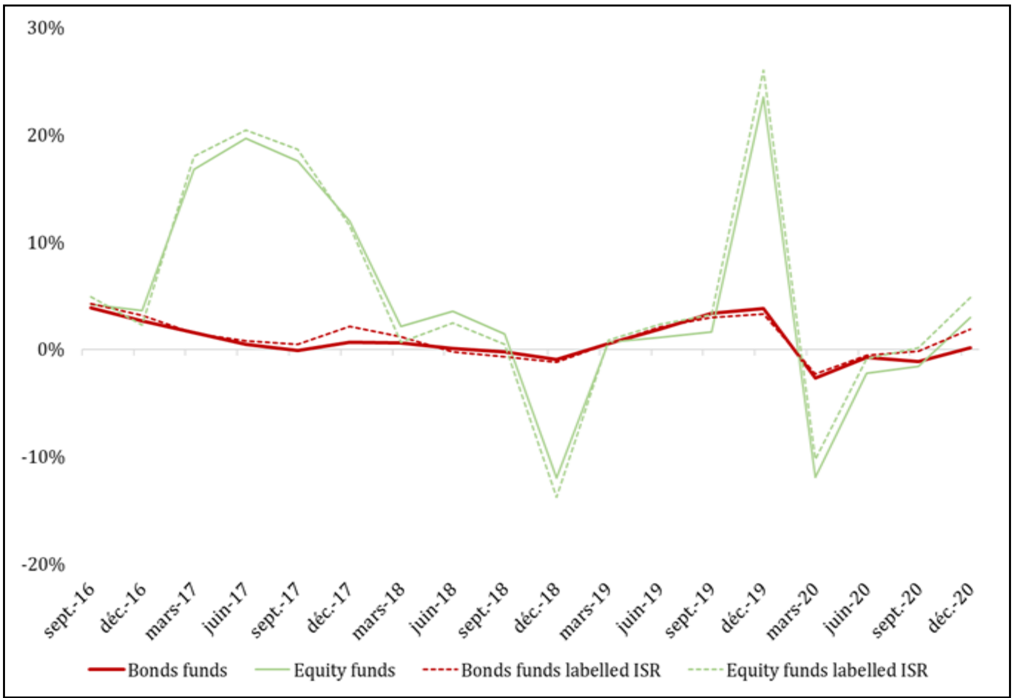
Figure 1 shows that on average French *ISR* labeled funds have higher subscription rates, irrespective of the funds' characteristics, than the average market subscription rates. For *Greenfin* labeled funds since the sample is small the comparison is not representative.

Fig. 1 - Subscription rates of French *ISR* funds compare to the average market subscription rates

Source: Banque de France, author' calculations

Investors' appetite for sustainable label funds appears to be uncorrelated with the financial performance of the funds. Figure 2 shows that on average French *ISR* labeled funds have comparable performance rates, irrespective of the funds' characteristics, than the average market performance rates.

Fig. 2 - Performance rates of French *ISR* funds compare to the average market Performance rates



Source: Banque de France, authors' calculations

The *ISR* label encompasses four categories of criteria:

- Environmental (carbon footprint, greenhouse gas emissions (GHG), electricity consumption, water and waste management, etc.);
- Social (training of employees, equal pay for men and women, place of women in the management of the company, employment of disabled people, etc.);
- Governance (transparency on executive compensation, place of women on the board of directors, fight against corruption, etc.);
- Respect for human rights (fight against poverty, for example).

The *ISR* label follows a *best in class approach*. Indeed, funds applying for the label have to provide evidences of the sustainable quality of their investments by demonstrating that they are, at all times, better than their benchmark index or their investment universe on at least two ESG indicators. For example, an equity funds investing in French stocks, and opting for the environmental criterion, will have to demonstrate to savers that its portfolio consists in French listed companies that have a better environmental rating than all French listed companies.

The *Greenfin* label however follows an *opt-out approach*: the label exclude funds that invest in companies operating in the nuclear and fossil fuels sectors. In addition, partial sectoral exclusions are also defined. Furthermore, labelling implies that the investment strategy complies with a nomenclature of eligible activities (energy, building, waste management and pollution control, industry, clean transport, information and communication technologies, agriculture and forest and adaptation to climate change). A majority share of the funds' portfolio is dedicated to these activities.

2. Data

To explore the behaviour of labeled funds we use a Banque de France's internal database covering the balance sheets of all the mutual funds licensed and registered in France. To obtain the details of securities-by-securities of the funds' balance sheets, we merge this database with a database of the European System of Central Banks (ESCB): the Centralized Securities Database (CSDB). The CSDB is a security-by-security reference database that contains, among others, data on instruments, issuers and prices for debt securities, equity instruments and investment fund shares issued by residents of euro area Member States, but also the securities likely to be held and transacted in by euro area residents; and securities denominated in euro, whoever the issuer is and wherever they are held. Thanks to this database, we have monthly data ranging from June 2011 to March 2021.

First, we define three types of funds samples. The first one corresponds to *ISR* and *Greenfin* labeled funds. The identification of these funds is made possible via their ISIN codes, which are public and available on the respective websites of the aforementioned labels[4]. Hereinafter we call this sample "Labeled funds". For the *Greenfin* labeled funds we obtain balance sheet information for 18 funds, which represents 79,207 observations about the securities detained from June 2011 to March 2021. For the *ISR* labeled funds we obtain balance sheet information for 424 funds, which represents 1,620,149 observations about the securities detained from June 2011 to March 2021.

The second sample relates to mutual funds that use in their names a word related to the sustainability lexical field but which are not labeled. The appendix provides the list of the word used to characterize our sample: it is the same list used in a previous paper of the Autorité des Marchés Financiers (AMF) (Darpeix & Mosson, 2021). Below a world-cloud diagram exhibits the 30 words with the highest occurrence in the name of the funds. Hereinafter we call this sample "Self-declared funds". For this sample, we obtain balance sheet information for 656 funds, which represents 2,685,159 observations about the securities detained from June 2011 to March 2021.

[4] https://www.ecologie.gouv.fr/label-greenfin

https://www.lelabelisr.fr/

Fig. 3 – Word-cloud of the 30 words with the highest occurrence

Source: Banque de France

The last sample corresponds to all the other funds, unlabeled and without any word related to the sustainability lexical field in their names. Hereinafter we call this sample "Non-ESG funds".

In addition, we use a Bloomberg database on Green Bonds. "Bloomberg's definition of what constitutes a market-accepted 'green' bond is based on the 2018 edition of the Green Bond Principles (GBP). The GBP are a voluntary set of guidelines established by the International Capital Markets Association to provide transparency, consistency and integrity in the green bond market. The GBP require bonds to satisfy four core pillars of the principles for them to be considered fully aligned. Bloomberg does not necessarily require full alignment to all four pillars for a Bloomberg Green Bond designation" (Bloomberg, 2020).

3. Measurement of portfolios' carbon footprint

To assess the carbon footprint of the funds' portfolios, we first construct an absolute score of carbon intensity by level-1 NACE sector (NACE Rev. 2 classification[5]).

First, we use Eurostat air emissions accounts by level-1 NACE sector database for the European Union (EU-28)[6]. It provides GHG emissions – expressed in CO_2 equivalent[7] – by economic sectors within the EU-28 from 2008 to 2019.

[5] The NACE Rev. 2 classification has a four layers structure with a first level based on alphabetical code, a second level based on a two-digit numerical code, a third level based on three-digit numerical code and finally a fourth level based on a four-digit numerical code.

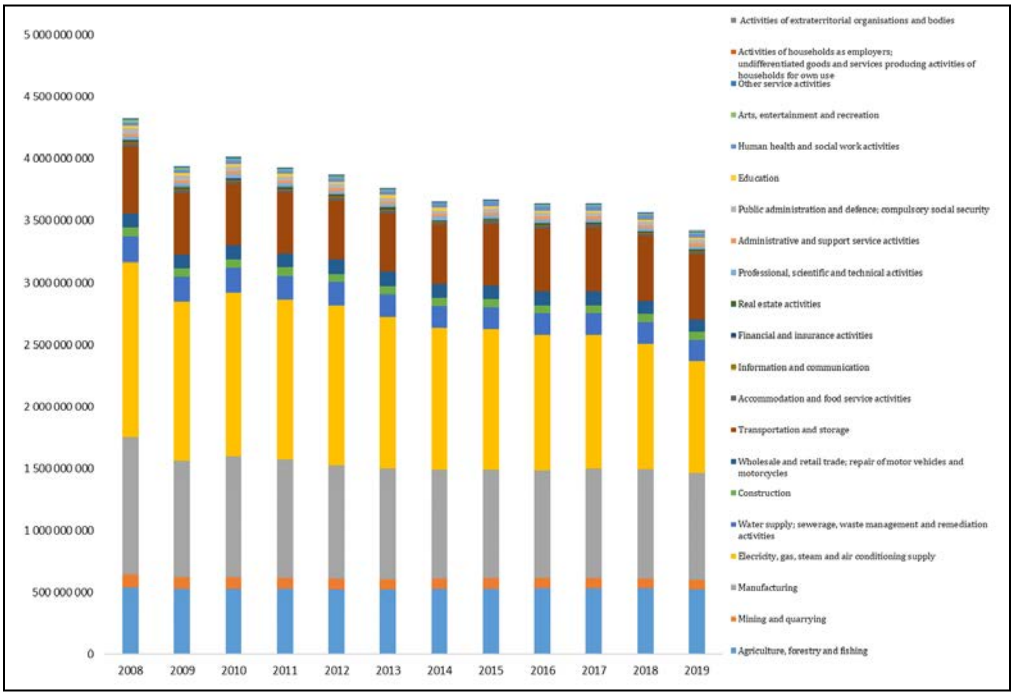
See: https://ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07-015-EN.PDF

[6] http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_air_gge&lang=en

[7] CO_2-eq is a metric measure used to compare the emissions from various GHG on the basis of their global-warming potential, by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential.

Figure 4 below exhibits the tons of CO2-equivalent emissions per level-1 NACE sectors, in the EU-28, from 2008 to 2019. During that time span, the overall level of emissions decreases by 21%. However, the contribution of each NACE sectors remains fairly stable (e.g. the contribution of the "Elecricity, gas, steam and air conditioning supply" sector is about 33% in 2008 and about 28% in 2019, while the "Transportation and storage" sector is about 13% in 2008 and about 15% in 2019 and the "Manufacturing" sector is about 26% in 2008 and about 25% in 2019).

Fig.4 – EU-28 tons of CO_2-equivalent emissions per level-1 NACE sectors



Source: Eurostat

Second, we use the National accounts aggregates by industry database[8]. It allows to obtain the gross value added (in volume) per level-1 NACE sectors for the EU-28.

Thus by linking the GHG emissions by level-1 NACE sectors to the corresponding value added, we estimate carbon intensity metrics by economic sector that expresses the average amount of CO_2-eq needed to produce a unit of value added.

To construct the score, we proceeded as follows:

$$Score_i = \frac{\left(\sum_{t=2008}^{2019} \frac{CO_2eq_{i,t}}{\left(\sum_{i=1}^{n} CO_2eq_{i,t}\right)}\right)}{\left(\sum_{t=2008}^{2019} \frac{VA_{i,t}}{\left(\sum_{i=1}^{n} VA_{i,t}\right)}\right)} \times 10 \qquad (1)$$

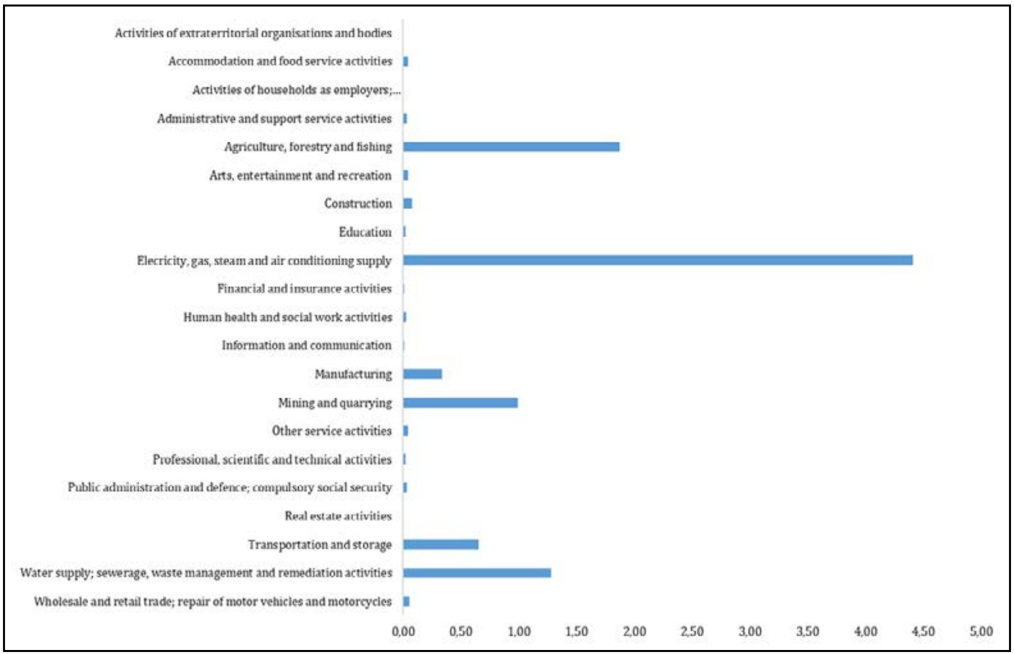
[8] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nama_10_a64&lang=en

Where $CO_2eq_{i,t}$ corresponds to CO_2-eq of the i-th NACE sector at the date t.

Where $VA_{i,t}$ corresponds to value added of the i-th NACE sector at the date t.

Thanks to this method, we obtain an ordinal scale of level-1 NACE sectors according to their carbon intensity[9]. Figure 5 below shows this classification.

Fig.5 – Carbon intensity score per level-1 NACE sectors



Source: Eurostat

Appendix provides a table of the carbon intensity score per NACE sector.

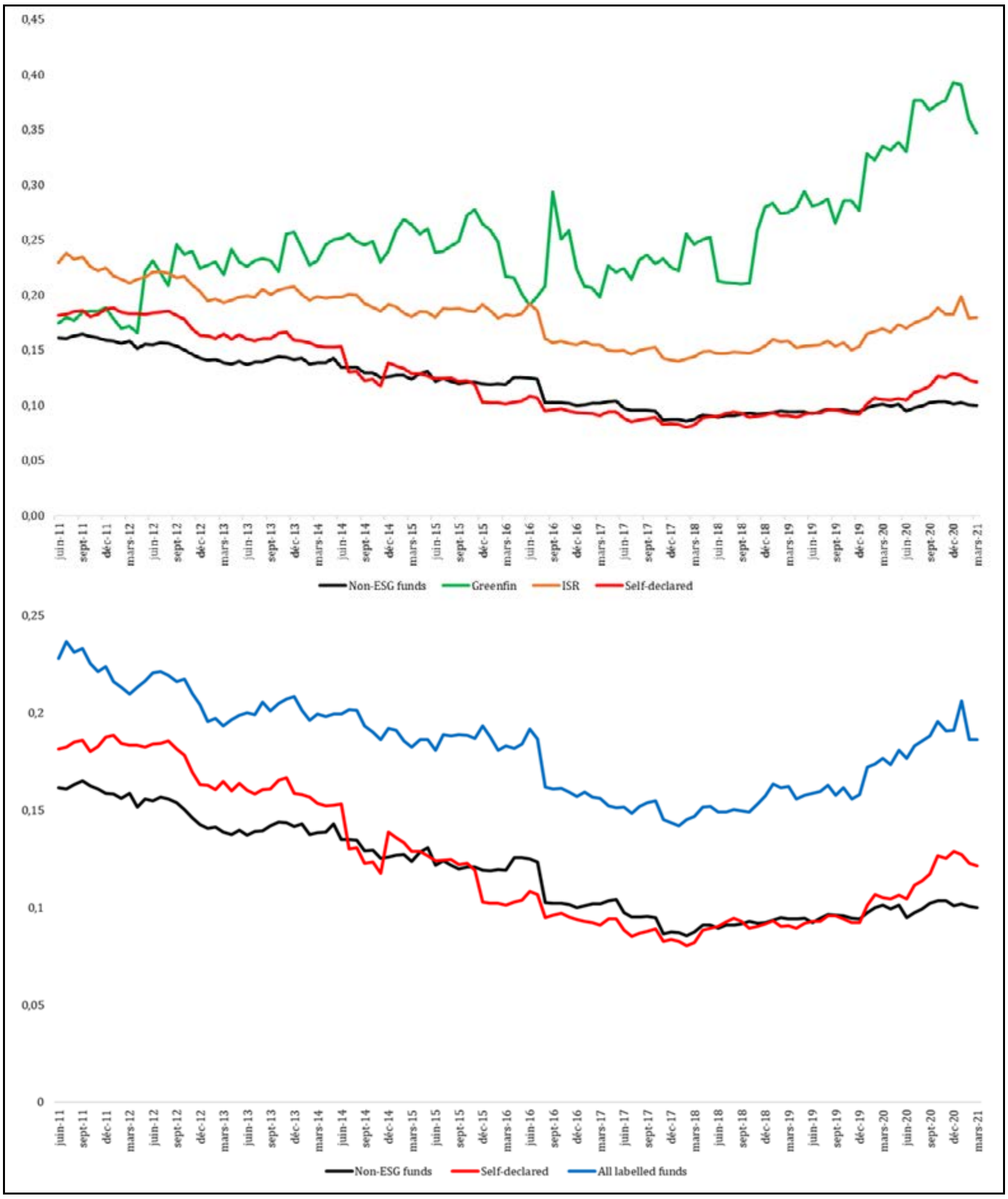
Second, since we have the issuer's level-1 NACE sector information for most securities, we can associate an absolute score to each security, if the issuer's NACE sector is known. Ultimately, to obtain a carbon footprint score for a fund's portfolio at each period, we associate for each security the score corresponding to the issuer NACE sector, then we weight the score of each security by the relative weight of the security in the fund's net assets. We calculate the weighted score as follow:

$$Weighted\ portfolio\ score_{i,t} = Score_i \times \left(\frac{security_{i,t}}{total\ net\ assets_{i,t}}\right) \qquad (2)$$

[9] To test the robustness of our method, we construct a carbon footprint score by level-1 NACE sectors based not on the carbon intensity metric but only the CO_2-eq by NACE sectors. The results we find are not significantly different from the method developed above.

For each category of funds, we take the average of the funds' carbon footprint score. The figures 6 below show the score of the different category of funds from June 2011 to March 2021.

Fig. 6 – Average portfolios carbon intensity score

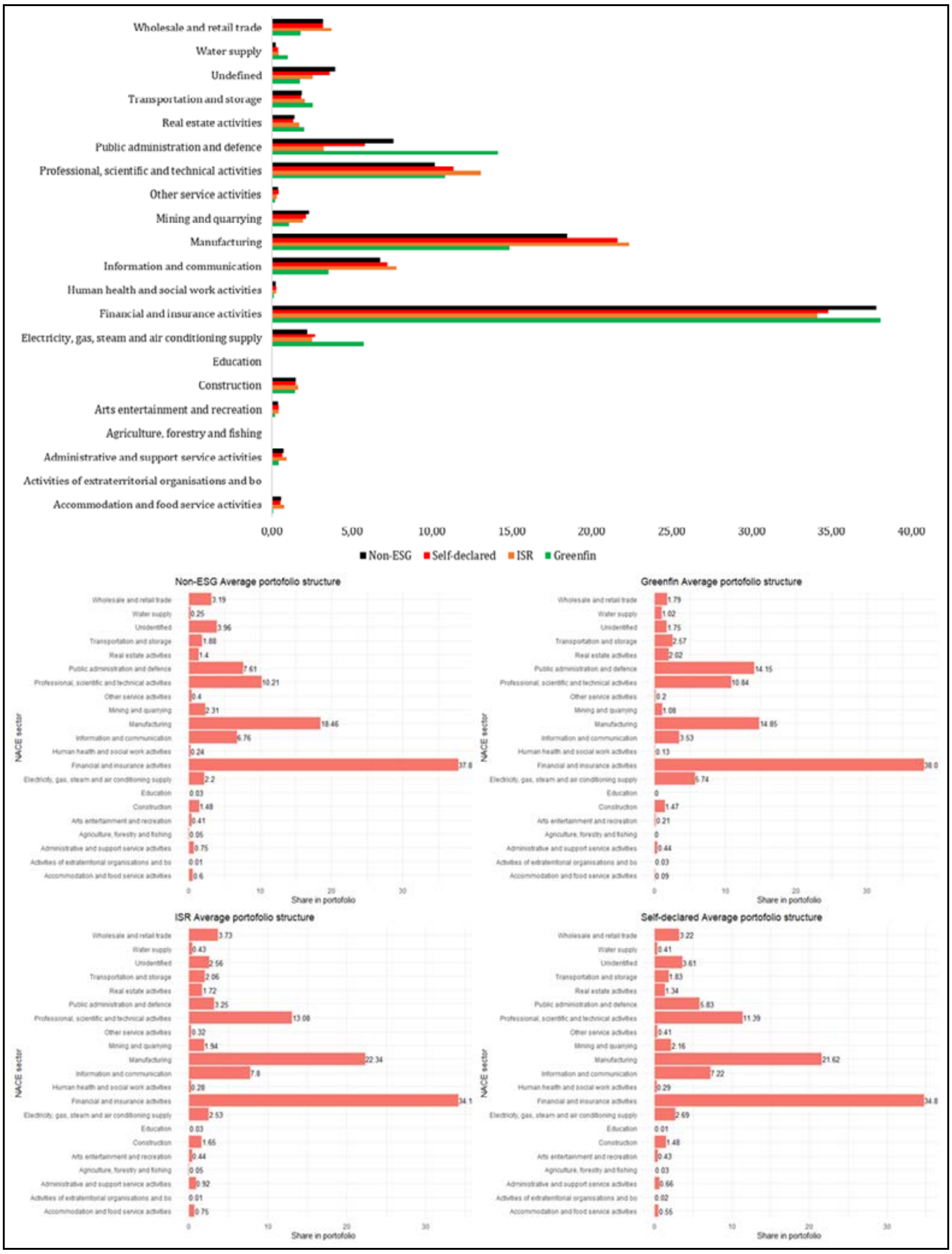


Source: Centralised Securities Database (CSDB), Banque de France, authors' calculations

The results we find are counterintuitive. Indeed, with our method labeled funds have, on average, a higher carbon score than the two other samples. To analyse more precisely these results we breakdown the average structure of the different categories of funds.

A quick look at the structure of the portfolios explain the counterintuitive results. The diagrams 7 below breakdown the share of securities by NACE sector. We see that *Greenfin* funds invest more in securities issued by the "Electricity, gas, steam and air conditioning supply" and "Water supply" sectors; which have high scores. *ISR* labeled funds, compared to Non-ESG and Self-declared funds, have relatively more securities issued by the "Manufacturing" "Wholesale and retail" sectors and less securities issued by sectors having low score (e.g. "Public administration).

Fig. 7 – Average portfolios structure per category of funds



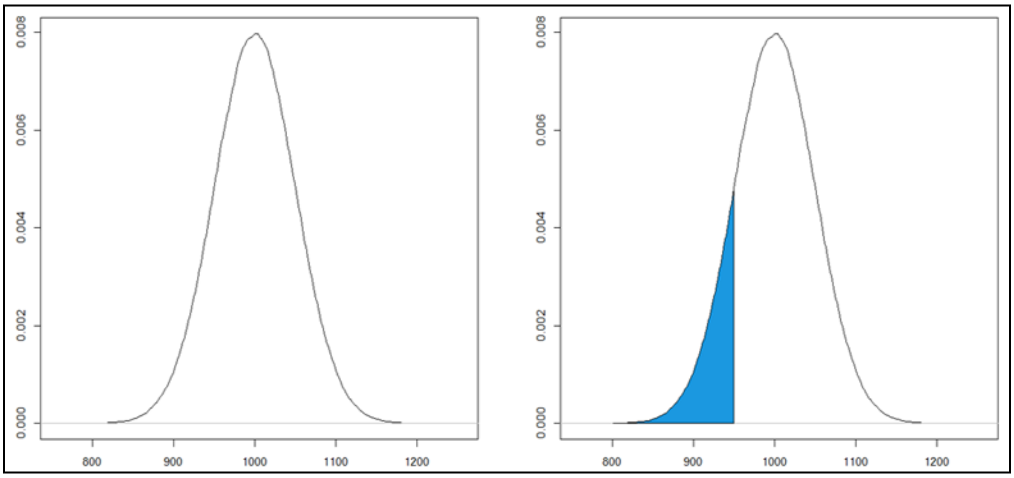
Source: Centralised Securities Database (CSDB), Banque de France, authors' calculations

The average portfolios structure per categories of funds explain partly the counterintuitive results. Around 35% of the securities are related to the "Financial and assurance activities" sector, so that we cannot identify the end use of financial flows.

The counterintuitive results also arise from an intrinsic bias of our method, specifically from the lack of granularity of the NACE sectors. For example, the "Electricity, gas, steam and air conditioning supply" sector includes sectors that produce completely carbon-free energy, such as the photovoltaic or wind sector, and extremely carbon-intensive sectors, such as coal, petroleum or natural gas.

Therefore, it does not allow taking into account the *opt-out or best in class* approaches of the labeled funds. Indeed, in theory, these approaches imply that the labeled funds following *best in class or best in universe* approach will choose in the statistical distribution function of GHG emitted by companies within a NACE sector, companies that are the less carbon intensive. Concerning funds following an *opt-out* approach, insofar as certain sectors are de facto excluded, the statistical distribution function by NACE sectors is not identical to the one without exclusions. However, with our method, the score is constructed "as if" the labeled funds chose companies in the mean of a standard statistical distribution function. Consequently, the score is upward biased. Figure 8 below offers a theoretical example of the bias.

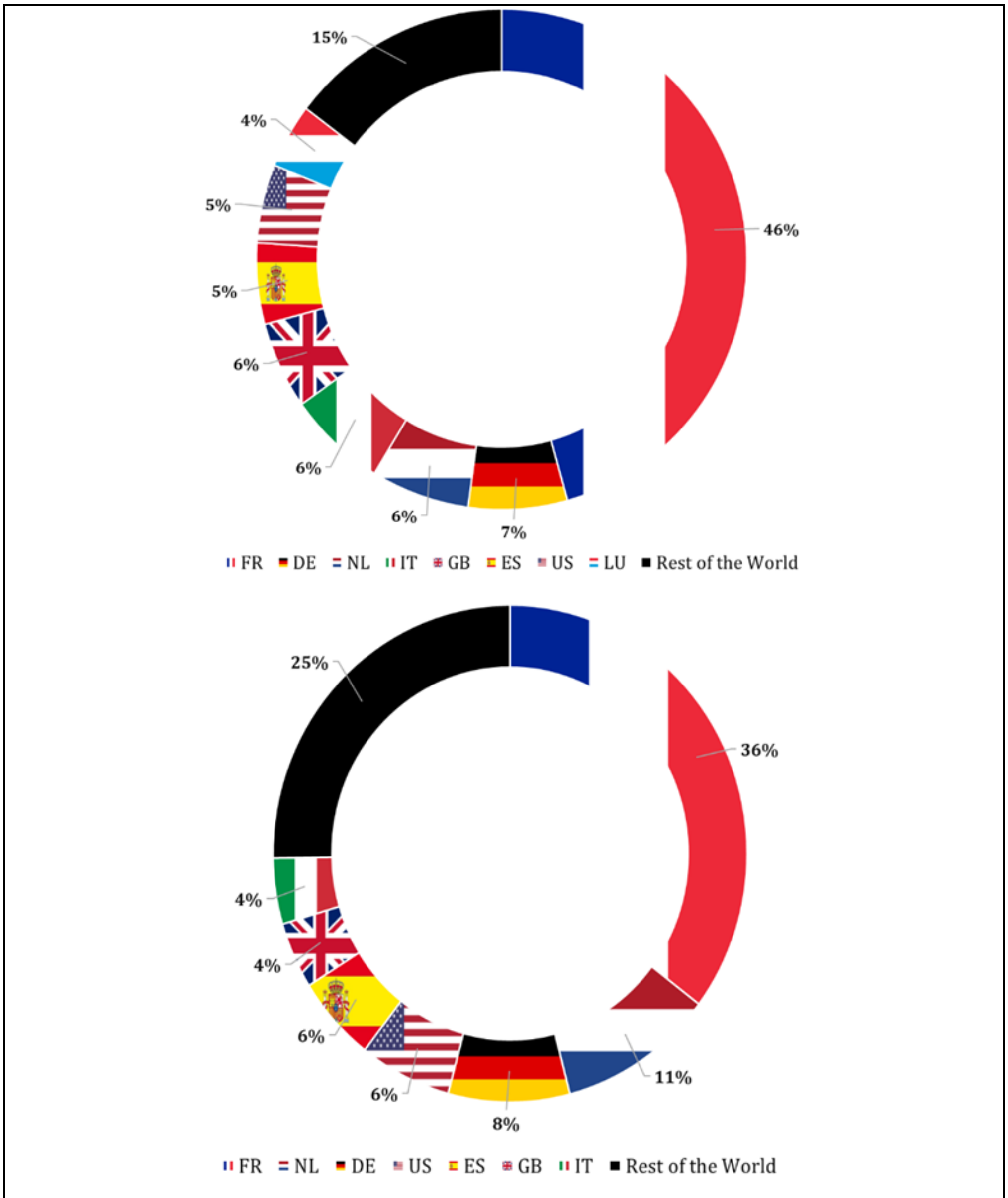
Fig. 8 – Theoretical standard statistical distribution function and *best in class* approach function



Notes: The left-hand side plot is the standard statistical distribution function of GHG emitted by companies within a NACE sector. The right-hand side represents the same function, but the blue area encompass companies that funds following a *best in class* approach invest in.

In addition, another drawback of the score is that it is inherently biased as it is constructed on GHG emissions and value-added by NACE sectors from EU-28. Nevertheless, as the method produces an ordinal ranking the effect is marginal, as the order between sectors that results from the construction of the score seems theoretically to be similar across the different regions of the world, the relative weight of GHG emissions by sector and the value-added per sectors may vary, however. This geographical bias must be qualified insofar as around four fifth of the securities detained by labeled funds come from EU issuers (see figures below).

Fig. 9 – *ISR* and *Greenfin* funds securities per country



Source: Centralised Securities Database (CSDB), Banque de France, authors' calculations

Finally, the weighted score can change according to valuation effects.

Considering all the biases of our ad hoc method and the counterintuitive results it yields, this suggests it is not robust enough. Indeed, the level-1 NACE sector appears to be too broad a level of analysis to be used to precisely assess the carbon footprint of mutual funds' portfolios.

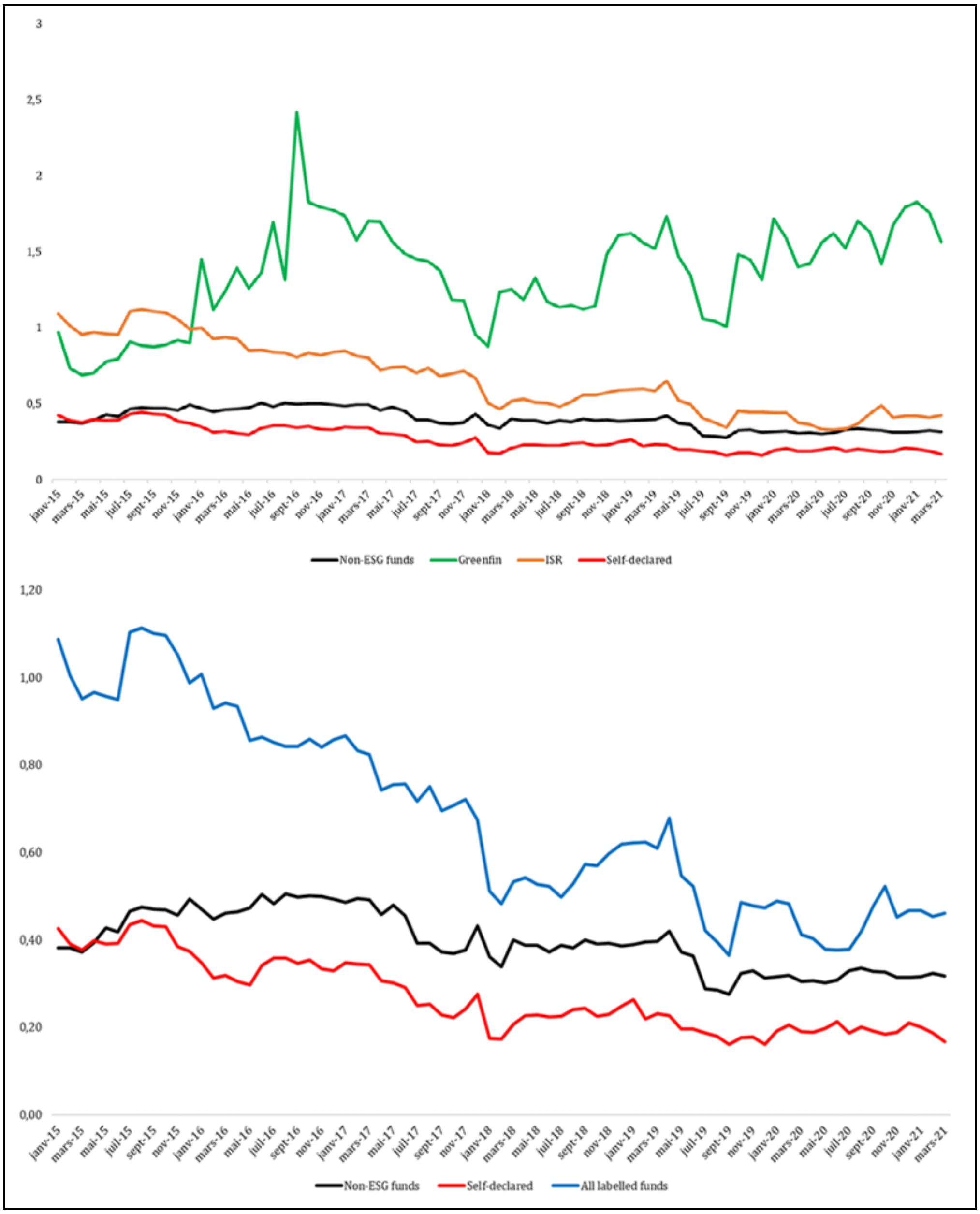
4. Share of securities issued by NACE sectors identified by the European green taxonomy

Given the shortfalls of the carbon footprint score method, we use a proxy to assess not the portfolios' carbon footprint but their "green content". We use the report of European Commission's Technical Expert Group (TEG) on Sustainable Finance to measure the share of securities issued by NACE sectors covered by the green taxonomy (see appendix). The taxonomy is based on a list of economic activities covered by technical screening criteria.

Precisely the TEG report states: "The Taxonomy sets performance thresholds (referred to as 'technical screening criteria') for economic activities which:

- Make a substantive contribution to one of six environmental objectives;
- Do no significant harm (DNSH) to the other five, where relevant;
- Meet minimum safeguards (e.g., OECD Guidelines on Multinational Enterprises and the UN Guiding Principles on Business and Human Rights)." (TEG, 2020).

Fig. 10 – Average share of securities issued by NACE sector covered by the EU taxonomy

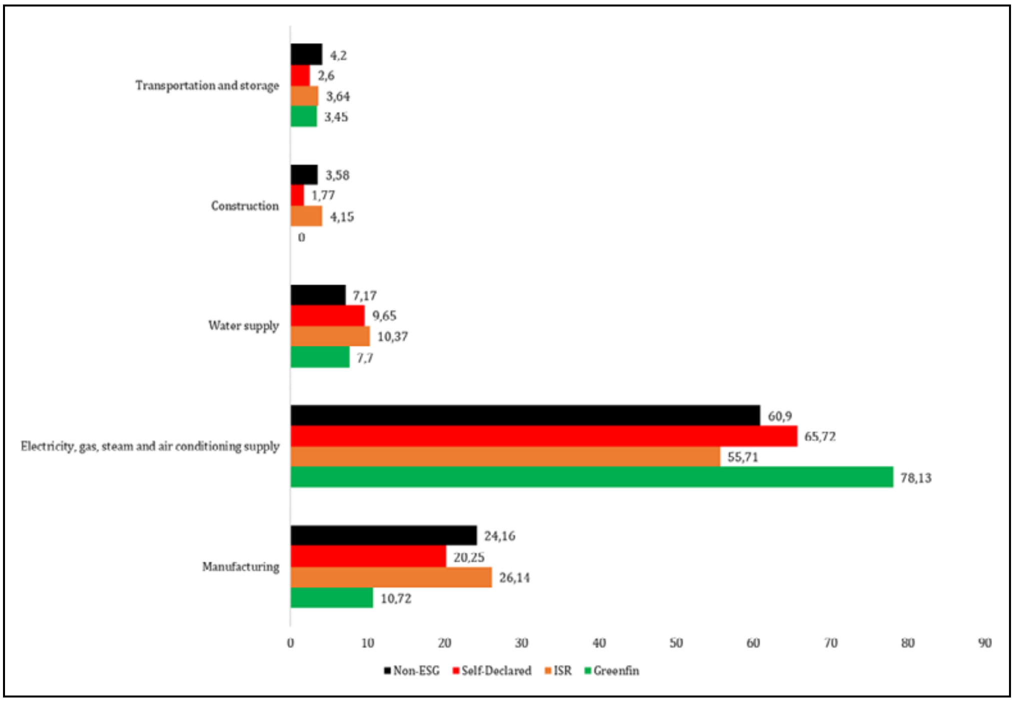


Source: Centralised Securities Database (CSDB), Banque de France, authors' calculations

Even though our results show that labeled funds have a higher share of securities issued by NACE sectors covered by the green taxonomy in their portfolios, these findings cannot be easily interpretable given the low share of securities in the funds' portfolios. Indeed, the figures above show that only *Greenfin* labeled funds exceed a share of 2%.

If we look at the average distribution of NACE sectors covered by the EU taxonomy in funds' portfolios (see figure 11), we notice an over-representation of the sector "Electricity, gas, steam and air conditioning supply", while it represents a small share in the overall portfolios' structures (see figures 7). The case is similar for the sectors "Transportation and storage", "Construction" and "Water supply". The "Manufacturing" sector represents a larger share in the overall funds portfolios' structure but it represents between a quarter and a fifth of the total share of securities issued by NACE sectors covered by the green taxonomy. In addition, our analysis is based on level-2 NACE sectors, which reduces scope of the titles included in the analysis.

Fig. 11 - Average distribution of NACE sectors covered by the EU taxonomy in portfolios



Source: Centralised Securities Database (CSDB), Banque de France, authors' calculations

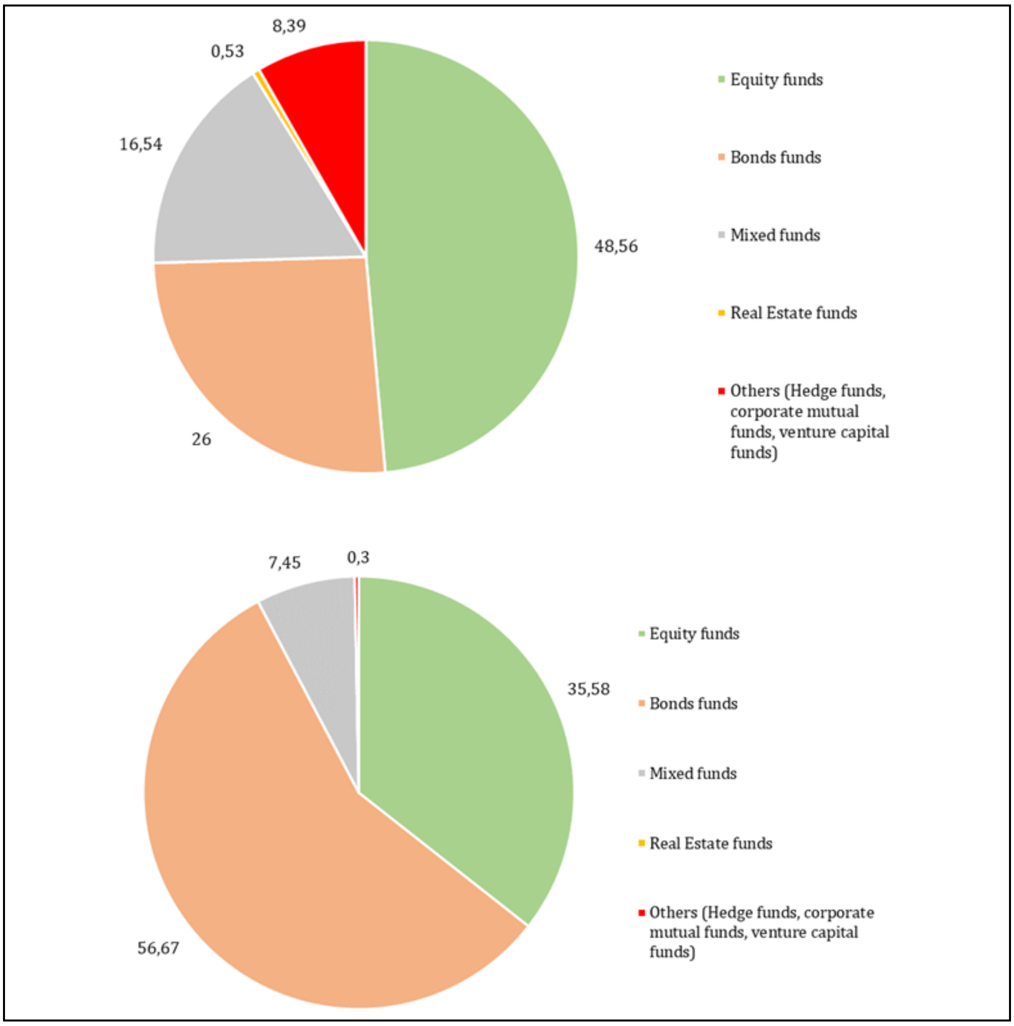
The shortcoming we face when using the list of NACE sectors covered by the EU taxonomy is equivalent to the one we faced in the previous section. The average portfolios' structure makes opaque the end use of financial flows due to the around 35% of the securities are related to the "Financial and assurance activities" sector. To overcome this shortfall it is necessary to look at another proxy that allows to identify the final use of financial flows.

5. Share of Green Bonds in portfolios

Another proxy to assess the "green content" of funds' portfolios, is to look at the share of GB. Let us say right off the bat that this method allows to overcome the shortfalls of the carbon footprint's score because it allows to capture the final destination of the financial flows. However, it creates at the same time a sampling bias, because it excludes from the analysis the equity and real estate's funds (see figures 12).

However, since we are comparing the average share of Green Bonds in fund portfolios, the average includes equity funds. This leads to the reduction of the average in level. On the other hand, the slope of the trend is only determined by bond funds and mixed funds that hold Green Bonds.

Fig. 12 – *ISR* and *Greenfin* funds per category of funds

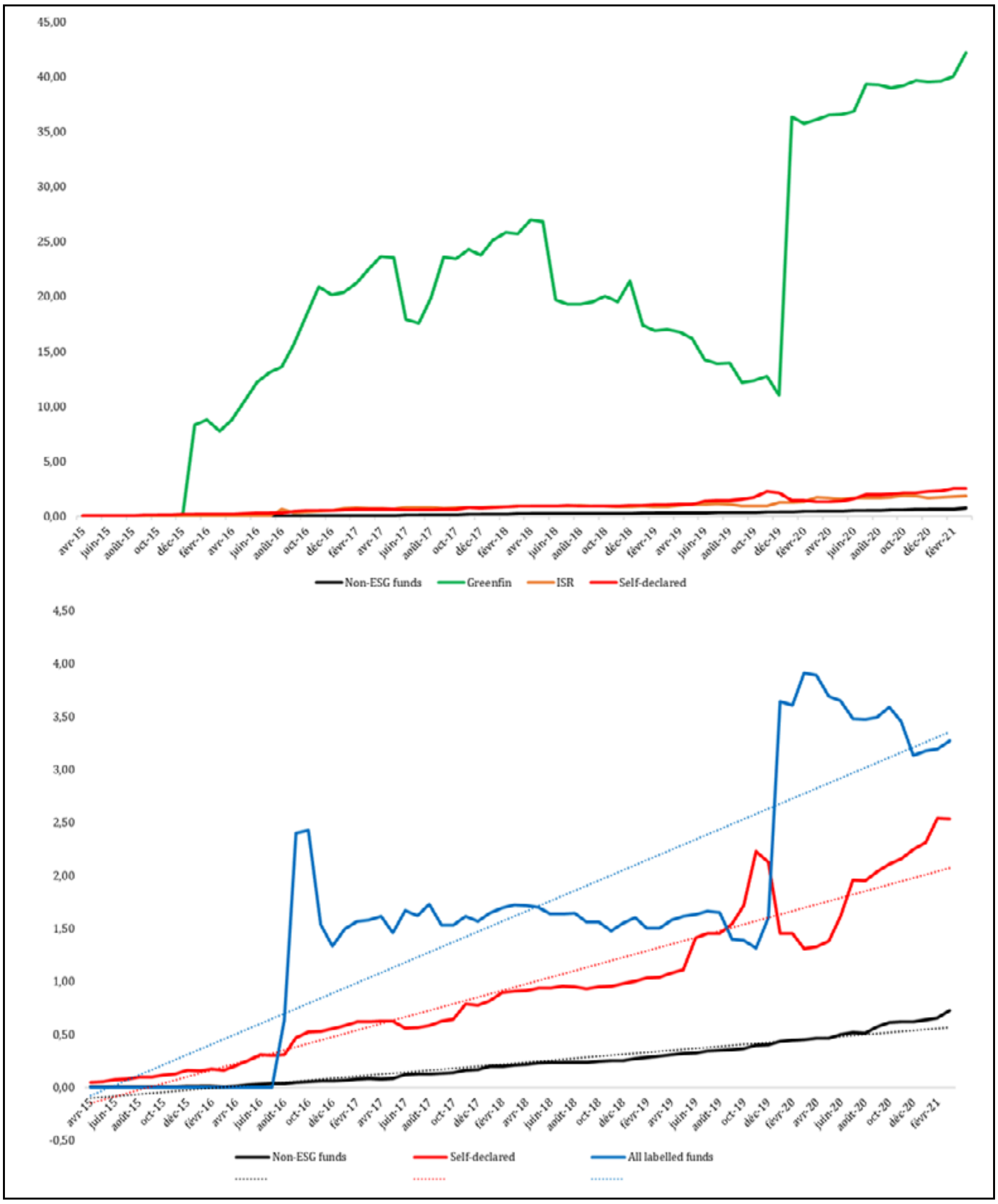


Source: Centralised Securities Database (CSDB), Banque de France, authors' calculations

To get accurate results let us precise that we include the funds in the sample of “labeled funds” only at the date of obtaining the label. Prior to the labelling, the funds not yet labeled are included in the sample “Self-declared”.

The figures 13 below exhibit the average share of GB in funds’ portfolios per category of funds.

Fig.13 – Average share of Green Bonds in portfolios



Source: Centralised Securities Database (CSDB), Banque de France, authors' calculations

If we aggregate both *Greenfin* and *ISR* funds and compare the average sample to our two other samples, the results suggest that the labeled funds have more, on average, GB in their portfolios than Self-declared funds, and the latter have more GB than the Non-ESG funds. These results also suggest that the trend is steeper for labeled funds than for Self-declared funds and that the trend of the latter is steeper than the Non-ESG funds.

Second, we regress the share of GB of labeled and Self-declared in funds' portfolios on time, on a dummy variable that takes the value of 1 if the fund is labeled and 0 otherwise, and on an interaction term of time and the dummy. Regressing the share of GB in funds' portfolios on time, implies a deterministic trend which can implicitly capture the growing share of GB in the total outstanding amounts of bonds.

This specification is written below:

$$Share\ of\ GB_{i,t} = \beta_0 + \beta_1 Labelled_i + \beta_2 Time_t + \beta_3 Labelled_i \times Time_t + \varepsilon_{i,t} (3)$$

Where the subscript i corresponds to category of funds (labeled or unlabelled).

Table 1 reports the result of equation (3). This method makes it possible to obtain the expression of two regressions. That of the regression of the GB share of self-declared funds over time $\left(Share\ of\ GB_{i,t} = \beta_0 + \beta_2 Time_t + \varepsilon_{i,t}\right)$ and that of the regression of the GB share of labeled funds over time $\left(Share\ of\ GB_{i,t} = (\beta_0 + \beta_1) Labelled_i + (\beta_2 + \beta_3) Time_t + \varepsilon_{i,t}\right)$. β_3 captures the difference in slope between self-declared and labeled funds. The coefficient is statistically significant at a 1% risk level.

If one agrees that the average share of GB in funds' portfolios is a good proxy to measure the "green content" of the investment strategy, this result suggests that there could be a label effect.

Linear Regression with interaction term

Table 1

Labeled	0.033 (0.152) [1]
Time	0.031*** (0.002)
Labeled x Time	0.017*** (0.004)
Constant	–0.202* (0.108)
Observations	146
R^2	0.807
Adjusted R^2	0.803
Residual Std. Error	0.455 (df = 142)
F Statistic	198.006*** (df = 3; 142)

[1] Values in brackets are the standard errors. signif. codes: 0.01*** 0.05** 0.1*

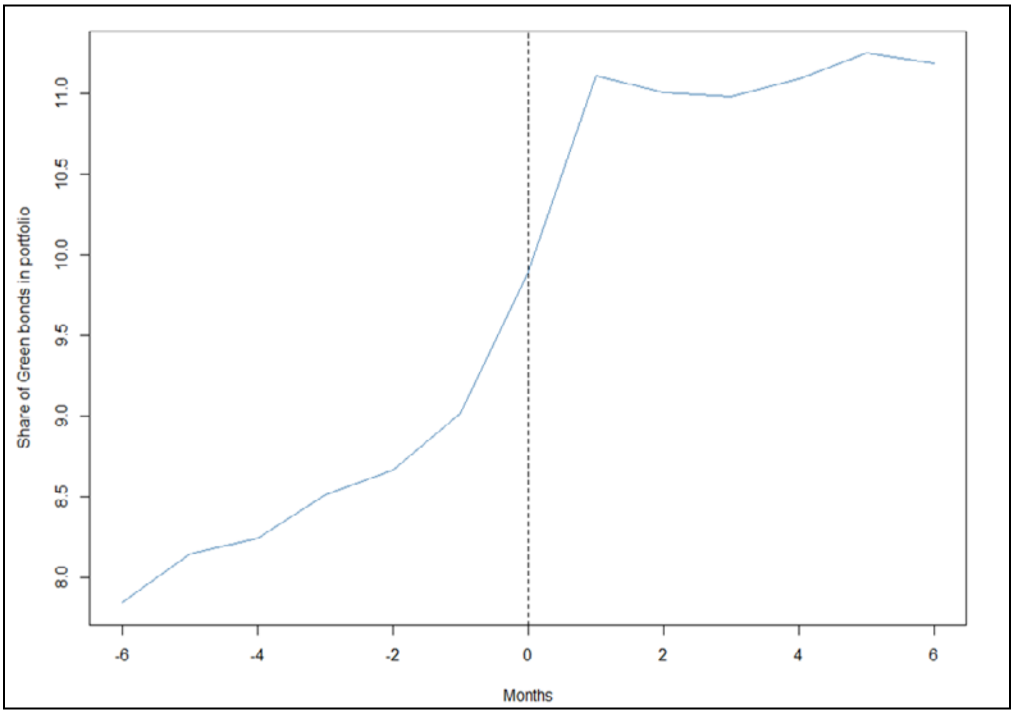
6. Is there a label effect?

In this section, we measure a potential "label effect". The "label effect" can imply that the labelling can either produce an ex-post modification in funds' investment behaviour or if conversely labelling acts as a reward (or a signal effect) to an ex-ante green investment policy, or even a combination of these two effects.

To measure this potential effect, we can use an econometric method to assess the impact of an event on a variable of interest. It can be used to measure the dynamic of the variable of interest before and after the event. Ideally, if there are no systematic changes over time except for the event, difference can be interpreted as causal. In our case, we compare the structure of the portfolios in this regard between labeled and non-labeled funds.

Figure 14 below shows the average of the labeled funds up to 6 months before and until 6 months after the labelling.

Fig. 14 – Average share of Green Bonds in portfolios before after the labelling



On a population, the average effect of the event on the variable of interest can be estimated by comparing the change in the mean up to t-periods after and t-periods before the event. Let us denote $Y_{i,2}$ the variable of interest after the event and $Y_{i,1}$ the variable of interest before the event, then the average effect can be estimated as follows:

$$\frac{1}{n}\sum_{i=1}^{n}(Y_{i,2} - Y_{i,1}) \tag{4}$$

(4) can be estimated via the following regression, it is the equivalent of β:

$$Y_{i,t} = \beta \times Event_t + u_{i,t} \tag{5}$$

The dummy variable $Event_t$ takes the value of 1 after the occurring of the event, and 0 otherwise.

Model (5) is not totally convincing because it implies that the labelling process explain all the variation of the share of GB, but one may suspect that it only tells part of the story. Other unobserved characteristics can also be correlated with the variations of the variable of interest ($Y_{i,t}$), and possibly with the explanatory variable. If the error term is not orthogonal to our explanatory variable[10], the parameters will be biased. Therefore, to get consistent estimators suppose that the error term $u_{i,t}$ includes a component specific to individual characteristics, and a random term specific to the considered observation, so that it can be rewrite as follows:

$$u_{i,t} = \alpha_i + \varepsilon_{i,t} \tag{6}$$

Consequently (5) can rewritten as follows:

$$Y_{i,t} = \beta \times Event_t + \alpha_i + \varepsilon_{i,t} \tag{7}$$

Where α_i capture the unobserved heterogeneity, invariant over time, in other words it captures the unobserved individual characteristics. In our case, it is relevant to include such individual fixed effects.

One might also want to account for unobserved heterogeneity, constant across entities, but varying over time. In other words, it can account for observed differences between treatment and control periods. To do so time fixed effects should be included in (7), so that it should be rewritten as follows:

$$Y_{i,t} = \beta \times Event_t + \alpha_i + \delta_t + \varepsilon_{i,t} \tag{8}$$

Hence, model (8) allows to eliminate biases from unobservable variables that vary over time but are invariant across funds, it also eliminate biases for unobservable variables that vary across funds but are invariant over time.

The specification (7) and (8) are estimated in the table below. The coefficient β indicates by how much the share of GB changes over time, on average, once the funds have been labeled. The average effect of the event is statistically significant: the change in the mean after and before the event is of 2.5 pp with the specification with individual fixed effects and of 3.3 pp with the specification with individual and time fixed effects.

The results suggest that there is a label effect. They show that during the 6 months after the labelling there is on average more GB in newly labeled funds' portfolios than 6 months before their labelling. A quick look at the figure 12 shows that before the labelling, the share of GB in funds' portfolios is steadily growing, but the trend becomes less steep once the funds is labeled. One might interpret the label effect as follows: the labelling requires the funds to cope with constraints that imply to follow a certain investment policy. That change occurs, on average, around the labelling process and seems to remains stable after the labelling.

[10] $Cov(After_t, u_{i,t}) \neq 0$

Panel Data Regression

Table 2

	Individual fixed effects	Individual and time fixed effects
Event	2.526*** (0.305)[1]	3.344*** (0.778)
Observations	1,014	1,014
R^2	0.959	0.959
Adjusted R^2	0.956	0.955
Residual Std. Error	4.849 (df = 937)	4.859 (df = 926)
F Statistic	284.292*** (df = 77; 937)	247.819*** (df = 88; 926)

[1] Values in brackets are the standard errors. signif. codes: 0.01*** 0.05** 0.1*

Concluding remarks

In this paper, we took a brief overview of the French mutual funds market, based on data from the two main French public labels for investment funds (*Greenfin* and *ISR*). After a presentation of indicators for monitoring this market (subscription rate, performance rate), we tried to estimate the carbon footprint, using only official statistics, of the labeled funds compared to two other category of funds (ESG self-declared and non-ESG) and we provided a comparative analysis of their portfolio structures. We conclude that the use of the carbon score at the NACE sectors level is not a satisfactory indicator, to get accurate estimates of the carbon content of the mutual funds' portfolios.

To get robust results, micro data at the entity level should have been used. Unfortunately, these type of data are not available, particularly at the level of GHG emissions at least for public-listed companies, but also the average level of GHG emissions per economic sector.

Because of the shortcomings of the score method, we then assessed the "green" orientation of the funds by using a proxy: the share economic activities covered by the technical screening criteria of the European green taxonomy. This method also revealed its limit given the average structure of funds' portfolios that makes opaque the end use of financial flows due to the around 35% of the securities are related to the "Financial and assurance activities" sector.

Finally, to overcome this shortfall we look at another proxy that allows to identify the final use of financial flows: the share of green bonds in funds' portfolios. It allows to measures a statistically significant "greener" orientation of labeled funds. Thanks to that this proxy, we are able to estimate a "label effect". Indeed, our findings show that, all things being equal, during the 6 months after the labelling there is on average more GB in newly labeled funds' portfolios than 6 months before their labelling,

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Appendix

1 List of words used to identify "Self-declared" funds

Theme	**Words**
SRI/ESG	- ISR - SRI - ESG
Sustainability	- Durable / Durables - Sustainable / Sustainability - SDG (« Sustainable Development Goals ») - Responsable - Responsible / Responsibility
Energy	- New energy - Alternative energy - Energy evolution - Energies renouvelables - Energy solution / solutions - Nouvelles énergies - Energy innovators

	- Energy transition - Smart energy - Clean energy - Carbon - Active solar
Water	- Sustainable water - Sustainable global water - Eco fund water - Eco CSOB water - Or bleu
Planet	- Planète - Planet
Environment	- Environnement - Environment / Environmental - Green - Renewable - Transition - Climat / Climatique - Climate - Terreneuve - Ecotrends - Ecology - Clean economy - Clean world - Eco solutions - Impact - Circular economy - Positive economy
Social	- Social - Faim - Fonds de partage - Investissement et partage - Partage sos - Solidaire / Solidaires / Solidarité - Solidarity - Humain - Human - Emploi - Happy - Shared Growth - Ethique / Ethiques - Ethical - Gender equality - Insertion - Engagement - Women empowerment

	- Valeurs féminines - Women leaders - Well-being - Gender diversity

2 Absolute carbon intensity score per level-1 NACE sectors

NACE sector	Score
Accommodation and food service activities	0,00
Activities of extraterritorial organizations and bodies	0,05
Activities of households as employers	0,00
Administrative and support service activities	0,03
Agriculture, forestry and fishing	1,87
Arts entertainment and recreation	0,05
Construction	0,08
Education	0,02
Electricity, gas, steam and air conditioning supply	4,41
Financial and insurance activities	0,01
Human health and social work activities	0,03
Information and communication	0,01
Manufacturing	0,34
Mining and quarrying	0,99
Other service activities	0,05
Professional, scientific and technical activities	0,02
Public administration and defence	0,03
Real estate activities	0,00
Transportation and storage	0,65
Water supply	1,28
Wholesale and retail trade	0,06

3 EU TEG Green Taxonomy

NACE Macro-Sector	Activity	Level 2	Level 3	Level 4
A - Agriculture, forestry and fishing	Afforestation	A2		
A - Agriculture, forestry and fishing	Conservation forest	A2		
A - Agriculture, forestry and fishing	Existing forest management	A2		
A - Agriculture, forestry and fishing	Growing of non-perennial crops	A1	A1.1	
A - Agriculture, forestry and fishing	Growing of perennial crops	A1	A1.2	
A - Agriculture, forestry and fishing	Livestock production	A2	A1.4	

A - Agriculture, forestry and fishing	Reforestation	A2		
A - Agriculture, forestry and fishing	Rehabilitation, Reforestation	A2		
C - Manufacturing	Manufacture of Aluminum	C24	C24.4	C24.4.2
C - Manufacturing	Manufacture of Cement	C23	C23.5	C23.5.1
C - Manufacturing	Manufacture of fertilizers and nitrogen compounds	C20	C20.1	C20.1.5
C - Manufacturing	Manufacture of Hydrogen	C20	C20.1	C20.1.1
C - Manufacturing	Manufacture of Iron and Steel	C24	C24.1 C24.2 C24.3 C24.5	C24.5.1 C24.5.2
C - Manufacturing	Manufacture of low carbon technologies			
C - Manufacturing	Manufacture of other inorganic basic chemicals - Manufacture of carbon black	C20	C20.1	C20.1.3
C - Manufacturing	Manufacture of other inorganic basic chemicals - Manufacture of chlorine	C22	C20.3	C20.1.5
C - Manufacturing	Manufacture of other inorganic basic chemicals - Manufacture of disodium carbonate (soda ash)	C21	C20.2	C20.1.4
C - Manufacturing	Manufacture of other organic basic chemicals	C20	C20.1	C20.1.4
C - Manufacturing	Manufacture of plastics in primary form	C21	C20.1	C20.1.6
D - Electricity, gas, steam and air conditioning supply	Cogeneration of Heat/Cool and Power from Bioenergy (Biomass, Biogas, Biofuels)	D35	D35.1 D35.3	D35.1.1 D35.3.0
D - Electricity, gas, steam and air conditioning supply	Cogeneration of Heat/cool and Power from Concentrated Solar Power	D35	D35.1 D35.3	D35.1.1 D35.3.0
D - Electricity, gas, steam and air conditioning supply	Cogeneration of Heat/Cool and Power from Gas (not exclusive to natural gas)	D35	D35.1 D35.3	D35.1.1 D35.1
D - Electricity, gas, steam and air conditioning supply	Cogeneration of Heat/Cool and Power from Geothermal Energy	D35	D35.1 D35.3	D35.1.1 D35.1
D - Electricity, gas, steam and air conditioning supply	District Heating/Cooling Distribution	D35	D35.3	D35.3.0
D - Electricity, gas, steam and air conditioning supply	Installation and operation of Electric Heat Pumps	D35	D35.3	D35.3.0
D - Electricity, gas, steam and air conditioning supply	Manufacture of Biogas or Biofuels	D35	D35.2	D35.2.1
D - Electricity, gas, steam and air conditioning supply	Production of Electricity from Bioenergy (Biomass, Biogas and Biofuels)	D35	D35.1	D35.1.1
D - Electricity, gas, steam and air conditioning supply	Production of Electricity from Concentrated Solar Power	D35	D35.1	D35.1.1
D - Electricity, gas, steam and air conditioning supply	Production of Electricity from Gas (not exclusive to natural gas)	D35	D35.1	D35.1.1

D - Electricity, gas, steam and air conditioning supply	Production of Electricity from Geothermal	D35	D35.1	D35.1.1
D - Electricity, gas, steam and air conditioning supply	Production of Electricity from Hydropower	D35	D35.1	D35.1.1
D - Electricity, gas, steam and air conditioning supply	Production of Electricity from Ocean Energy	D35	D35.1	D35.1.1
D - Electricity, gas, steam and air conditioning supply	Production of Electricity from Solar PV	D35	D35.1	D35.1.1
D - Electricity, gas, steam and air conditioning supply	Production of Electricity from Wind Power	D35	D35.1	D35.1.1
D - Electricity, gas, steam and air conditioning supply	Production of Heat/cool from Bioenergy (Biomass, Biogas, Biofuels)	D35	D35.3	D35.3.0
D - Electricity, gas, steam and air conditioning supply	Production of Heat/cool from Concentrated Solar Power	D35	D35.3	D35.3.0
D - Electricity, gas, steam and air conditioning supply	Production of Heat/Cool from Gas (not exclusive to natural gas)	D35	D35.3	D35.3.0
D - Electricity, gas, steam and air conditioning supply	Production of Heat/cool from Geothermal	D35	D35.3	D35.3.0
D - Electricity, gas, steam and air conditioning supply	Production of Heat/cool using Waste Heat	D35	D35.3	D35.3.0
D - Electricity, Gas, Steam and Air Conditioning Supply	Storage of Electricity			
D - Electricity, Gas, Steam and Air Conditioning Supply	Storage of Hydrogen			
D - Electricity, Gas, Steam and Air Conditioning Supply	Storage of Thermal Energy			
D - Electricity, gas, steam and air conditioning supply	Transmission and Distribution of Electricity	D35	D35.1	D35.1.2 D35.1.3
D - Electricity, gas, steam and air conditioning supply H - Transporting and storage	Retrofit of Gas Transmission and Distribution Networks	D35 H49	D35.2 H49.5	D35.2.1 H49.5.0
E - Water Supply; sewerage, waste management and remediation activities	Anaerobic digestion of bio-waste	E38	E38.2	E38.2.1
E - Water Supply; sewerage, waste management and remediation activities	Anaerobic digestion of sewage sludge	E37	E37.0	E37.0.0

E - Water Supply; sewerage, waste management and remediation activities	Capture of anthropogenic emissions	E39	E39.0	E39.0.0
E - Water Supply; sewerage, waste management and remediation activities	Centralized wastewater treatment	E37	E37.0	E37.0.0
E - Water Supply; sewerage, waste management and remediation activities	Composting of bio-waste	E38	E38.2	E38.2.1
E - Water Supply; sewerage, waste management and remediation activities	Direct Air Capture of CO2	E39	E39.0	E39.0.0
E - Water Supply; sewerage, waste management and remediation activities	Landfill gas capture and utilization	E39	E39.0	E39.0.0
E - Water Supply; sewerage, waste management and remediation activities	Material recovery from non-hazardous waste	E38	E38.3	E38.3.2
E - Water Supply; sewerage, waste management and remediation activities	Permanent Sequestration of captured CO2	E39	E39.0	E39.0.0
E - Water Supply; sewerage, waste management and remediation activities	Separate collection and transport of non-hazardous waste in source segregated fractions	E38	E38.1	E38.1.1
E - Water Supply; sewerage, waste management and remediation activities	Transport of CO2	E39	E39.0	E39.0.0
E - Water Supply; sewerage, waste management and remediation activities	Water collection, treatment and supply	E36	E36.0	E36.0.0
F - Construction	Building renovation	F41 F43	F41.1 F41.2	
F - Construction	Construction of new buildings	F41 F43	F41.1 F41.2	
F - Construction	Infrastructure for low carbon transport (land transport)	F42	F42.1	F42.1.1 F42.1.2 F42.1.3
F - Construction	Infrastructure for low carbon transport (water transport)	F42	F42.9	F42.9.1
F - Construction M - Professional, scientific and technical activities	Individual renovation measures, installation of renewables on-site and professional, scientific and technical activities	F41 F43	F41.2	
H - Transporting and storage	Freight Rail Transport	H49	H49.2	H49.2.0

H - Transporting and storage	Freight transport services by road	H49	H49.4	H49.4.1
H - Transporting and storage	Inland freight water transport	H50	H50.4	H50.4.0
H - Transporting and storage	Inland passenger water transport	H50	H50.3	H50.3.0
H - Transporting and storage	Interurban scheduled road transport	H49	H49.3	H49.3.9
H - Transporting and storage	Passenger cars and commercial vehicles	Not defined		
H - Transporting and storage	Passenger Rail Transport (Interurban)	H49	H49.1	H49.1.0
H - Transporting and storage	Public transport	H49	H49.3	H49.3.1
J - Information and communication	Data processing, hosting and related activities	J63	J63.1	J63.1.1
J - Information and communication	Data-driven climate change monitoring solutions	J61 J62 J63	J63.1	J63.1.1
L - Real estate activities	Acquisition and ownership of buildings	L68		

Measuring the development of French labeled funds and their contribution to the sustainable financing of the economy

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September 15, 2021

Motivation

- Are labeled funds more "environmentally-friendly" than non-labeled funds ?
- In France, two labels created in 2015: the *Investissement Socialement Responsable (ISR)* (best in class approach), and *Greenfin* (opt-out approach).
- In March 2021, the assets under management of the french labeled funds was about 399 billions euros

Overview

Data

Internal Banque de France database covering the balance sheets of all UCITS licensed and registered in France.

ESCB securities-by-securities database: the Centralized Securities Database (CSDB).

Three samples corresponding to different types of funds.

- The first one corresponds to the labeled funds.
- The second sample relates to unlabeled mutual funds using in their names a word related to the sustainability lexical field.
- The last sample corresponds to all the other funds, unlabeled and without any word related to the sustainability lexical field in their names

Portfolios' carbon footprint score

Carbon intensity score by portfolios at each period:

$$Portfolio\ score_{i,t} = score_i \times \frac{security_{i,t}}{total\ net\ assets_{i,t}} \tag{1}$$

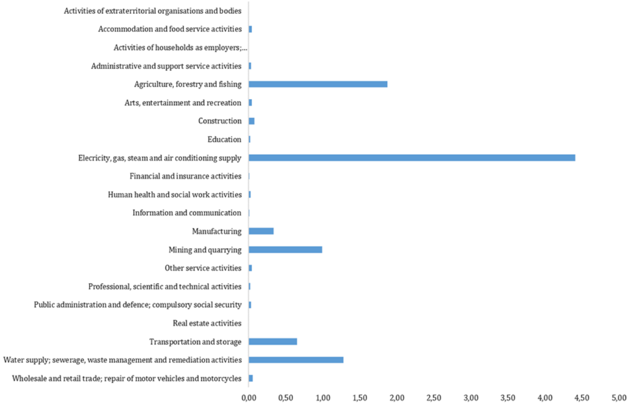
To construct an absolute score of carbon intensity by level-1 NACE sector.

- GHG emissions – expressed in CO_2 equivalent – by level-1 NACE sectors within the EU-28 from 2008 to 2019.
- Second, gross value added (in volume) per level-1 NACE sectors for the EU-28.
- Carbon intensity metrics by economic sector: expresses the average amount of CO_2-eq needed to produce a unit of value added.

$$Score_i = \frac{\left(\sum_{t=2008}^{2019} \frac{CO_2eq_{i,t}}{(\sum_{i=1}^{n} CO_2eq_{i,t})}\right)}{\left(\sum_{t=2008}^{2019} \frac{VA_{i,t}}{(\sum_{i=1}^{n} VA_{i,t})}\right)} \times 10 \tag{2}$$

Portfolios' carbon footprint score

Thanks to this method, we obtain an ordinal scale of level-1 NACE sectors according to their carbon intensity.



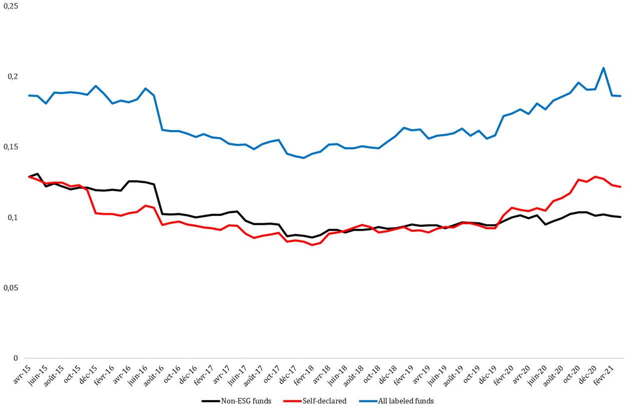
Green content of portfolios

To assess the green content of funds portfolios we use two different proxies:

- First, we use the share of securities issued by NACE sectors covered by the green taxonomy.
- Another proxy to assess the green content of portfolios, is to look at the share of GB. This method captures the final destination of the financial flows. However, it creates at the same time a sampling bias.

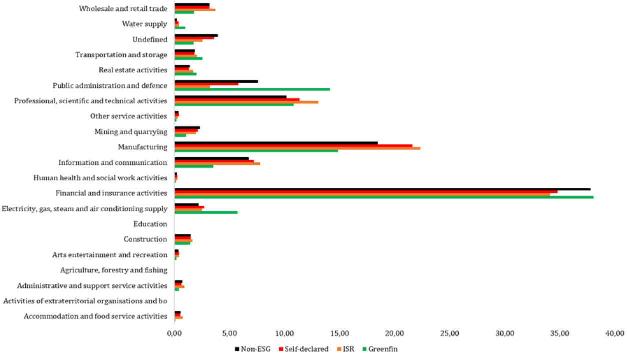
Portfolios' carbon footprint score

Labeled funds have, on average, a higher carbon footprint than the two other samples.



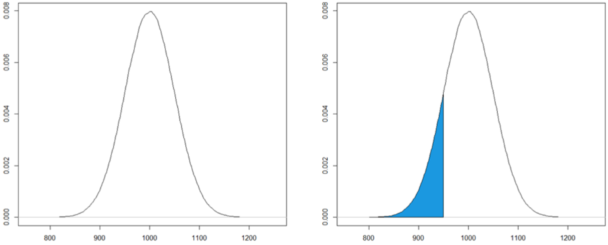
Portfolios' structure

The average portfolios structure per categories of funds explain partly the counter-intuitive results.



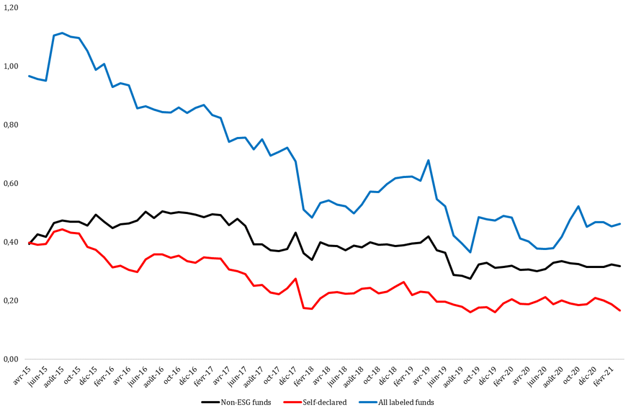
The shortcomings of the carbon footprint score

The counter-intuitive results also arise from an intrinsic bias of our method, specifically the lack of granularity of the NACE sectors does not allow taking into account the opt-out or best in class or best in universe approaches of the labeled funds.



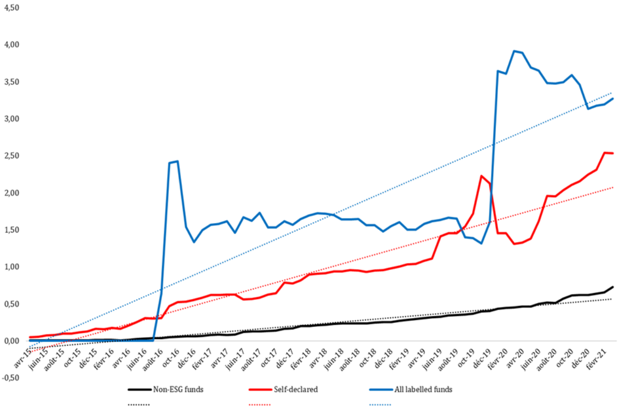
Share of securities by sectors covered by the EU taxonomy

Labeled funds have a higher share in the their portfolios of securities issued by sectors covered by the taxonomy; difficult to interpret given the low share of securities in portfolios.



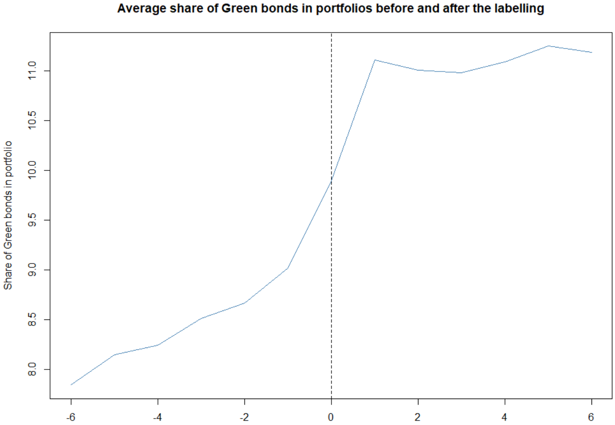
Share of Green Bonds in portfolios

Labeled funds have more, on average, GB in their portfolios than self-declared funds, and the latter have more GB than the Non-ESG funds. The trend is steeper for labeled funds than for self-declared funds and the trend of the latter is steeper than the Non-ESG funds.



Is there a label effect?

Up to 6 months before the labeling the share of GB in funds' portfolios is steadily growing, but the trend becomes less steep once the funds is labeled. There is on average more GB in newly labeled funds portfolios than before the labeling.



Is there a label effect?

We estimate the specifications (3) and (4). The coefficient β indicates by how much the share of GB changes, on average, once the funds have been labeled.

$$Y_{i,t} = \beta \times Event_{i,t} + \alpha_i + \varepsilon_t \tag{3}$$

$$Y_{i,t} = \beta \times Event_{i,t} + \alpha_i + \delta_t + \varepsilon_t \tag{4}$$

Table 2: Panel Data Regression

	Individual fixed effects	Individual and time fixed effects
Event	2.526***	3.344***
	(0.305)	(0.778)
Observations	1,014	1,014
R^2	0.959	0.959
Adjusted R^2	0.956	0.955
Residual Std. Error	4.849 (df = 937)	4.859 (df = 926)
F Statistic	284.292*** (df = 77; 937)	247.819*** (df = 88; 926)

Notes: Values in brackets are the standard errors. signif. codes: 0.01 *** 0.05 **0.1 *.

Concluding remarks

- The findings of this paper on French mutual funds suggest that level-1 NACE appears to be too broad a level of analysis to be used to precisely assess the carbon footprint of mutual funds' portfolios.
- Our work highlights the needs for granular data at the entity-level to precisely estimate not only the carbon footprint of financial institutions, but also the effectiveness of public policies contributing to climate change mitigation.
- Meanwhile, our work suggest that using granular data at the securities level allows to overcome some aforementioned shortcomings. In our opinion, looking at the GB share in portfolios is a good proxy to assess the green content of an investment strategy.

Thank you for your attention

International Conference on "Statistics for Sustainable Finance", co-organised with the Banque de France and the Deutsche Bundesbank

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Accelerated Data Science, AI and GeoAI for Sustainable Finance in Central Banking and Supervision[1]

Jochen Papenbrock, NVIDIA GmbH, Germany; John Ashley, NVIDIA Corp., USA;
and Peter Schwendner, Zurich University of Applied Sciences

[1] This presentation was prepared for the conference. The views expressed are those of the authors and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

Accelerated Data Science, AI and GeoAI for Sustainable Finance in Central Banking and Supervision

Jochen Papenbrock, John Ashley and Peter Schwendner[1]

Abstract

Sustainable finance – the umbrella term for investing based on Environmental, Social, and Governance (ESG) considerations – requires the analysis and integration of massive amounts of complex data – including but not limited to geospatial terrain and elevation data, climate data, company news, market data, regulatory filings, supply chains & logistics. Traditional analytic techniques will not suffice. Here, we lay out the argument for computing platforms and strategies derived from scientific and industrial high-performance computing (HPC) and the emerging field of Artificial Intelligence (AI). We highlight some of the critical considerations in building such systems to support the data analytics and, equally importantly, the controls required to build supervisory systems for sustainable finance. Lessons learned from leading HPC, and AI systems point to GPU accelerated compute as being a key feature of these systems, along with data-centric system design. We also highlight the role of explainable and trustworthy AI as catalysts for accelerated computing and their challenges. Finally, we propose a concrete use case: a cross-regional, shared system that integrates geospatial data with economic and market data to illustrate the benefits of accelerated computing in building these systems.

Keywords: spatial finance, environmental exposures, sustainable finance, central banks, data processing, explainable AI, RAPIDS, ESG

JEL classification: Q58; Q57; Q56; E58; G28; C31; C81

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Contents

Introduction and Overview

Sustainability and Artificial Intelligence (AI) are two of the megatrends that will shape the development of the financial services and the supervisory sector for the near future.

Sustainable finance considers environmental, social, and corporate governance factors when making investment and underwriting decisions. These factors are, in many cases, both qualitative and quantitative; combining this information into a decision-making framework is complex, and best practices are still evolving. While some of the data needed for this is available via standard, machine-friendly sources, a considerable proportion is uncurated and unstructured – in text, images, audio, or video. Artificial Intelligence is the subject of much debate in both definition and execution. Here, we use it to mean systems that learn how to do tasks by repeated training with relevant data, especially in cases where that data may be unstructured (text, speech, images, or video). It is compelling in uncovering and acting on complex patterns in and among datasets.

Collecting sustainable finance data and closing the data gaps will be crucial in implementing data-driven, evidence-based policymaking in areas like micro-prudential supervision, financial stability, macroeconomic analysis, and risk and reserve management. The amount, complexity and innovative character of the required data will pose enormous challenges as the data characteristics need to be aligned with the policy requirements.

Assessing the appropriate level of protection against sustainability risks is a challenge for central banks. Climate risk is the area that gained the most attention during the last 20 years. Public scrutiny is substantial: a legal opinion commissioned by Greenpeace Germany (Verheyen 2021) identifies a liability of ECB and Bundesbank to use monetary policy for sustainability objectives. Dafermos et al. (2021) suggest three policy scenarios to address the climate footprint of bonds in the ECB collateral portfolio.

Despite the massive impacts, the marginal contributions to climate risks are intrinsically difficult to measure accurately, notably due to the radical uncertainty that characterizes climate risks in the form of tipping points, non-linearities and regime shifts. Climate-related financial risks may directly impact central banks' counterparties and financial assets used in monetary policy operations and collateral management.

Beyond climate risks, the commonly accepted sustainable development goals (SDGs) consider environmental risks relating to water quality, deforestation, land use and biodiversity loss. In contrast to climate risks, the impacts of ecological footprints of companies happen in a local context and can have far-reaching consequences along with the supply and value chain. Upcoming regulations like extensions to the Taxonomy for Sustainable Finance will aim for the more forward-looking "net zero loss" instead of the current "do not harm" objective.

Existing sustainability ratings from different providers diverge significantly for the same investable asset (Berg et al., 2019). This implied risk for greenwashing. In position papers and public consultations, IOSCO (2021), FCA (2021) and BaFin (2020) already addressed this risk. A naive solution would be to select just one specific data source for each of the environmental (E), social (S) and governance (G) exposures across investable assets and rely entirely on this assessment. Pedersen et al. (2020) build an ESG-efficient frontier and argue which balances investors with different preferences between Sharpe ratios, and ESG scores will take. They also find a positive risk premium for a governance factor, no significant risk premium for a carbon-based environmental factor and a negative risk premium for a social factor. However, this single selection of ESG data would introduce substantial model risk, which might be inappropriate for more significant exposures, especially for public institutions with a complex structure of stakeholders.

An example in the literature for different interpretations even of the same ESG ratings is (Giese et al. 2021). They find MSCI ESG data to enable investment outperformance, especially for governance ratings and social and environmental ratings. However, (Bruno et al. 2021) find no alpha in the same data after adjusting for equity factor exposures: they attribute 75% of the outperformance to the standard "quality" equity factor that reflects simple financial statements information. They also point out a substantial tech sector bias in ESG ratings and suggest that ESG performance's main drivers are strong tech sector performance and increasing investor attention. These conflicting findings prompted a letter to the FT (Edmans, 6.5.2021) calling for more scientific rigour in ESG evaluation studies.

Therefore, portfolio managers should consider the full set of information to find the optimal portfolio that incorporates all external environmental, social and governance exposures and costs after evaluating diverse and conflicting data sources. From a theoretical viewpoint, the optimal portfolio position would solve a Bayes-optimal classification problem across an ensemble of different models and objectives. To implement such a solution, model ensemble techniques like stacking (Spilak and Härdle 2020) are promising for incorporating information from various sources.

Obviously, for these purposes, standard numerical, tabular and/or time-series data sets need to be combined with alternative data sets, mainly derived by remote sensing (Damm et al., 2020, Santos and Decker, 2020 and Schneider et al., 2017) with a mix of textual and tabular economic and financial data, along with network-based (e.g., transactions, supply chain and geospatial data) information. Patent data analysis can be used to detect investment opportunities in specific sustainable technologies (Guderian et al. 2021).

Even more challenging will be the merging of sustainable data sets with the existing ones used in central bank use cases like business cycle analysis, risk indicators and financial risk assessments, the behaviour of market participants, monitoring financial transactions and capital flows, surveillance exercises, market abuse, flagging misconduct and fraud, assessing system-wide risks. Modern AI tools and techniques can combine these datasets in a technical sense; exactly which datasets to connect and how to interpret the results are open questions.

Sorensen et al. (2021) point out the advantages of a quantitative treatment for ESG investing. They recognize the ESG rating divergence documented by Berg et al. (2019) as an opportunity for active investing. Furthermore, they argue for a quant-based expert system with four advantages relative to a discretionary investment process: better integration with MPT, better integration of big data using natural language processing (NLP), better systemizing into domain knowledge and better replication with digital estimation. Chen et al. (2021) warns of a bias in ESG ratings: companies that publish more ESG data tend to receive better ratings, so investors need to analyze the details of the rating process before including the resulting ratings in an automated investment process. Sokolov et al. (2021) propose an approach that combines modern machine learning techniques in NLP with portfolio optimization to incorporate views of companies' ESG performance. Martellini and Vallée (2021) discuss measuring and managing ESG risks in sovereign bond portfolios and implications for sovereign debt investing.

In implementing policies, monitoring tools, and stress scenarios in individual financial institutions and supervisors, one of the main challenges of this topic area will become acute: The availability and analysis of reliable data.

The collection and evaluation of this data and the establishment of deep insights and links to future policies can only succeed with massive use of new and already established technologies. This is where the two megatrends, Sustainable Finance and AI, that will shape the financial sector in the coming years overlap.

AI computing platforms will play a crucial role here as they are the key technology enabler to implement sustainable finance using AI, big data processing and effective data filtering and data science visualization. Such platforms can enable automation to process the required sustainability data, make insights, and model explanations available to all relevant parties.

Providers of such platforms and the technology companies building solutions on top of them will be the future trusted advisors and key technology providers on the journey to more data and AI-driven central banking, policymaking, and supervision.

These computing platforms need to be designed holistically, providing a scalable path to support growth in data storage, movement, and compute demand while meeting necessary security requirements., New sustainability data always need to be added, usually under high time pressure, requiring new processes and new tools to be integrated into the environment. Otherwise, there is a significant risk of an emerging patchwork of individual solutions. A fragmented IT landscape would not scale sufficiently and therefore would not meet the organization's long-term goals.

Establishing such computing platforms must start from a well-designed base, but evolve in parallel, going hand in hand with the data collection and curation process. Several factors drive this need for a co-evolutionary approach:

1. Data, IT systems, operations and policies must be fully aligned and integrated. As all eventual data sources and data quality and curation processes cannot be known on day one, the architecture must be designed with a degree of flexibility and an expectation that it will evolve over time. Ideally, this evolutionary process will be agile and scalable. There is an adaptive, auditable process to evolving data quantity and quality in which modern AI supports and automates the model building and updating steps, and additional data improves other models. A key issue is to ensure that nowcasts and predictions based on big data are accurate, auditable and interpretable, helping to identify specific explanatory causes or factors. These audibility and interpretability requirements are challenging to retrofit into models and architectures, and again, will need to evolve with the system. The potential to evolve is crucial for the communication and building up trust with the external stakeholders.
2. Visualization of data, models, and tools to create narratives around the models and their results will be increasingly required in direct proportion to the amount of data, variety of datasets, and complexity of the models being deployed. Large scale visualization, clustering and network analysis can support the explorative, visual inspection of substantial amounts of complex data, helping human understanding of complex systems and results.
3. Compute-intensive AI/ML techniques can help improve the data quality, detect outliers and bias in existing datasets. It can also help fill gaps, identify fewer valuable data with a low signal-to-noise ratio or point to data that should potentially receive more attention. An emerging and critical data science field is using AI to create "realistic" synthetic data. This has numerous motivations, like enriching existing datasets, filling gaps, creating adverse and stress data sets, and amplifying models. It can also sometimes be used to enhance explainability. Synthetic data can be calibrated with real data sets, and there are parameters to generate additional data that lies outside of the original distributions but still exhibits similar statistical properties and stylized facts as the original data. Agent-based simulation, using procedural and AI agents, can also be used where underlying assumptions and properties of the data generating processes suggest such an approach.
4. High-Performance Computing (HPC) incorporates general system design principles and platforms allowing organizations to run large-scale mathematical models and simulations. These simulations can include environmental, economic, and financial models to get more insights and understand the relationships. HPC also helps to solve complex multi-objective optimization problems to find the optimal policies under constraints.
5. The size of data and number of sources will increase, and so will the number, complexity, and frequency of updates of models. Storage, networking, compute, and operations will need to evolve with this growth.

There are human and environmental factors involved as well. Data scientists and technical personnel who can develop and manage these systems are expensive and in short supply, so it is also essential to build systems and processes that are efficient with their time. Large computing systems can consume significant amounts of energy, so any system should be as energy efficient as possible.

A modern AI computing platform needs to address the factors identified above. The recent draft of the AI Act of the European Commission characterizes computing platform by the following points:

- Integrated hardware and software stack
- Build and manage robust models at scale in an efficient way
- Include the human user in the process: simplified, transparent, explainable
- Enable strategies for AI model maintenance, risk management and incident management.

Fortunately, modern HPC and AI computing systems address both the European Commission's points and the factors we have identified above. An elementary building block in AI and high-performance computing platforms (HPC) are GPUs – "Graphics processing units". According to the IFC-BIS publication "Computing platforms for big data analytics and artificial intelligence" (see Bruno et al. 2020) ", Central banks' experience shows that HPC platforms are primarily developed to ensure that computing resources are used in the most efficient way, so that analytical processes can be completed as rapidly as possible. [...] A processor core (or "core") is a single processing unit. Today's computers – or CPUs (central processing units) – have multiple processing units, with each of these cores able to focus on a different task. Depending on the analytical or statistical problem at hand, clusters of GPUs (graphics processing units, which have a highly parallel structure and were initially designed for efficient image processing) might also be embedded in computers, for instance, to support mass calculations." Today the superb computing power of GPU clusters is widely used in research where most of the supercomputers are powered with GPUs. Industrial firms and other research organizations have long since adopted GPU computing to address high-performance computing requirements. (e.g. Cambridge 1).

The efficiency of such computing platforms is often measured in floating-point operations per unit of energy consumed. This measure is significant when supercomputing is used in support of Sustainable Finance. GPU-based super-computers lead the global top500 HPC list[2], and many regional GPU-powered leadership class supercomputers are considered 'greenest'[3].

The use case presented in this paper covers alternative, non-tabular data and advanced technologies that will be necessary to address Sustainable Finance and the more traditional statistics and data collection initiatives already underway or currently emerging. We cover approaches that are a mixture of Earth Science and especially geospatial/geostatistical data, geographic information systems (GIS), big spatial data, climate science, scalable high-performance computing, machine learning, artificial Intelligence, deep learning plus professional rendering and visualization, and massive simulation. These techniques are often referenced in the literature as AI-powered systems or platforms delivering on-demand, personalized and actionable Intelligence for enterprises, governments, regulators, and supervisors, using approaches like GeoAI, Climate Intelligence, Geo Knowledge Discovery, and Earth Science AI. Spatial science offers tools and technologies that enable us to understand, analyse, and visualize real-world phenomena according to their locations. Such systems process, analyse and synthesize petabytes of geo-related, sensor-based data to create a unified perspective on critical issues like climate risk at global and individual levels.

(Geo-)Spatial finance offers socio-economic and environmental insights that have the potential to enhance data transparency in the financial system. Sustainability related risks can be better managed when models include geospatial data. It can also assist in the analysis and management of other factors affecting risk and return in different asset classes or central bank collaterals and to support a transition to sustainable development and to monitor environmental and economic activity day and night. These technologies will generate insights and enable us to tackle a wide variety of global challenges in new ways and to forecast the impact of climate change and to respond

[2] https://top500.org/lists/green500/

[3] https://www.hpcwire.com/off-the-wire/meluxina-named-eus-greenest-supercomputer/

to societal challenges. In the financial domain this means that (spatially located) asset owners can verify their investments, asset managers can engage with their investment objects, corporates can verify internal data collection, compare performance with peers, and understand environmental risks and impacts within their supply chains. Regulators will be able to assess environmental and social systemic risks more accurately within the financial system and policymakers will be able to better track progress.

The selection and orchestration of the underlying IT platforms, processing units, and distributed, parallelized computing and algorithms will be crucial to process this kind and quantity of data and to support the policy and decision-making process. Virtualization will allow for faster computing to be accessible from any device anywhere and for remote collaboration. Advanced visualization and rendering allow us to create 3D/4D experiences in support of these efforts. Today it is already possible to create physics-aware, true-to-reality, physics-based simulations with digital landscapes and earth twins, realizing the full technical potential to address spatial, sustainable finance and full technical support for policymaking. Our paper is dedicated to outline and and describe these data and technologies which are already available today and how Sustainable Finance will benefit from them.

The structure of the paper is as follows:

- We cover “Tools, Platforms and Communities to access and develop Sustainability Data” and "Computing Platforms for SupTech, AI Explainability and Compliance".
- Then we present a specific use case for computing platforms in sustainable finance: "Empowering Regions regarding their Environmental Exposures"
- We also attach an Appendix: GPU-Accelerated Data Science and AI Computing Platforms at Central Banks.

Tools, Platforms and Communities to access and develop Environmental Sustainability Data

From the perspective of asset owners, responsibility for getting access to the necessary data for sustainable investing is clearly with their asset managers. Most ESG data providers primarily see asset managers, banks and real-economy corporates as their clients. Beyond the large commercial data providers, specialized technology companies, NGOs and the scientific community also offer platforms and tools. Innovative governments explicitly support fintech companies working on ESG data solutions and connect them with scientific institutions as they recognize the opportunities not only for the environment and for better portfolios, but also specifically for commercial innovation. Examples for state-funded initiatives are the Green Fintech Network[4] assisted by the Swiss State Secretariat for International Finance (SIF) and the Networking Event Series – Sustainable Finance Technology[5] organized by Zurich University of Applied Sciences (ZHAW) and Swiss Sustainable Finance (SSF) and supported by Innosuisse. The Business@Biodiversity[6] platform organized by the European Union is an example of a state-funded community to scale data access and awareness for corporate users. ENCORE[7] is developed by UNEP-WCMC in partnership with the Natural Capital Finance Alliance and funded by the Swiss government and the MAVA foundation. It shows how business sectors depend on ecosystem services and natural capital assets. Currently, it is expanded to also include the impacts on businesses on biodiversity and enables an impact assessment of corporate and financial investments. WWF Sight[8] is a global platform tool including spatial datasets, satellite data, information about species and industrial assets. Restor[9] is a new community-based data platform set up in 2021 specifically for ecosystem restoration projects. It is based on research from the Crowther Lab of ETH. IBAT[10] (Integrated Biodiversity Assessment Tool) is developed by a consortium of BirdLife, Conservation International, IUCN and UN-WCMC. It offers both reports and GIS data downloads based on a database of protected areas and protected and endangered species. IBAT includes the Species Threat Abatement and Restoration (STAR) metric. STAR documents the contribution of specific conservation and restoration actions in specific places by businesses, governments, civil society, and other actors towards global goals for halting extinctions. The geoFootprint[11] initiative launched by Quantis in collaboration with 25 other partner institutions is focused on the life-cycle environmental impact of agricultural crop production. The independent Responsible Mining Foundation (RMF) is focused on ESG impacts of the extractive industry, but announced it will close at the end of 2022[12]. Satelligence is focused on agricultural and industrial impacts on deforestation as this is measurable by remote sensing in high quality. CDC Biodiversité together with Carbon 4 Finance form a French joint venture to offer biodiversity

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[4] https://www.sif.admin.ch/sif/en/home/dokumentation/fokus/green-fintech-action-plan.html

[5] https://www.zhaw.ch/en/sml/institute-zentren/iwa/veranstaltungen/translate-to-english-networking-event-series-sustainable-finance-technology/

[6] https://ec.europa.eu/environment/biodiversity/business/workstreams/methods/index_en.htm

[7] https://encore.naturalcapital.finance

[8] https://wwf-sight.org/

[9] https://restor.eco

[10] https://www.ibat-alliance.org

[11] https://quantis-intl.com/strategy/collaborative-initiatives/geofootprint

[12] https://www.responsibleminingfoundation.org/2022-status-announcement/

exposure assessments for financial sector clients. EconSight[13] analyses technology innovations using ML applied to patent data and therefore contributes to detecting interesting investment targets also in the sustainable technology space. RepRisk and Truevalue labs are established sophisticated ESG data platforms running large-scale news-based ML analytics.

Establishing forward thinking and efficient market structures on the implementation of sustainable financing strategies is a goal of the 'Green and Sustainable Finance Cluster Germany"[14] which is also part of the FC4S Network[15] where green finance is a central theme of the agenda, including the question of "how could financial centres contribute to the delivery of the Sustainable Development Goals and the Paris Agreement?". The Impact Festival[16] is a platform for sustainable technologies and innovations.
The Financial Big Data Cluster (FBDC) is the use case in the financial domain of European GAIA-X initiative. The FBDC represents the central use case for the financial sector. Closely linked to the establishment of the cluster is the research and development project "safeFBDC." During the safeFBDC project, data sets will be used to create five applications that will be researched, developed and prototypically validated using artificial intelligence and machine learning. One of the applications is on Sustainable Finance. The aim is to improve the currently often insufficient availability and quality of ESG data and to establish a local ESG data platform. The central approach is to test and further develop innovative AI and ML methods both to close identified ESG data gaps and to develop new methods for ESG data generation. Financial market participants, especially banks, should thus be able to better integrate sustainability risks into their operational risk modeling and relevant decision-making processes[17]. A related project is the Financial AI Cluster (FAIC[18]) addressing one of the central topics in the Finance & Insurance Data Space of GAIA-X, namely the implementation of trustworthy, explainable AI, AI Assurance and AI Audit based on computing platforms.
The Spatial Finance Initiative[19] has been established by the Alan Turing Institute, Satellite Applications Catapult, and the Oxford Sustainable Finance Programme to bring together research capabilities in space, data science and financial services and make them greater than the sum of their parts. 'Spatial finance' is the integration of geospatial data and analysis into financial theory and practice[20]. Earth observation and remote sensing combined with machine learning have the potential to transform the availability of information in our financial system. It will allow financial markets to better measure and manage climate-related risks, as well as a vast range of other factors that affect risk and return in different asset classes.
The BRIDGE Discovery project 'Spatial Sustainable Finance'[21] run by Zurich University of Applied Sciences and University of Zurich aims to set a global rating standard that enables financial institutions and companies to reduce their water and biodiversity footprint.

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[13] https://www.econsight.ch

[14] https://gsfc-germany.com/en/

[15] https://www.fc4s.org/about/

[16] https://impact-festival.earth/

[17] https://www.fs-unep-centre.org/project/financial-big-data-cluster-fbdc-use-case-sustainable-finance-susfi/

[18] https://www.data-infrastructure.eu/GAIAX/Redaktion/EN/Blog/2020-12-16-the-innovation-potential-of-gaia-x-technologies-for-the-trusted-use-of-artificial-intelligence-in-the-finance-sector.html

[19] https://www.cgfi.ac.uk/spatial-finance-initiative/

[20] https://www.refinitiv.com/perspectives/ai-digitalization/using-spatial-finance-for-sustainable-development/

[21] https://www.spatial-sustainable-finance.ch

The Future of Sustainable Data Alliance[22] is looking to answer the question "What data do investors and governments need to deploy capital sustainably and in line with the requirements of regulators, citizens and the market now and in the future?" GeoWorks[23] is Southeast Asia's first geospatial industry centre.
We also see the first combined platforms for banks and insurers that are both dedicated to socially responsible investment (SRI) and compliant with the principles of transparent artificial intelligence as set out in the proposed European regulation[24], respecting the European principles of autonomy, interpretability, explicability, transparency, responsibility and robustness.. The platform combines algorithmic know-how with expertise in data management and decarbonization. Based on artificial intelligence and deep learning, the solution leverages financial and extra-financial data, including accurate and standardized ESG data. The attention paid to data integrity, combined with advanced management tools, allows the design, large-scale deployment and management of transparent machine learning models. Additionally, the models can be manually modified to take into account company policies and regulatory obligations (e.g. the European regulation on green finance SFDR).
There are other platforms that gives users access to real-time geo Copernicus satellite data and enables them to combine it with their own data and tools, to build new innovative products and services that integrate accurate and real-time information from satellites[25].
Monitoring risks in real-time is a classical task for NLP to support human analysts with. It is important to constantly monitor news and trends that could impact different markets around the globe. A data gathering and processing solution is needed that reduces the workload while keeping the quality of the information a risk analyst has to monitor on a daily basis. News and articles are automatically summarized and analyzed to be able to monitor hundreds of entities and real-time[26].
There are also real-Time ESG insights from vast amounts of structured and unstructured data with a no-code data science platform[27], using techniques like adaptive Natural Language Processing (NLP)[28]. In this way, native language extraction in dozens of languages can real-time coverage of public and private companies can be achieved. NLP can be used to tracking of climate impact and controversies, to anticpate risk and generate ESG scores, to detect ethical and social impacts, and to increase ESG transparency.
NLP platforms convert unstructured information into structured data and NLG (Natural Language Generation) turns this data into stories[29] and narratives. The following NLP-related technqiues can be used for ESG-related analyses: knowlegde graph, market sentiment, named entity recognition, summarization, question answering, topic modelling/clustering, patent and enterprise search, knowledge graphs, synonym search, etc.
Other platforms are dedicated to build Climate Intelligence[30]. Climate Intelligence is mass intelligence for managing climate decisions on valuable assets. providing insight into how risks such as flooding, droughts, and extreme temperatures will impact these assets.

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[22] https://futureofsustainabledata.com/

[23] https://www.geoworks.sg/

[24] https://atos.net/en/2021/press-release_2021_04_21/atos-and-dreamquark-advance-responsible-finance-with-transparent-artificial-intelligence

[25] https://atos.net/en/2018/press-release_2018_06_21/atos-announces-satellite-data-platform-mundi-now-live

[26] https://tryolabs.com/work/allianz-GI/

[27] https://accern.com/esg-investing

[28] https://accern.com/adaptive-nlp

[29] https://www2.deloitte.com/us/en/insights/industry/financial-services/natural-language-processing-investment-management.html

30 https://www.linkedin.com/company/cervest/

Other platforms are capable of linking the sustainability factors to business performance. They combine AI and ESG big data to assess the performance and sustainability of corporations and to evaluate the alpha impact of sustainability, using self-learning quantitative models[31].
ESG data science leverages the combination of AI and machine learning with human intelligence to systematically analyze public information and identify material ESG risks[32].

[31] https://www.arabesque.com/ai/

[32] https://www.reprisk.com/

Computing Platforms for SupTech, AI Explainability and Compliance

The mandate of central banks and financial supervisors has become challenging. Pandemics, economic instability, cyber risks, sanctions, climate change, and sustainable investing are just a few examples of complex, emerging risks. Also, the digital, technological disruption of the financial ecosystem, as well as the speed of change and the growing complexity of the industry and its unbundling, increase the likelihood of supervisory blind spots.

For this reason, regulators will need to significantly adapt their operating model over the next decade to include technology and collaboration with (fin)tech firms. Many regulators are beginning to move in this direction with a variety of initiatives. Big Data Analytics, ML and AI will play a critical role, for example, in improving the quality and timeliness of risk identification and monitoring. Central banks already have access to vast amounts of valuable data, drawn from traditional, structured, and unstructured sources; streaming, complex, multi-layered, and alternative data to provide a holistic picture. Using advanced data collection and analytics techniques, certain areas of supervision will be able to use real-time monitoring of emerging risks and generate much earlier warning signals. Regulators will be able to nearcast the developments and provide a holistic picture of issues but also will be able to drill down into more granular micro developments and trends.[33]

While the authors (nor the firms with which they are affiliated) do not endorse all these points, they do offer valuable insights into areas of supervisory concern and identify valuable topics for discussion. According to a speech (https://www.bis.org/review/r180307d.htm) on AI and Banking by Prof. Joachim Wuermeling, Member of the Executive Board Deutsche Bundesbank, held at the 2nd Annual FinTech Conference in Brussels, there are six 'warnings' for supervisors sone of which we would like to highlight in this context:

- Do not miss the opportunities of Artificial Intelligence in finance … – Human shortcomings in dealing with finance can be mitigated. As behavioral finance has taught us, biases, inertia, and ignorance lead to the malfunctioning of markets. AI allows humans to reach out beyond their intellectual limits or simply avoid mistakes.
- Central banks should embrace Artificial Intelligence – Central banks have access to vast amounts of valuable data stemming from market operations, supervision, payments, and statistics. They are well-positioned to tap the benefits of AI so they can enhance their ability to fulfil their mandate for price stability and the stability of the financial system.

The Bank of International Settlements (BIS) has published a survey report on the application of big data by central banks (see Serena et al. (2021)) with the following main conclusions:

Central banks have a comprehensive view of big data, they are increasingly using it, the range of big data sources exploited is diverse, and is effectively used to support central bank policies. Most central banks also report using big data for micro-level supervision

[33] For further reading and on the future of central banking see the following resources:

- https://www.oliverwyman.com/content/dam/oliver-wyman/v2/publications/2019/feb/Oliver-Wyman_Supervising-Tomorrow.pdf
- https://www.oliverwyman.com/our-expertise/insights/2020/apr/risk-journal-vol-9/redefining-business-models/future-proofing-financial-supervision.html
- https://www.oliverwyman.com/content/dam/oliver-wyman/v2/publications/2020/apr/future-proofing-financial-supervision.pdf
- https://www.forbesmiddleeast.com/leadership/opinion/how-big-data-and-ai-are-hailing-a-new-future-for-finance

and regulation. The survey also underscored the need for adequate IT infrastructure & human capital.

Supervisory Technology and Sustainable Finance Technology will be key topics in the digitalization of financial supervision (see Zeranski and Sancak (2020)).

A key issue in financial big data will be interpretable modelling. This is because to make evidence-based policy decisions central banks need to identify specific explanatory causes or factors which they can take action to influence. Furthermore, transparency regarding the information produced by big data analysis is essential to ensuring that its quality can be checked and that public decisions can be made on a sound, clearly communicated basis. Lastly, there are important legal constraints that reduce central banks' leeway when using private and confidential data; interpretable modelling helps address all these issues.

The focus of ML/AI models in central banking and supervision cannot be just predictive accuracy. Models must be trustworthy, interpretable, explainable, interactive, fair, robust, accountable, and secure. Proper risk management, data/AI governance, and compliance must be in place. For an in-depth description see Deutsche Bundesbank (2020).

A bank, commercial bank or supervisor using AI in production needs to overcome the explainability gap to produce transparent, appropriate governance, risk management, and controls over AI. The publication "Financial Risk Management and Explainable, Trustworthy, Responsible AI" (Fritz-Morgenthal et al. 2021) discusses further details.

More specific use cases can be found, moving the discussion from the realm of the general to the specific. One related use case can be found in Bussmann et al. (2020). The use case had been selected as the best AI case in the EU Horizon2020 project FIN-TECH (www.fintech-ho2020.eu) by the European financial services community including the European supervisors. Other related Explainable AI (XAI) use cases can be found in Jaeger et al. (2021) and Papenbrock et al. (2021). The developed approaches can help to implement Explainable AI using techniques like SHAPley values (a local, and global variable importance method with mathematical footings in co-operative game theory) even for large and complex models. For classical datasets, these methods can already substantially improve the transparency of portfolio allocation processes. They also enable the visualization of the variables and their influences of the entire data set in a single analysis. Clustering and network analysis of the variables and their influences are often used to find overall model structure and connections. Real-time monitoring of model drift in continuous learning machines is applied. Simulations and perturbations to test the robustness of the model can be run at large scale. Iterative and evolutionary approaches are now able to create and evaluate millions of models, allowing supervisors to select those that best balance prudential goals. It will also be necessary to meet the upcoming requirements from the European AI Act, especially the technical and auditing requirements for High-Risk AI[34]:

- Creating and maintaining a risk management system for the entire lifecycle of the system.
- Testing the system to identify risks and determine appropriate mitigation measures, and to validate that the system runs consistently for the intended purpose, with tests made against prior metrics and validated against probabilistic thresholds.
- Establishing appropriate data governance controls, including the requirement that all training, validation, and testing datasets be as complete, error-free, and representative as possible.
- Detailed technical documentation, including around system architecture, algorithmic design, and model specifications.
- Automatic logging of events while the system is running, with the recording conforming to recognized standards.
- Designed with sufficient transparency to allow users to interpret the system's output.

[34] See https://datainnovation.org/2021/05/the-artificial-intelligence-act-a-quick-explainer/

- Designed to maintain human oversight at all times and prevent or minimize risks to health and safety or fundamental rights, including an override or off-switch capability.

In summary, meeting the overall combination of the supervisory, legal, diverse stakeholder, and technical requirements will drive model development, deployment, monitoring and retirement process that features enhanced auditability, transparency, and explainability. The ever-increasing data volume, velocity, and variety – across structured and unstructured sources – combined with the rapid pace of AI development will drive an overall system architecture that is scalable, flexible, and secure. To be efficient with both people's time and energy, the system must strongly adopt lessons learned in the leading HPC and AI supercomputers of today, leveraging GPU accelerated compute and networking that can accelerate workloads across the diverse, end-to-end data science use cases of today and tomorrow.[35]

[35] For additional information, see "Computing Platforms for Big Data Analytics and Artificial Intelligence" (Bruno et al. (2020)), which highlights the experiences of central banks with respect to HPC platforms.

Use Case: Empowering Regions regarding their Environmental Exposures

We suggest an open-source-based accelerated platform to empower regions to join forces to tackle similar environmental challenges, to quantify and track changes in their environmental exposures in time, and to identify groups of regions with similar ecological exposures for policy and risk assessment purposes. Any common features and insights will also support more consistent and reliable supervisory analysis and reporting against sustainability goals.

Introduction

Legislation is provided on a national or supranational level, but the actual impact of environmental exposures happens on a regional level, as does the operational implementation of environmental protection. Regions with similar environmental challenges are interested in collaborating to exchange experiences, improve their negotiation leverage, and support each other in joint projects or ad-hoc emergencies like floods or wildfires. Improved transparency of regions' environmental exposures can also help decrease insurance and funding cost for public or private purposes.

Our suggested platform allows stakeholders to quickly build and deploy accelerated applications for large data sets of environmental exposures such as climate, deforestation, land use and population. It supports financial institutions, corporates, regulators, and supervisors (e.g., central banks) to visualize, assess and monitor the current and evolving physical risks at the level of regions and groups of regions with similar environmental exposures. This will allow regions, firms, and regulators to evaluate environmental risks more quickly, accurately, and more easily connect these risks to other macro and financial risks.

The tool's first objective is to quantify environmental exposures of regions using multiple layers of raster data from remote sensing with varying spatial resolutions as inputs. We apply unsupervised and semi-supervised learning to cluster regions based on the quantified environmental features within their borders. The identified region clusters can be used for coordinated policy development and implementation as well as for relative risk assessments even though the regions within the clusters may be geographically separated. Our proposed process allows connecting global raster data from diverse sources with macroeconomic and financial data to include environmental considerations into country risk analysis and policy considerations.

The tool's second objective is visualization. Large data from multiple sources can be interactively analysed on an ad-hoc basis without the need to pre-aggregate the population or use data subsets. The cluster analysis results from the machine learning steps are also displayed in the interactive dashboards and the macro and financial data per cluster.

The required High-Performance Computing (HPC) is done with GPUs: Graphics Processing Units. As we have mentioned previously, this allows us to take advantage of a variety of state-of-the-art tools, deliver faster time to insight, manage large and diverse datasets – all in an energy efficient fashion.

Data

Geospatial environmental data layers derived from satellite measurements have a raster format and need to be connected and enriched with relevant country and sector data to allow decision-makers from the public and private sectors analysis. The raster data is collected and displayed at open access sites like https://globalforestwatch.org or https://earthdata.nasa.gov/ but not yet further connected or processed. The open-access data contains a variety of data: land cover (tree cover, primary forests, tree cover height, forest landscape integrity indices, tree plantations and mangrove forests) land use (concessions for logging, mining, oil palm plantations and mills, oil, gas, and wood fiber; major dams; indigenous and community lands, population density and resource rights) climate change measurements (carbon flux, carbon density, potential carbon gains). Restor[36] is a data platform specifically for ecosystem restoration projects.

The data are of varying global coverage, spatial resolution, spatial granularity, and time resolution across datasets and sometimes even within one dataset. Therefore, evaluation across data layers and across time is not a trivial task.

Methodology

To connect the environmental raster data with region-specific data, we apply an unsupervised learning approach:

1. For each environmental data layer, and for each snapshot in time: Project raster image data to a political map.
2. Compute the mean raster values within the boundary of each region. This leads to regional features as their mean raster value, i.e., to a table (rows: regions, columns: mean raster values of each feature layer).
3. Cluster regions by the similarity of their feature vectors.
4. Characterize the regions by their mean feature vectors across all regions of this cluster.
5. Enrich cluster features with regional macro data and financial market data within the clusters.
6. Determine changes in cluster composition and cluster characteristics in time to allow for a cross-sectional comparison of regions and groups of regions.

Implementation and Technology Platform

Licensed under Apache 2.0, the RAPIDS suite of open-source software libraries and APIs gives the ability to execute end-to-end data science and analytics pipelines entirely on GPUs, including data engineering and preparation, ML/AI, graph analytics, cross-filtering, and visualization. RAPIDS exposes GPU parallelism and high-bandwidth memory speed through user-friendly Python interfaces. See the appendix for further information.

Cuxfilter is a real-time cross-filtering library on GPUs. This empowers data scientists to extract valuable insights by working independently across the whole stack — from raw data to user interface — and quickly deliver interactive dashboards without the need for large developer and IT teams. Computed live using GPUs, there is no need to pre-aggregate the population or use data subsets.[37]

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[36] https://restor.eco

[37] Related visualization examples from developer blogs:

- https://developer.nvidia.com/blog/interactively-visualizing-a-drivetime-radius-from-any-point-in-the-us/
- https://developer.nvidia.com/blog/an-interactive-2010-census-plotly-dash-visualization-accelerated-by-rapids/
- https://medium.com/rapids-ai/plotly-census-viz-dashboard-powered-by-rapids-1503b3506652
- Related videos on the visualization technologies proposed: https://www.youtube.com/watch?v=3tSLwK8p210 (covid related dashboard w/ plotly

Appendix: GPU-Accelerated Data Science and AI Computing Platforms at Central Banks

Data science workflows have traditionally been slow and cumbersome, relying on CPUs to load, filter, and manipulate data and train and deploy models. GPUs reduce infrastructure costs and provide superior performance for end-to-end data science workflows using RAPIDS open-source software libraries. GPU-accelerated data science and AI workloads is available regardless of the location where GPUs are deployed, whether in the laptop, the workstation, in the data center, at the edge or in the public cloud.

In the following we will briefly discuss some use cases based on large financial data that benefit from several aspects of a GPU accelerated computing platform. The reference architecture is the following: enterprise-class GPUs using the Ampere Architecture (A100), featuring CUDA and Tensor cores, ultra-high memory bandwidth, NVLink for inter-GPU communications and the resource sharing and security isolation feature called MIG. Details are provided in Choquette et al. (2021). It is impossible to analyse the given amount of data in reasonable timeframes with traditional non-accelerated systems based on conventional CPUs.

- Using large-scale accounting data for financial statement audits: monitoring trustworthiness of financial statements and detecting potential misstatements by applying neural networks to learn representations of accounting data that constitute a representative audit sample and using these systems to detect potential anomalies.

- Deep learning (DL) for anomaly detection methods is used to identify opportunities and risks across many industries. Accurate methods are required to produce actionable predictions that don't simply add to an already noisy data environment. These techniques are especially applicable in fighting financial crimes like fraud and AML.

- Accelerating deep learning product recommendations with the transformer-based model BERT: a deep learning-based product recommendation system that provides a personalized ranked list of products to their sellers that help them to manage, run, and grow their business in the most efficient way possible.

- Neural networks for exotic options and risk: complex derivative modelling can be significantly accelerated using GPUs and neural nets. The unavailability of analytical solutions, the higher dimensionality for complex interest-rate and foreign-exchange products (volatility surfaces, multiple curves), and the requirements to compute sensitivities for hedging pose unique challenges. The oracles of traditional modelling can do complex computations, but they are expensive and slow, and are traditionally done on computer grids overnight. A modern GPU accelerated computing platform can obtain accurate valuations in well under a second. Buehler et al. (2019) developed deep hedging approaches to replace sensitivities-based hedging with reinforcement learning.

- The application of generative adversarial networks (GANs) for simulating market data for direct predictive analytics or for training other machine learning models. Generative adversarial networks are one tool for developing synthetic financial datasets that can be used as training data across many classes of machine learning models. GANs can complement and augment the value of Monte Carlo simulations and replicate regime-specific conditions to better prepare models for more robust predictive analytics. Using a generator and discriminator, with care, the model will transition the simulated data so that it converges to an empirical distribution in a Nash or Quasi-Nash process, preserving more of the real-world temporal characteristics consistent with the targeted market regime.

For DL workloads, GPU-based computing platforms have set records for the MLPerf[38] benchmark (an industry-standard set of benchmarks across a variety of AI modelling tasks), handily surpassing all other commercially available systems (see Mattson et al. (2020)). Comparable results are documented with respect to the STAC-A2™ Benchmark suite[39] which is the industry standard for testing technology stacks used for compute-intensive analytic workloads involved in pricing and risk management.

According to Li et al. (2020), gaining performance from multi-GPU scaling is not trivial, mainly because traditionally, inter-GPU communication shares the same bus interconnect as CPU-GPU communication, such as PCIe. This situation changed with the introduction of NVIDIA's DGX server line due to the introduction of dedicated GPU-oriented interconnects such as NVLink, and NVSwitch. The NCCL library allows multiple applications to efficiently optimize their communications within and across systems at the software layer. NCCL automatically understands the underlying hardware network topology to enable orchestrated mapping of functions and updates; it handles the issue of synchronization, overlapping and deadlock; and allows applications to prefer different performance metrics (e.g., latency-oriented for small transfers but bandwidth-oriented for large transfers).

RAPIDS

The RAPIDS software suite of open source[40] accelerated Python libraries give the ability to execute end-to-end data science and analytics pipelines entirely on GPUs. Integration into existing workflows normally requires only a few lines of code, because its API was deliberately designed to be consistent with existing data science utilities (e.g., Pandas DataFrame, SciKit Learn). RAPIDS is incubated by NVIDIA based on extensive hardware and data science experience both internal to NVIDIA and from customers and other contributors. RAPIDS wraps NVIDIA CUDA primitives for low-level compute optimization and exposes GPU parallelism and high-bandwidth memory speed through user-friendly Python interfaces. RAPIDS focuses on common data preparation tasks for analytics and data science. This includes a familiar data framedataframeintegrates with a variety of machine learning algorithms for end-to-end pipeline accelerations without paying typical serialization costs. RAPIDS also includes support for multi-node, multi-GPU deployments, enabling vastly accelerated processing and training on much larger dataset sizes. RAPIDS projects include cuDF, a pandas-like dataframe manipulation library; cuML, a collection of machine learning libraries that will provide GPU versions of algorithms available in scikit-learn; and cuGraph, a NetworkX-like accelerated graph analytics library. RAPIDS also provides tight integration with the key deep learning frameworks. This means data processed by RAPIDS can be seamlessly pushed to deep learning frameworks that accept an array interface or work with DLPack, such as Chainer, MXNet, and PyTorch.

RAPIDS democratizes the power of GPU accelerated data science for everyone with observed accelerations from CPU to GPU that can range from a factor of 10x to 1000x in some cases.

According to Entschev, Kirkham, and Ronaghi (2020), the Oak Ridge Leadership Computing Facility (OLCF) provides a variety of tools to perform data wrangling and data analysis tasks, CPU-only Python based tools often lack scalability, or the ability to fully exploit the computational capability of OLCF's Summit supercomputer. OLCF started a detailed performance evaluation on NVIDIA RAPIDS and Dask and to exploit how it helps to distribute data analytics workloads from personal computers to heterogeneous supercomputing systems. The performance evaluation of NVIDIA RAPIDS also included a subset of RAPIDS libraries, i.e., cuDF, cuML, and cuGraph, and Chainer's CuPy, and their multi-GPU variants when available.

[38] https://mlcommons.org/en/

[39] https://stacresearch.com/

[40] Apache 2.0 License

According to Liu, Tunguz, and Titericz (2020), RAPIDS has been proven to be a very efficient for black-box optimization algorithms. According to the paper the authors implemented a fast multi-GPU accelerated exhaustive search on the DGX-1 to find the best ensemble of optimization algorithms. The ensemble algorithm has been generalized to multiple optimizers and the proposed framework scales with multiple GPUs. They evaluated 15 optimizers by training 2.7 million models and running 541,440 optimizations. On a DGX-1, the search time is reduced from more than 10 days on two 20-core CPUs to less than 24 hours on 8-GPUs. Multi-GPU-optimized framework to accelerate a brute force search for the optimal ensemble of black-box optimization algorithms by running many experiments in parallel.

According to Yang, Buluc, and Owens (2020), there is a mismatch between the high-level languages that users and graph algorithm designers would prefer to program in (e.g., Python) and programming languages for parallel hardware (e.g., C++, CUDA, OpenMP, or MPI). To address this mismatch, many initiatives, including NVIDIA's RAPIDS effort, have been launched in order to provide an open-source Python-based ecosystem for data science and graphs on GPUs.

Ocsa (2019) present BlazingSQL, a SQL engine build on RAPIDS open-source software, which allows accelerated query of enterprise data lakes with full interoperability with the RAPIDs stack.

According to Richardson et al. (2020), the lines between data science (DS), machine learning (ML), deep learning (DL), and data mining continue to be blurred and removed. This ushers in vast amounts of new capabilities, but it also brings increased complexity and a vast increase in the number of tools/techniques that must be learned. It is common for DL engineers to use one set of tools for data extraction/cleaning and then pivot to another library for training their models. After training and inference, it is common to then move data yet again to another set of tools for post-processing. The RAPIDS suite of open-source libraries not only provide a method to execute and accelerate these tasks using GPUs with familiar APIs, but it also provides interoperability with the broader open-source community and DL tools while removing unnecessary serializations that slow down workflows. GPUs provide massive parallelization that DL has leveraged for some time, and RAPIDS provides the missing pieces that extend this computing power to more traditional yet important DS and ML tasks (e.g., ETL, modelling). Complete pipelines can be built that encompass everything, including ETL, feature engineering, ML/DL modelling, inference, and visualization, all while removing typical serialization costs and affording seamless interoperability between libraries. All experiments using RAPIDS can effortlessly be scheduled, logged and reviewed using existing public cloud options.

RAPIDS SPARK 3.0

Given the parallel nature of many data processing tasks, it's only natural that the massively parallel architecture of a GPU should be able to parallelize and accelerate Apache Spark data processing queries, in the same way that a GPU accelerates deep learning (DL) in artificial intelligence (AI). NVIDIA has worked with the Apache Spark community to implement GPU acceleration through the release of Spark 3.0 and the open-source RAPIDS Accelerator for Spark[41]. The RAPIDS Accelerator for Apache Spark uses GPUs to:

- Accelerate end-to-end data preparation and model training on the same Spark cluster.
- Accelerate Spark SQL and DataFrame operations without requiring any code changes.
- Accelerate data transfer performance across nodes (Spark shuffles).

As ML and DL are increasingly applied to larger datasets, Spark has become a commonly used vehicle for the data pre-processing and feature engineering needed to prepare raw input data for the learning phase. Because Spark 2.x has no knowledge about GPUs, data scientists and engineers perform the ETL on CPUs, then send the data over to GPUs for model training.

The Apache Spark community has been focused on bringing both phases of this end-to-end pipeline together, so that data scientists can work with a single Spark cluster and avoid the performance penalty of moving data between Spark based systems for data preparation and PyTorch or TensorFlow based systems for Deep Learning. Apache Spark 3.0 represents a key milestone, as Spark can now schedule GPU-accelerated ML and DL applications on Spark clusters with GPUs, removing bottlenecks, increasing performance, and simplifying clusters. In Apache Spark 3.0, you can now have a single pipeline, from data ingest to data preparation to model training on a GPU powered cluster.

NGC

The NVIDIA GPU Cloud (NGC)[42] is a container repository with GPU optimized container images for popular Deep Learning and machine learning frameworks and comes bundled with the CUDA and DL libraries. With the introduction with NVIDIA NGC, deployment and development was dramatically simplified as described in Radhakrishnan, Varma, and Kurkure (2019). The traditional non-virtualized approach typically is to access GPU in bare-metal or native environments. This entails installing the DL software stack (DL framework, libraries, CUDA libraries) along with the GPU drivers on the bare metal system. A containerized DL solution bundles the DL framework, referenced run-time libraries and CUDA libraries in a tested, supportable container for ease of deployment and portability.

[41] https://nvidia.github.io/spark-rapids/

[42] https://www.nvidia.com/en-us/gpu-cloud/

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Accelerated Data Science, AI and GeoAI for Sustainable Finance in Central Banking and Supervision

Int. Conference on Statistics for Sustainable Finance (14th & 15th Sept 2021)

Session 5: Leveraging Innovation

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LEVERAGING INNOVATION

Abstract

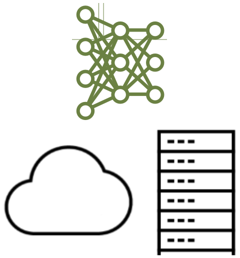
- Sustainability and Data Science / Artificial Intelligence (AI) are the two megatrends in FSI and supervision
- Use of massive amount of complex data
- Demand for computing platforms, HPC, and 'AI'
- We see systems with data centric design, explainable/trustworthy AI models, GPU acceleration as key feature,
- Practical examples in ESG investing and data-driven policy design and investment/risk management

TRANSFORMED SUPERVISORY MODELS

Supervisory Technology (SupTech)

- synthetizes the vast quantities of structured and unstructured data
- improves actuality and timeliness (‘real-time’) of (emerging) risk identification, monitoring, early warning/intervention.
- supports both ‘full picture’ as near cast and granular, zooming level
- The same applies to Sustainable Finance Technology

NEED FOR COMPUTING PLATFORM



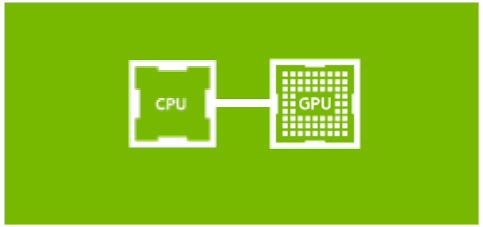
Establishment of computing platforms going hand in hand with the data collection and curation process. Several factors drive this need for a co-evolutionary approach:

1. Data, IT systems, operations and policies must be fully aligned and integrated: adaptive, auditable process to evolving data quantity and quality; validation, interpretability, narrative
2. filling data gaps and improve data quality (outliers)
3. HPC for simulating data and for complex optimization
4. large scale visualization, clustering and network analysis for data exploration
5. size of data and number of sources will increase, and so will the number, complexity, and frequency of updates of models

Compliance with the proposed AI Act for high-risk AI might also require a computing platform

RISE OF GPU COMPUTING

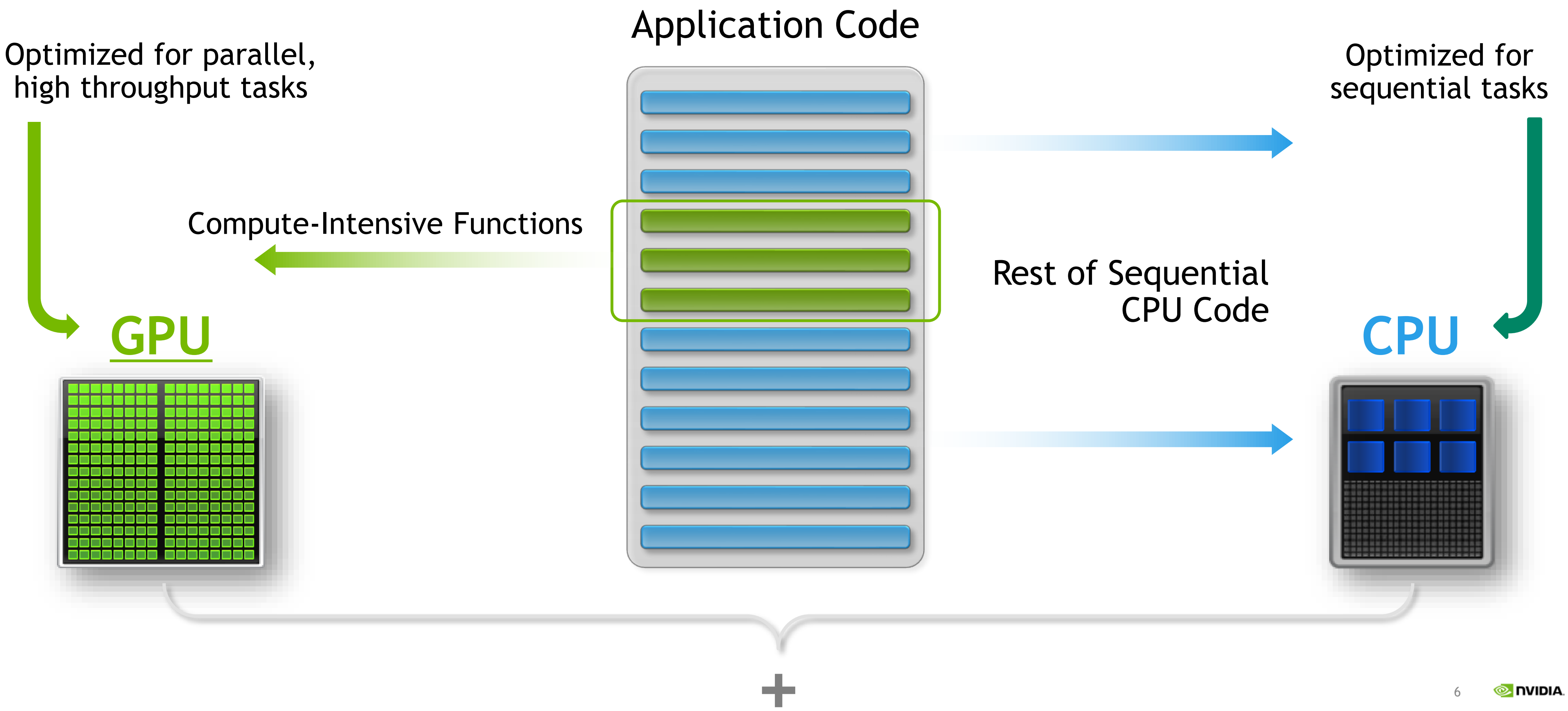
'Computing platforms for big data analytics and artificial intelligence.'
IFC Reports 11. Bank for International Settlements.
https://ideas.repec.org/p/bis/bisifr/11.html



"Central banks' experience shows that HPC platforms are primarily developed to ensure that computing resources are used in the most efficient way, so that analytical processes can be completed as rapidly as possible. […]

A processor core (or "core") is a single processing unit. Today's computers – or CPUs (central processing units) – have multiple processing units, with each of these cores able to focus on a different task. Depending on the analytical or statistical problem at hand, clusters of GPUs (graphics processing units, which have a highly parallel structure and were initially designed for efficient image processing) might also be embedded in computers, for instance, to support mass calculations"

HOW GPU ACCELERATION WORKS



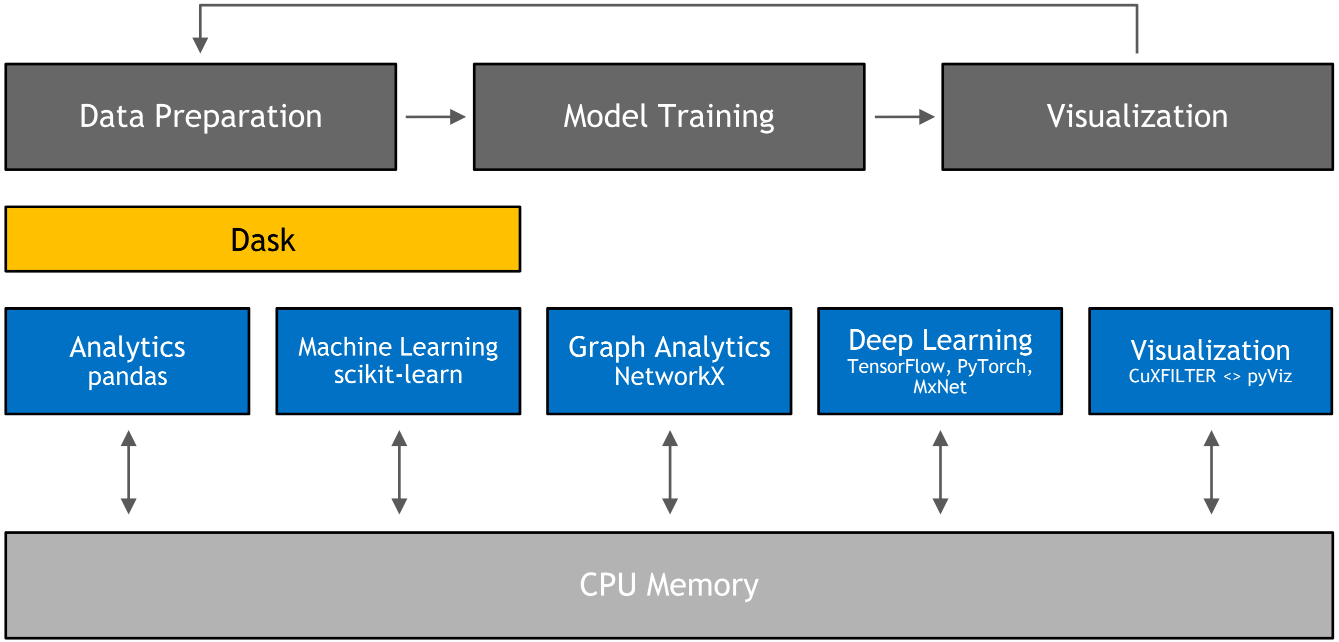
PYTHON TOOLS HAVE DEMOCRATIZED DATA SCIENCE

ACCESSIBLE, EASY TO USE TOOLS ABSTRACT COMPLEXITY

Python is the most-used language in Data Science today. Libraries like NumPy, Scikit-Learn, and Pandas have changed how we think about accessibility in Data Science and Machine Learning.

While great for experimentation, PyData tools lack the power necessary for enterprise-scale workloads. This leads to substantial refactoring to handle the size of modern problems, increasing cycle time, overhead, and time to insight.

These pain points are further compounded by computational bottlenecks of CPU-based processing.



Code refactors and inter-team handoffs decrease data-driven ROI

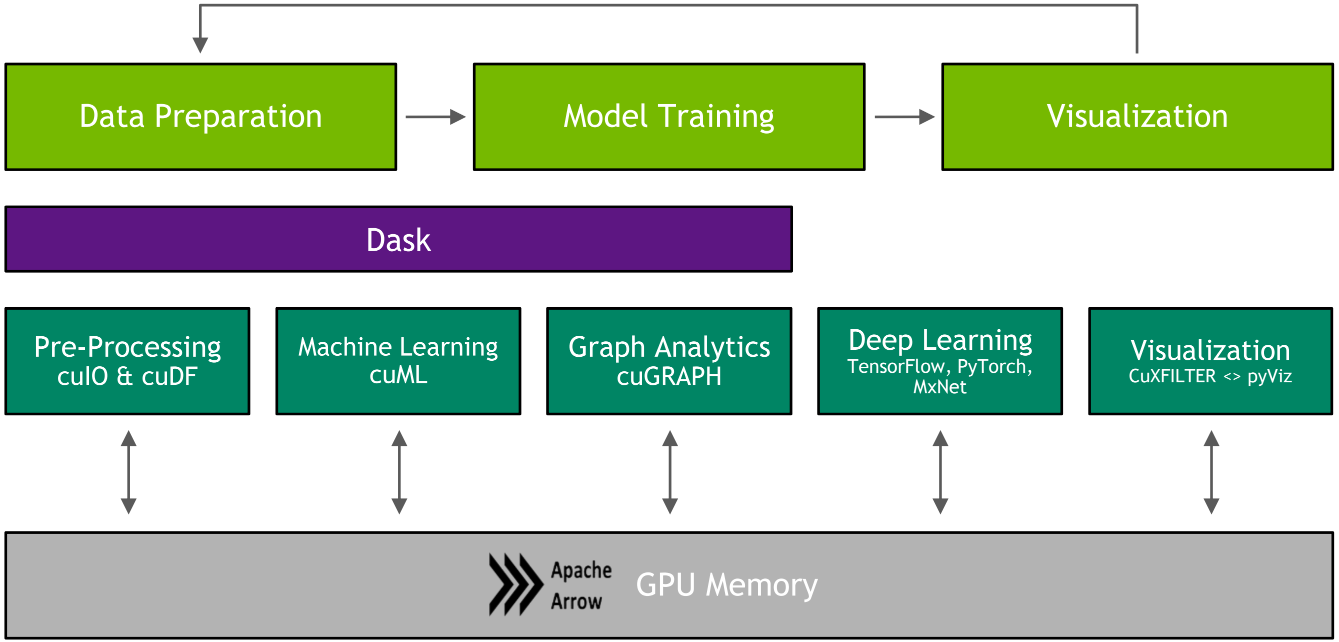
RAPIDS ACCELERATES POPULAR DATA SCIENCE TOOLS

DELIVERING ENTERPRISE-GRADE DATA SCIENCE SOLUTIONS IN PURE PYTHON

The RAPIDS suite of open source software libraries gives you the freedom to execute end-to-end data science and analytics pipelines entirely on GPUs.

RAPIDS exposes GPU parallelism and high-bandwidth memory speed through user-friendly Python interfaces like PyData.

With Dask, RAPIDS can scale out to multi-node, multi-GPU cluster to power through big data processes.



RAPIDS enables the PyData stack with the power of GPUs

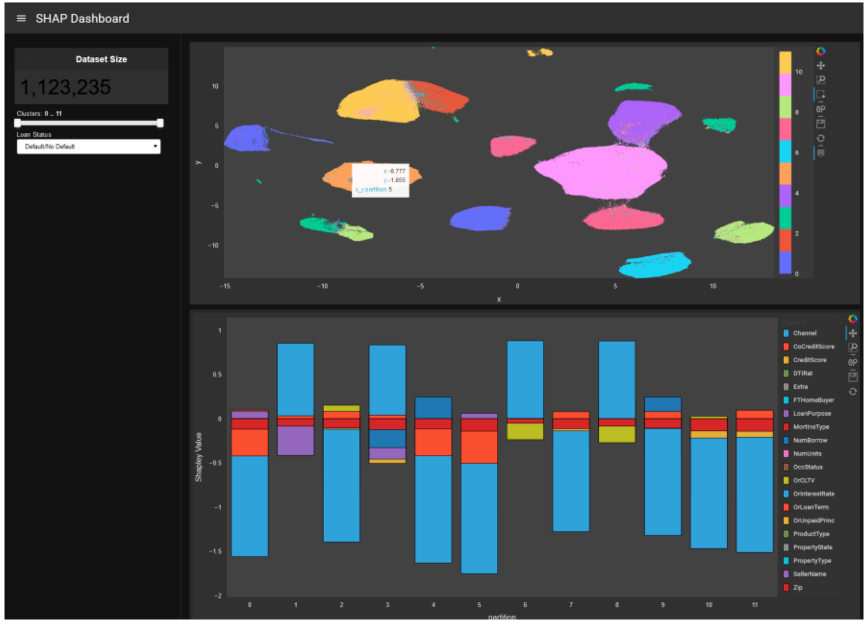
XAI USE CASE ON ENTERPRISE PRODUCTION LEVEL

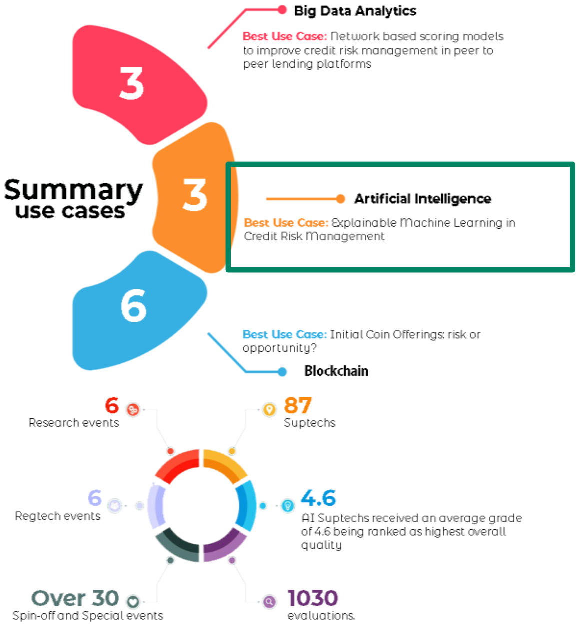
NVIDIA acceleration of XAI use case accelerated with RAPIDS

- Use case on credit portfolio risk with realistic data (11.2 million dataset from Fannie Mae)
- General speedups of up to 19x for SHAP values, and 340x for SHAP interaction values
- use case based on best AI use case in EU Horizon2020 project FIN-TECH *)

FINTECH RISK MANAGEMENT www.fintech-ho2020.eu

European Commission

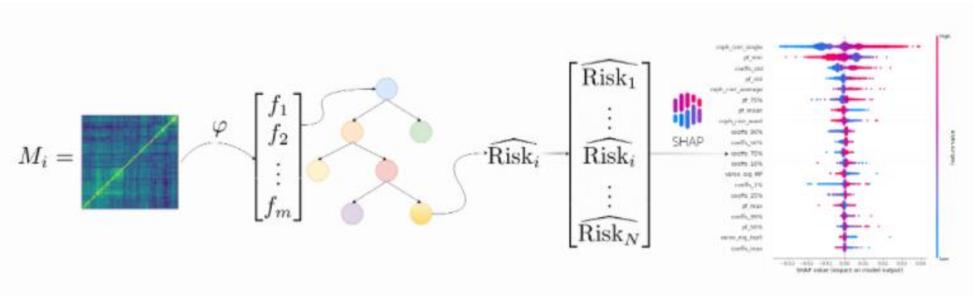




This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement no. 825215 (topic ICT-35-2018, Type of action: CSA)The content reflects only the author's view and the Commission is not responsible for any use that may be made of the information it contains.

XAI FOR PORTFOLIO CONSTRUCTION

- Collaboration with Munich Re
- 3 Publications in top Journal of Financial Data Science
- Implementing a new workflow and combine XAI with synthetic market data generation to enhance the explainability
- Additional paper with cryptos is in the pipeline:
  “Can adaptive seriational risk parity tame crypto portfolios?”



SUSTAINABLE FINANCE AND ESG INVESTING

Problem

- assessing the appropriate level of protection against sustainability risks is a challenge for central banks
- existing sustainability ratings from different providers diverge significantly for the same investable asset (Berg et al. 2019). This implies risk for greenwashing.
- also conflicting findings of ESG alpha (Bruno et al. 2021 vs Giese et al. 2021);

➡ calling for more scientific rigour in ESG evaluation studies (Edmans 2021)

Solution

- consider full set of data and information from multiple source
- process them with explainable AI/NLP models and aggregate them in a large-scale, transparent portfolio construction and optimization process
- This is where the two megatrends, Sustainable Finance and AI, that will shape the financial sector in the coming years overlap; computing platforms will play a crucial role

EMPOWERING REGIONS REGARDING THEIR ENVIRONMENTAL EXPOSURES (1/3)

Use Case

Purpose: empower regions to jointly tackle environmental challenges; identify regions with similar environmental exposures (climate, deforestation, land use, population, etc.)

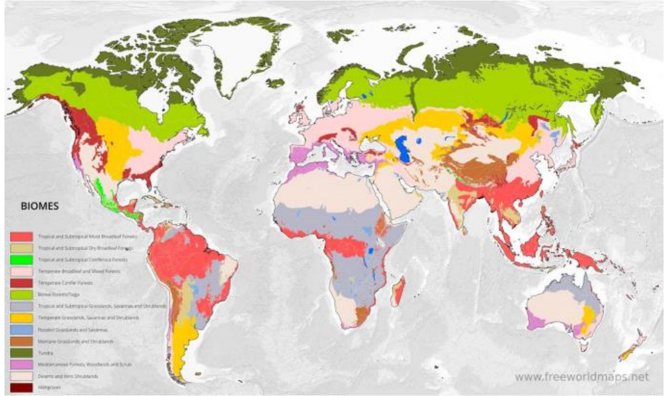
- Why?
    - improve and benchmark ESG data
    - exchange experiences
    - improve their negotiation leverage
    - support each other in joint projects or ad-hoc emergencies like floods or wildfires
    - decrease insurance and funding cost for public or private purposes
    - monitor transition and physical risk

EMPOWERING REGIONS REGARDING THEIR ENVIRONMENTAL EXPOSURES (2/3)

Use Case

Data

- Geospatial environmental data on land cover, land use, climate change measurements, etc.
- data layers derived from satellite measurements have a raster format and need to be connected and enriched with relevant country and sector data (e.g. also with economic and financial data)
- potential sources: https://globalforestwatch.org, https://earthdata.nasa.gov/, https://www.restor.eco/, etc.
- the data are of varying global coverage, spatial resolution, spatial granularity and time resolution across datasets
- Non-trivial task



https://www.freeworldmaps.net/biomes/biomes-map.jpg

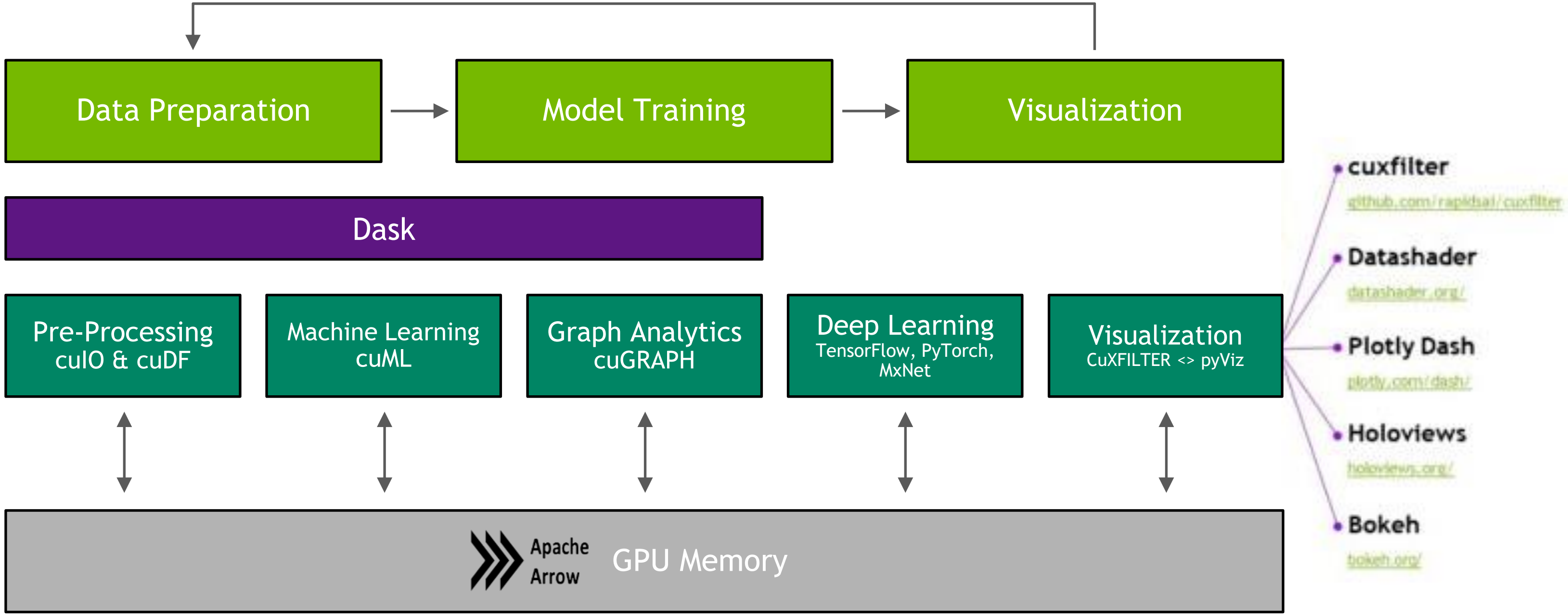
Method

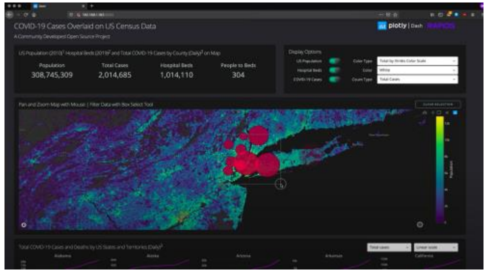
- Similarity Clustering, Network Analysis, Visualization and real-time cross-filtering, typical RAPIDS use case

EMPOWERING REGIONS REGARDING THEIR ENVIRONMENTAL EXPOSURES (3/3)

Use Case

Potential implementation with RAPIDS





OUR ENGAGEMENT IN XAI IN FINANCIAL SERVICES

Webinar series on XAI

Editorial and publishing activity

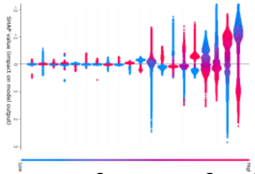
FINTECH RISK MANAGEMENT www.fintech-ho2020.eu European Commission

Extension of a XAI use case of EU Horizon2020 project

gaia-x

Initiated a project on XAI

dmlc XGBoost



Accelerating open-source software for XAI

International Conference on "Statistics for Sustainable Finance", co-organised with the Banque de France and the Deutsche Bundesbank

14-15 September 2021, Paris, France, hybrid format

Carbon costs – Towards a system of indicators for the carbon impact of products, enterprises and industries[1]

Ulf von Kalckreuth,
Deutsche Bundesbank

[1] This presentation was prepared for the conference. The views expressed are those of the author and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

Carbon costs

Towards a system of indicators for the carbon impact of products, enterprises and industries

Ulf von Kalckreuth, Deutsche Bundesbank[1]

Abstract

This paper studies data needs and policy options in the field of climate mitigation and sustainable finance. It presents a system of greenhouse gas (GHG) indicators that provides a large part of the information required by markets and policymakers. The system is lean and informative. It condenses the relevant product and enterprise-specific information into a single number: *carbon cost*. Like prices, carbon costs are easy to understand, manage and communicate. Implementation options are discussed in a stylised way. A coherent system of carbon costs may evolve from an initial stage in which indirect inputs are valued using proxies. With appropriate institutional underpinning (standards, auditing requirements and dissemination), the disclosure process may become largely self-sustaining. The envisaged scenario is one in which, *at all levels of production, goods and services have two price tags – the financial price to pay and the carbon cost.*

At an enterprise level, carbon costs can be computed using standard information from environmental data providers. The paper provides a brief introduction to the empirics.

From the discussion on how a system of carbon costs could be implemented, the paper derives a number of policy options for central banks and international organisations that aim at supporting the creation and diffusion of a comprehensive indicator system. Specifically, a centralised data platform for reference purposes is needed.

Keywords: carbon footprint, GHG intensities, carbon accounting, environmental accounts, carbon disclosure, green finance

JEL classification: Q56, Q51, C81

[1] The author is Principal Economist at the DG Statistics of the Deutsche Bundesbank. He is grateful for comments from Fabienne Fortanier, Caroline Willecke, Justin Dijk, Dilyara Salakhova, Katja Michaelowa, Olga Wittchen, Robert Kirchner, Christoph Meinerding and Mark Weth, as well as from participants of the Workshop on Climate Research, Deutsche Bundesbank Research Centre in March 2021 and of the International Conference for Statistics on Sustainable Finance, Paris, 14th and 15th September 2021, organised by the Deutsche Bundesbank, the IFC and the Banque de France. He received a large amount of support from colleagues at the Sustainable Finance Data Hub of the Deutsche Bundesbank. This draft paper represents the author's personal opinions and does not necessarily reflect the views of the Deutsche Bundesbank or its staff.

Contents

1. Introduction and summary

Today, climate mitigation occupies the centre stage of policy discussion and planning. We expect policymakers to act and markets to react proactively and efficiently. As statisticians, we can contribute data, and, what is more, concepts. If there are concepts but no data, we can begin gathering the missing data. However, if there are data but no concepts, we will not be able to make meaningful use of the information we have.

This paper proposes a consistent system of indicators for the carbon impact of industries, companies, products and activities, from the top level aggregate down to the level of single activities. The framework condenses the existing information on carbon impacts for decision makers – in the policy arena, on the financial markets as investors and on the commodity markets as producers and consumers – in a way that is easy to interpret and to process. It allows consumers, investors and policymakers to differentiate between goods, activities and firms based on their carbon impact.

The main contribution of the paper is to look at carbon costs as a price system. Besides describing a useful information structure, the paper also shows how this system of indicators can be generated in an almost entirely decentralised way. The carbon impact of a certain activity or product is analogous to a price tag, and exactly in the way input prices are processed in cost calculation, the carbon impact of activities and products can be passed along the stages of the value chain. Just as in the case of product prices, consumers or producers of final goods do not have to be aware of the stages of the value chain – they only need the carbon cost indicators of their immediate suppliers.

In the world of sustainable finance, carbon costs can provide the granular-level information for climate mitigation issues that is so badly needed. Considering the proposed system will help us understand what is required and thus be useful in the discussion regarding the desired format for carbon disclosures. It may inform policy activity. New disclosure directives are beginning to take shape, but there is much that remains undefined. At the same time, central banks and international organisations are considering assuming an active role in sustainability issues in line with their mandates. The paper develops a perspective both for disclosure legislation and the role of central institutions.

This paper aims at convincing the reader that carbon costs is a promising way to go. Outlining an “ideal” information system and the conditions under which it can be made operational may, as an additional merit, provide a reference that allows discussing the trade-offs that go with less encompassing alternatives.

Annex 1 reviews IO models that may be used for approximating input carbon costs. Annex 2 gives an overview of the availability of microdata on emissions and describes some of the key legislative initiatives regarding mandatory disclosure of environmental information.

2. Carbon cost and carbon cost accounting

2.1 An indicator system —the vision

At the heart of environmental problems is a situation in which the effect that producing and using goods has on scarce resources is not properly reflected in the price system. In the case of greenhouse gases (GHGs), the scarce resource is the capacity of the environment to absorb carbon emissions – or, to be more precise, the maximum quantity of carbon emissions in line with global warming targets.

For a massive reduction of GHG emissions, it is vital that consumers, investors and policymakers be able to properly evaluate the environmental consequences of production activities so that they can make the right choices as decision-makers.

What is it one would ideally expect from an indicator system for the use of climate mitigation and specifically for financial sustainability purposes? We need exact quantitative information on the relevant emissions on the level of both firms and products. All emissions, direct and indirect need to be covered, the latter not as loose estimates, but based on realised material flows and micro level production interdependences. Granular information is notably scarce, especially on the Scope 3 level. It is granular information that is needed, however, to make meaningful distinctions that go beyond favouring products and firms in sectors with a low carbon intensity or selecting stocks that happen to be in high tech sectors.

A metric that summarises all the relevant information needed to make decisions on the production, use and consumption of goods and services is the *carbon cost, defined as the total amount of carbon emitted in the course of production of a good or service, either directly or indirectly through the use of intermediate input products.*[2]

Consumers can use carbon costs to compare alternatives. If they systematically choose less carbon-intensive alternatives and they are willing to pay the price, this creates competitive pressure. The pressure carries over to earlier stages of production: Along the entire value chain, buyers of intermediate inputs will opt for less carbon-intensive alternatives. Supervisors and policymakers are provided with a solid foundation for classifying firms – for taxes or subsidies, industrial policy or taxonomies for sustainable finance purposes. As an example: carbon cost information is precisely what is needed to get EU plans for a carbon border adjustment mechanism off the ground.[3] At each stage of production, the metric captures and carries forward the resources that have been used up to that point. In a peer group of goods that are close substitutes, carbon costs allow for the identification and weeding-out of inefficient producers and production technologies. Regarding unrelated goods, consumers and policymakers can compare and weigh their respective usefulness against their consequences for the climate.

2 Other expressions in use for related concepts are "carbon footprint" and "carbon content". While the author appreciates how both of these terms can be intuitively understood, the term "carbon cost" has a price-like connotation.

3: As part of the European Green Deal, the European Commission intends to put a carbon price on targeted imports by 2026 to avoid "carbon leakage", i.e. the migration of industries to countries with more relaxed emissions policies. Technically, importers need to buy carbon certificates corresponding to the carbon price that would have been paid if the products had been produced in the EU; see here official information with further links to the proposed legislation. Without a quantification of carbon content, the WTO may well consider the proposal an illegal tariff.

This is all that measurement can give. The rest of this paper argues that this metric can in fact be implemented. The key is the recursive nature of the concept.

2.2 Defining carbon cost

Here and in the following, the terms "carbon" and "carbon cost" refer, as a shorthand, to all GHGs. GHG emissions are converted into carbon equivalents using global warming potential (GWP) factors. To evaluate the carbon impact of a given production process or of the resulting product, it is not enough to consider direct GHG emissions. Direct emissions critically depend on the level of vertical integration. We therefore need to take into account the indirect emissions, as given by intermediate products or services that went into the production. To fix ideas, consider the following. In production planning, every process is defined by a *bill of material* (BoM) that specifies all inputs, plus a *route sheet* that explains how to combine them. A complex production process may be decomposed into several stages. Consider the BoM of product *k*,

$$\mathbf{a}_k = \begin{pmatrix} a_{k1} & a_{k2} & \dots & a_{kK} \end{pmatrix}',$$

with a_{ki} being the quantity of good i needed in the production process. Let the amount of carbon emitted directly be given as d_k. Let scalar c_i be the (total) carbon cost of good *i*, the quantity of carbon that is emitted in the production of one unit of good *i*. List the carbon cost of all input goods in a vector as well:

$$\mathbf{c} = \begin{pmatrix} c_1 & c_2 & \dots & c_K \end{pmatrix}'.$$

The carbon cost of good *k* is then given as the sum of direct and indirect emissions:

$$c_k = d_k + \mathbf{c}'\mathbf{a}_k = d_k + \sum\nolimits_i c_i a_{ki} . \tag{1}$$

Equation (1) takes the form of a cost equation, where the a_{ki} are input quantities and the c_i are the corresponding factor prices. The equation is both perfectly general and encompassing. It relates to products and activities and – for a defined time span – to enterprises and sectors as well.

The equation is a definition. It helps us understand the problems associated with gathering and processing information. For actual computation, all the c_i corresponding to non-zero elements of the BoM of product *k* are required.[4] If $\mathbf{c}$ is known, we calculate the carbon cost of product *k* in a straightforward way from direct emissions and the BoM. This is like computing the energy content of food: it is enough that producers know the composition of their product and the energy content of the ingredients.

If $\mathbf{c}$ is unknown, we can use equation (1) recursively and try to compute the carbon cost c_k, going up the value chain from more complex intermediate inputs to primary and primitive inputs. It is helpful to note that equation (1) and the corresponding equations for all other goods constitute a simultaneous equation system. The structure of the problem is well known from linear production planning and input-

[4] We may even need to know c_k itself if a certain quantity of the product *k* is used as an input for its own production, as will be the case in biological processes or the production of electricity. We can avoid this by defining the left-hand side as the carbon content of *net production*.

output analysis.[5] Conceptually, we can solve for the carbon cost of all products simultaneously. Let

$$\mathbf{A} = \begin{pmatrix} \mathbf{a}_1 & \mathbf{a}_2 & \dots & \mathbf{a}_K \end{pmatrix}$$

be the matrix of the BoMs for all output goods, $1,\dots K$. With $\mathbf{d}$ being the column vector of direct emissions for products $1,\dots K$, one may write:

$$\mathbf{c}' = \mathbf{d}' + \mathbf{c}'\mathbf{A}\ .$$

This structure is equivalent to the (open) Leontief model of production.[6] Reordering and postmultiplying the "Leontief inverse" $(\mathbf{I}-\mathbf{A})^{-1}$ yields for $\mathbf{c}$:

$$\mathbf{c}' = \mathbf{d}'(\mathbf{I}-\mathbf{A})^{-1}\ . \tag{2}$$

The carbon cost of products (product *k* and all the others) result from their respective direct carbon inputs and the direct inputs of all the intermediate goods used for their production by intermediation of a matrix derived from the BoM that reflects the interlinkages in production. If the coefficients in the carbon cost equation refer to empirical production technologies actually being used to produce goods $1,\dots K$, it can be taken for granted that the inverse exists and all its elements are non-negative.[7]

As simple and beautiful as this relationship is, it cannot be used directly. **A** comprises the BoMs for all products in the economy, including those that have been imported, and if a certain input is produced using two different technologies, it should actually have two separate entries. Meanwhile, **d** collects the direct emissions that characterise all of these processes. Except for simple cases, this is impossible to deal with at the micro level. However, sector-level approximations of factor intensities using input-output (IO) models are feasible, as will be explained in more detail later. And just as the price mechanism is able to process an enormous amount of information in a decentralised way, we can think of ways to make the coordinated exchange of information between producers do the work.

In the following, equations (1) and (2) will enable the tracing of information requirements and policy options for setting up a comprehensive and informative system of GHG indicators. Before this, however, a third equation is presented that allows for the identification of carbon costs at the enterprise level.

5 Input-output analysis is closely associated with the name Wassily Leontief, who was awarded the 1973 Nobel Prize for the development of this model. Leontief (1966, 1986) covers much of his work.

6 See Miller and Blair (2009), ch. 10, for a description of this structure on the industry level. To be precise, the structure corresponds to the "dual" price system that results from the Leontief structure, yielding a linear relationship between the value added of industries and the prices of goods; see Pasinetti (1977), chapter 4. Interestingly, Pasinetti (p. 61) writes that no important practical application of the dual system has yet been found.

7 If some of the relationships are estimated, postulated or extrapolated from the past, as will be the case in real-world implementations, the existence of non-negative solutions **c** given non-negative elements in $\mathbf{A}$ and **d** cannot be taken for granted a priori. For a non-negative solution to exist, it is necessary and sufficient that all principal minors of $\mathbf{I}-\mathbf{A}$ are positive (Hawkins-Simon conditions). Equivalently, all characteristic roots of $\mathbf{A}$ are less than 1. See e.g. Takayama, (1985), chapter 4, specifically the summary collection on p. 386. Intuitively, the amount of direct carbon emissions needed must not "explode" as we use equation (1) recursively. Iteratively, the Leontief inverse can be computed as a power series, $(\mathbf{I}-\mathbf{A})^{-1} = \mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \cdots$. This expansion will converge only if the eigenvalues of $\mathbf{A}$ stay within the unit circle. Pasinetti (1976), chapter 4, specifically pp. 66 ff. and the references to the appendix, and Schumann (1968), pp. 35 ff., give clear expositions.

2.3 Carbon cost and GHG emission classes

Given the widespread use of the GHG Protocol emission classes in environmental reporting (see the Annex 2), it is useful to rephrase the definition of carbon cost in these terms. In the production of good k, let $sc1_k$ and $sc2_k$ be Scope 1 and Scope 2 emissions, and $sc3u_k$ be *upstream* Scope 3 emissions (cradle to gate). Then we have:

$$c_k = sc1_k + sc2_k + sc3u_k. \tag{3}$$

Carbon cost is equal to the sum of Scope 1, Scope 2, and upstream Scope 3 emissions. Downstream emissions critically depend on decisions to be made by others, and their inclusion would destroy the recursive nature of the carbon cost: they lead to double counting if later stages of production use carbon costs to evaluate their inputs.[8] The identity in equation (3) ensures that we can make use of GHG Protocol standards for data gathering and processing, specifically the binding norms relating to Scope 1 and 2 emissions. Regarding upstream Scope 3 emissions, it is necessary to make decisions on a number of options in the GHG Protocol standards for practical implementation purposes. The carbon emissions of commuting workers, for example, are difficult to monitor and only loosely related to the company and its product.[9]

Using equation (3), carbon costs and carbon cost intensities can be computed at the enterprise level for companies that report their emissions in compliance with the GHG Protocol; see section 5 below.

2.4 Carbon cost and carbon accounting

Carbon costs are framed here as a close, almost perfect analogue to financial costs. Both are *valued resource consumption*. The same input vector may figure in both the financial cost equation and the carbon cost equation, with only the valuation vectors differing. This analogy enables making use of standard accounting techniques, the outcome of centuries of experience with valuation problems. Carbon costs are fraught with a large number of such valuation issues: emissions from overhead activities such as the heating of production facilities and office buildings, transportation, the carbon costs of capital goods, or combined production technologies. They require the *allocation* of company-level costs. The good news is that all of these issues have been solved conceptually, at least to a large extent. The cost accounting solutions that exist simply need to applied to the task of calculating carbon costs. The close analogy has been noted; see e.g. Stechemesser and Guenther (2012) for a literature review on carbon accounting or, for a practical introduction, Eitelwein and Goretzki (2010). With a valuation vector for input goods at hand, it is possible to carry out information

8 One could choose to define the carbon cost slightly differently in terms of carbon *input* (as opposed to *emissions*) in order to take account of the physical carbon content of the product that will lead to emissions at a later stage. If d_k in equation (1) is the direct carbon input into production at the given stage rather than direct emissions, then c_k and all the $c_i, i = 1, \dots, K$ are to be interpreted as physical carbon content, emissions included. The difference between this concept and the one given in equation (1) above would largely be waste disposal emissions as a part of downstream Scope 3 emissions.

9 For direct emissions and the use of energy, see the standards for disclosure of GHG Scope 1 and 2 emissions: WRI and WBCSD (2004). For Scope 3 (indirect) emissions, see the two closely related standards for enterprise-level and product-level disclosure: WRI and WBCSD (2011a and 2011b). Further, see the Technical Guidance for Calculating Scope 3 Emissions in WRI and WBCSD (2014).

aggregation and processing using standard cost accounting software, both at the product and at the enterprise level.

At this point, one might ask whether carbon costs should not better be stated in monetary units. Physical carbon quantities may be converted in monetary units using a "carbon price", a factor that indicates the value of saving one unit of carbon. However, this price will change over time, affecting comparability. Carbon costs from earlier periods could not easily be used as weights for inputs.

For final demand, especially in private and government consumption, stating carbon costs in monetary units may help decision makers, as they enable comparisons with the utility of the product to the consumer. Decision makers may ask themselves whether this utility really justifies the damage to climate. Thus, on the retail level, it may be useful to state carbon costs both in physical and in value terms.

Result 1: *The carbon costs of an activity or product are a simple recursive metric for climate effects. Used consistently in a production system, they yield a set of metrics that allow consumers, producers and policymakers to make informed decisions. Corresponding metrics can be calculated for enterprises and sectors. They are consistent with the carbon intensities from IO models and with emission classes according to GHG Protocol standards. Given carbon costs for inputs, the carbon cost computation for a product or an enterprise can rely on established cost accounting procedures.*

3. Towards informative carbon cost valuations

As equation (1) shows, a producer's problem of calculating carbon cost is recursive. Imagine for a moment that the producer knows the carbon costs of inputs. Then they only need to allocate direct emissions and set up a detailed list of inputs, based on the knowledge of their own production technology. This is a *Hayekian situation: just like the price system, the resulting system of carbon costs embodies all the technology constraints and interdependencies of the entire system, without any individual producer having to know more than their own technology and the cost vector common to all agents.*

In general, however, producers will be ignorant of the carbon costs of their inputs. On the way towards the Hayekian situation, there is already much to be gained from a valuation vector for the inputs that is only approximately accurate. It gets the proportions right and makes environmental accounting independent of the level of vertical integration. Market participants and supervisors obtain product and enterprise-level information on Scope 1, 2 and upstream Scope 3 emissions into which the producers' knowledge of production technology and the composition of inputs is fully incorporated. Today, the information available at the enterprise level is on Scope 1 and 2 emissions at best; information on Scope 3 emissions is a rare exception.

Thus, to start with, we may assume that no granular, product-level valuation vector for inputs is available. What happens if every producer is willing to make and provide their best estimate for others to use? It will be demonstrated that this leads to an efficient equilibrium of decentralised information processing. In practical terms, producers can use their BoM with the carbon costs provided by their suppliers, if available. If not, carbon costs of reference products or sectoral approximations from IO models can be used instead. This will discussed in more detail below.

3.1 Top down: using EEIO models for generating proxies for input carbon costs

It was already mentioned that, conceptually, input-output (IO) models are the appropriate approach to deal with the recursive nature of the carbon cost definition. The total emission intensity of a sector, as calculated from an input-output model, can be used as sector level proxy for input carbon costs on the right hand side of equation (1). In principle, carbon intensities can be calculated with any IO model that depicts the relevant industry interlinkages, provided that appropriate sector level information on direct carbon emissions are available. IO models with a focus on environmental issues are called "environmentally extended IO models", or EEIO models.[10]

For the purpose at hand, it is useful to have those interlinkages defined in terms of physical units and not, as it is the rule, in value terms. Given the strong interdependence of national economies, the IO base should be international and not treat the "rest of the world" as a black box. In order to capture heterogeneity, the model ought to distinguish a variety of sectors, possibly considering certain types of firms separately.[11] Ideally, the IO model comes near to providing carbon cost proxies at a product level. Therefore, fine distinctions are important especially in sectors with strong industry interlinkages, eg manufacturing. Data quality is of paramount importance, however, and there is no use in trying to make distinctions that cannot be supported with reliable data.

Annex 1 gives a short overview of some of the existing IO data bases potentially suitable for generating proxy information on input emission intensities.

Result 2: *Carbon content according to EEIO models may serve as an industry-level proxy for the carbon costs of inputs according to equation (2). In the case of missing product or firm-specific information on inputs, we can use the carbon intensity of the respective industry to generate product-specific carbon costs in equation (1).*

This allows producers or analysts to characterise the carbon costs of inputs on an industry-by-industry basis. It yields initial values for an iterative approach. Near the bottom of the supply chain, producers can compute rather accurate carbon costs using sector proxies for their inputs. At later stages, producers will still obtain consistent and mean-preserving estimates into which their detailed micro-level knowledge of production technology is fully incorporated.

3.2 Other approximations for the carbon cost of inputs

Using sector-level intensities from EEIO models is indeed one of the ways proposed by the GHG Protocol guides for calculating Scope 3 emissions. There are other ways

10 Again, it was Wassily Leontief (1970) who first proposed using IO models for analysing pollution generation associated with interindustry activity. For input-output analysis in general, see Miller and Blair (2012), and specifically ch. 10 for environmental input output analysis. Suh (2010) collects extensions and applications in industrial ecology.

11 In analysing global value chains, Fortanier et al. (2019) suggest distinguishing multinational enterprises and domestic controlled firms. The production technology of MNEs as well as their import content and export orientation are sources of intra-industry firm heterogeneity. In the same vein, in some developing countries one may want to distinguish between informal and formal activities within the sector, as the former may be less responsive to government environmental policy.

of obtaining estimates. The GHG Protocol guides generally recommend an in-depth and detailed analysis of the entire product value chain. Producers should then make an effort to gather intelligence on Scope 1 and 2 emissions at earlier stages. While this is feasible in cases where producers oversee the entire value chain, or within the confines of companies of the same group, it is tedious and impractical in the more general case of dispersed production activity. Input suppliers will not be forthcoming with providing detailed technological information to their B2B customers. The beauty of carbon cost is that it encapsulates all required information on carbon use without disclosing anything technology-related beyond this, not even on the amount of direct emissions.

Apart from analysing the supply chain, the GHG Protocol recommends the use of proxies and of firm-level information on the emissions of the provider. If the carbon cost is known for one input good, it can be used to calculate carbon costs for close technological substitutes. Using standardised intensities is especially practical for staple goods, where there is little technological variability. Low-intensity goods and services such as banking and insurance can be grouped and accounted for using an overhead factor common for the industry of the producer. If the product-level carbon cost is not available but the input provider publishes enterprise-level GHG Scope 1 and 2, or even Scope 3, emissions, the resulting intensities can be used as a basis for an estimate, similar to EEIO sector-level intensities. Section 5 below takes a first look at such intensities. If they contain direct information on Scope 1 and 2 emissions, enterprise-level intensities are preferred to their sector-level counterparts, even if the Scope 3 emissions figure is based on estimates.

3.3 Bottom up: pulling oneself up by one's bootstraps

With initial values for the carbon costs of inputs, e.g. from sectoral or firm-level intensities, the carbon cost of a product can be calculated according to equation (1). This will not immediately lead to a consistent set of measures: typically, the carbon cost c_k according to equation (1) will not be equal to the approximations used for the same good in calculating the carbon costs of other goods.

Importantly, however, each producer will be able to pass a measure of carbon content on to the buyers of intermediate products. Assume that, along with the price of the product, producers communicate a measure of its carbon content. This allows for a *second stage*. If the buyers of intermediate products use the approximations of their suppliers instead of the industry averages, the estimation error will diminish greatly, as the direct emissions of intermediate inputs are correctly accounted for. In equilibrium, the error will disappear completely, provided there are no products without proper carbon content estimates, such as imports. It is easy to see why: industry averages or other approximations are needed only when there is no individual-level carbon cost available. If there is one such measure for every good, and if these measures are consistently used to evaluate inputs according to equation (1), the industry averages will never enter the picture, not even indirectly.

Result 3*:* *If all producers give a fair estimate of equation (1) using the information they have, i.e. direct emissions, BoMs, and carbon costs of input or estimates thereof, and if this information is passed on to the market, in equilibrium the resulting system of carbon costs will correctly reflect the interlinkages as given by equation (2).*

This is key for feasibility: producers do not need to know the carbon costs for products in the entire economy, only those of their own suppliers (or estimates thereof), just as for cost accounting we do not need to know the entire price system, but only what our suppliers charge. If not all carbon costs are available, producers can use proxies, either from reference products or from sectoral models. Over time, the system will converge.

4. Is there scope for voluntary disclosure?

To a certain extent, carbon cost disclosure may rely on voluntary action by producers. The existence of the GHG Protocol and its increasing use shows that there is a distinct commercial interest in obtaining and communicating carbon accounting information; see Annex 2. In 2016, according to the GHG Protocol, 92% of the Fortune 500 enterprises that responded to a survey on carbon disclosure were running programmes based on GHG Protocol standards. Another non-profit-entity, CDP (formerly the Carbon Disclosure Project), disseminates a standardised questionnaire on GHG activities. More than 2,000 companies worldwide provide answers on a voluntary basis, which are then made available to the public and used as inputs in commercial databases.

On the other hand, it is also clear that some firms have reasons to declare their carbon costs either incorrectly or not at all. Just as with financial costs, if there is an opportunity to make products look cheaper than they really are or to avoid talking about prices altogether, some market participants will take it.

To establish a carbon cost system, some reporting obligations will be necessary. However, this section makes the argument that reporting obligations may not have to be broad-based. Instead, legislation only needs to make sure that a threshold volume of disclosure, e.g. from large companies, is surpassed. *Under certain conditions, this will trigger a process that will end in almost universal voluntary disclosure*.

As a first component, we need *formal auditing* to make sure that the carbon cost is a fair estimate, using the information on direct emissions and production interlinkages existing at the company level. The auditing is carried out against disclosure standards that have to be specified in advance. It is best organised in parallel with financial auditing, with governments having the right to scrutinise dubious statements. In this respect, it is extremely promising that the IFRS is about to change its statutes in order to set up a board on disclosing standards for environmental information.

Second, an *information platform* is required that makes available the existing information on:

- industry averages;
- direct emissions from company reports;
- carbon cost estimates, as far as they exist.

There is a path that leads to voluntary disclosure by (almost) all firms. Suppose that the information platform, in addition to making existing information publicly available, computes estimated average carbon content for firms of a given industry that do not disclose their carbon cost -- from the known industry averages and the known carbon costs of the firms that do disclose. These estimates will be used to evaluate the carbon cost of inputs produced by non-disclosing firms.

Producers with low carbon costs, relative to their peer group, will have a clear incentive to disclose. With low carbon costs, they can charge higher prices or reap the rewards of positive publicity. This generates a signal value for the decision not to disclose. The signal will be reinforced by calculating sector averages for carbon costs conditional on not disclosing. With many companies disclosing, those that do not disclose will look increasingly unattractive. We may envisage an iterative process where first the cleanest firms disclose, then those that are not top tier, but still well above average, etc. In the end, the only firms to not disclose will be those with rather extreme carbon costs, and the fact that they do not disclose will be informative enough. In order to create an incentive that is large enough to get this mechanism going on a broad scale, we may need to overcome a threshold number of participating firms.[12]

This process of unravelling due to using the industry average as a proxy for non-disclosing firms is quite similar to the Stiglitz and Weiss (1981) account of the possible breakdown of the credit market under asymmetric information. In the scenario at hand, however, the result is a separating equilibrium with voluntary disclosure.

Result 4*: Given a sufficient degree of competitive pressure, an equilibrium with voluntary disclosure will result if:*

1) *firms are audited according to predefined disclosure standards;*
2) *sector-level information and the disclosed carbon costs are made publicly available; and*
3) *carbon intensity estimates based on the unaccounted-for parts of industry totals are disseminated to be used for firms that do not disclose.*

By mimicking the diffusion of information via the price system, information on carbon usage can be processed in a decentralised and efficient manner, even without any formal reporting obligation. The key ingredients are micro-level auditing and a centralised information platform. This is where central banks may have an important role to play. They need to collect much of the required information anyway in order to classify their assets and collateral and, at least in some cases, to rate companies. In addition, they have the mandate to disseminate statistical information for policy purposes as well as all the necessary infrastructure, experience and working routines.

One obvious challenge is imports. Exporters may not have the same incentives to disclose if their markets are located largely outside a country that implements a system of carbon cost indicators. Many large international companies disclose their carbon usage data voluntarily, and the upcoming EU legislation on the carbon border adjustment mechanism will further expand the information available on emissions. Still, for many products and companies, the information will likely be missing permanently. For those products and firms, industry averages specific to the exporting country can be used. See Destatis (2019) for a tabulation of the carbon content of imports from major trading partners by industry in the years 2013 to 2015. Alternatively, one can find reference producers in the home country. It is clear that

[12] Some enterprises are already reporting carbon costs for their products today. A Swedish company producing oatmeal gathered more than 57,000 signatures for its petition to the Deutsche Bundestag, the German Federal Parliament, to make carbon cost disclosure obligatory for retail food. Given the size of the petition, there was a public hearing. There is also a market for consultancies that help compute product-specific carbon costs; see here a link to a Frankfurt consultancy. Competitive pressure will increase considerably once reporting carbon costs becomes commonplace and accountants offer standardised and cheap solutions.

the problem is less acute if countries within a large economic zone such as the European Union act in unison.

5. Company level carbon costs: some descriptives

Equation 3 allows us to study carbon cost at the (aggregate) company level. Since the GHG Protocol first published emission reporting standards in 2001, an increasing number of companies have been voluntarily reporting on Scope 1, Scope 2 and even Scope 3 emissions. This information is collected by centralised data platforms, with CDP being the most prominent. Commercial providers augment them with imputations on missing data and estimations to give investors a broad information base; see Annex 2 to this paper.

Based on equation (3) above, company-level carbon costs can be computed if information on the components of emissions according to scope is available. This is the case for the emissions data of Trucost.[13] In this section, they will be used to show some stylised facts and provide initial insight into magnitudes.

For 2019, Trucost reports GHG emission data on 19,405 companies, most of them listed. Among them are 4,576 companies from China, including Hong Kong, 3,134 from the United States, 2,397 from Japan and 343 from Germany. Only a fraction of these emissions data is fully collected from company disclosures: 9.2% of the Scope 1 emissions data worldwide and 19.8% from Germany are collected as exact figures. Fortunately, reporting incidence is much higher for large companies. Weighted by revenues, 69.9% of Scope 1 emissions data worldwide and 81.1% in Germany are collected as exact figures from company reports. The rest are either derived from partial information or estimated using the Trucost EEIO model. Trucost also reports upstream and downstream Scope 3 emission intensities. For upstream Scope 3 emissions, the agency does not make use of reported information: all data are estimated using its proprietary EEIO model.[14]

[13] Trucost is an affiliate of S&P Global.

[14] Downstream emissions data make partial use of reported information.

Table 1: Company-level GHG emission intensities and carbon costs

Trucost environmental data, 2019, worldwide

	Mean	Median	Std Dev	# Obs
Intensity levels				
Scope 1 & 2	338.56	39.33	2034.17	19,405
Scope 3 upstream	160.29	97.70	197.07	19,405
Carbon cost	498.84	169.84	2073.89	19,405
Log intensities				
Scope 1 and 2	3.794	3.672	1.790	19,405
Scope 3	4.577	4.582	0.990	19,405
Carbon cost	5.150	5.135	1.266	19,405

[1] Emission intensities are given as tons of CO2 equivalents, normalised by company revenue in USD million. Scope 1 and 2 emissions are direct emissions plus purchased electricity, heat and steam. Scope 3 upstream emissions are indirect emissions that result from intermediate inputs. Carbon cost is defined according to equation (3) as the sum of Scope 1, Scope 2 and upstream Scope 3 emissions. All data are reported unweighted.

Sources: Trucost environmental data, author's calculations.

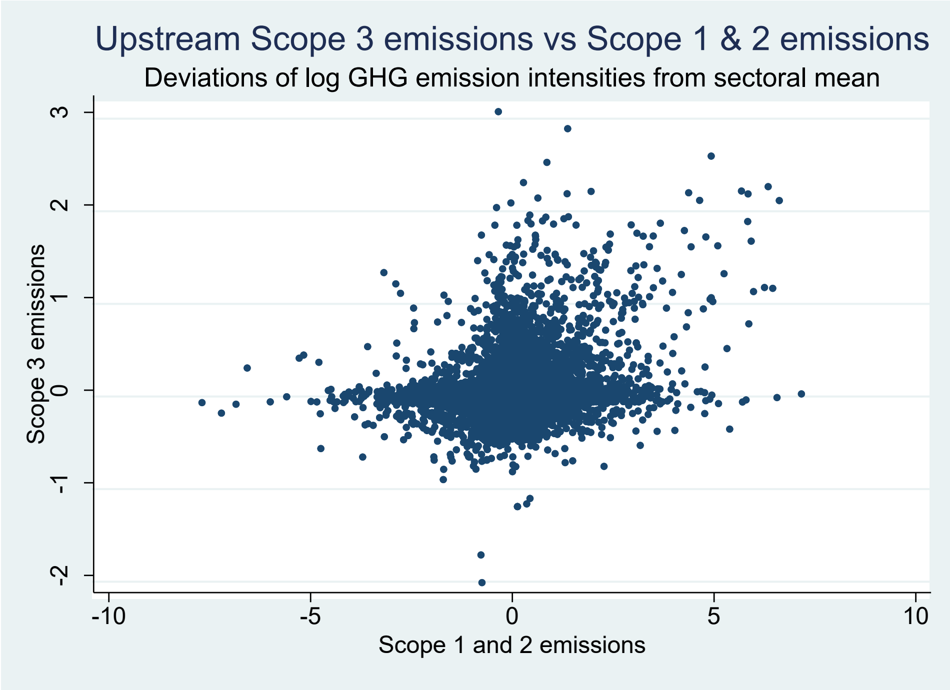
Table 1 lists descriptives on company-level emission intensities (normalised by revenues) according to scope, namely the sum of Scope 1 and 2 emissions, the Scope 3 emissions, and the resulting carbon costs. The table provides descriptive information on both the levels of intensity and the logs. The Trucost database contains both holdings and operative companies, thus there may be some double counting. The data have not been cleaned to remove outliers.

Scope 1 and 2 intensities are highly skewed. The standard deviation is dominated by extreme values, it is much higher than the mean. The upstream emissions, being fully estimated, do not contribute much to the variability of the carbon cost measure, although in terms of levels they have a share of around one-third. The logs are far better behaved. Means and medians are about equal. With log intensities, average upstream Scope 3 emissions are larger than Scope 1 and 2 emissions. For carbon costs, therefore, the carbon content of inputs is of central importance.

Much of the information on intensities is associated with the sector of the producer. This may be especially the case for estimated emissions. Scope 3 emissions are a key component of the carbon cost concept. It is interesting to see whether and how much individual variation the estimated Scope 3 emissions can contribute beyond the level information from the sector. To this end, the deviations of log intensities from their sectoral means are computed.[15] Graph 1 plots the mean deviations of log Scope 1 and 2 intensities against the mean deviations of log Scope 3 intensities. It is clearly evident that the dispersion of Scope 3 mean deviations is lower than those computed from Scope 1 and 2 emission intensities, but it is equally clear that Scope 3 emission data do carry a considerable amount of independent information.

[15] For 2019, the standard deviation of this measure takes a value of .9273174. For Scope 2 and Scope 3 emissions the standard deviations are .835826 and .2129105, respectively.

Graph 1: Carbon cost: checking information content of main components



6. Policy perspectives

At the heart of sustainable finance is the idea that investors need to *distinguish*: between aligned and non-aligned projects, between firms with a higher or a lower environmental risk, and between portfolios with a higher or lower carbon footprint. The information used to make this type of distinction is granular by necessity, i.e. firm-level or even product-level. Carbon costs make it possible to evaluate whether a firm's output portfolio is sustainable. If carbon costs are higher than the carbon costs of similar products, chances are high that the firm is not viable if the environmental cost of production is duly taken into account. More generally, if the carbon cost of a firm's output is high compared with that of others (similar or not), it can be expected that the growth potential of this business model is limited. High carbon costs therefore reflect an elevated market risk.

Currently, there is much to be done and, by consequence, there is much that can be achieved. Annex 2 describes two strands of current and upcoming EU legislature. The draft CSRD, which is yet a rather empty legislative shell, will soon be filled with concrete reporting requirements. The Taxonomy Regulation and its associated delegated acts aim at distinguishing firms that are aligned to environmental transition goals from those that are not, and this policy will need a firm foundation. Apart from these two strands, the "Fit for 55" legislative package envisages new reporting requirements for key activities, and it enlarges the scope for emission trading considerably.[16] The European Banking Authority (EBA) discusses a framework for

16 For an overview on the entire "Fit for 55" package, see the official communication. There will be separate emissions trading systems (ETSs) for buildings and road transport, and the existing ETS will cover maritime transport. The ETS is important for data availability as it creates a need for careful accounting. Here is a link to the proposed Directive.

prudential disclosures on ESG risks that would force banks to report on their engagement with counterparties that are among the top carbon-intensive in the world, be it in the European Union or in the home country of the institution.[17] The IFRS Foundation is overhauling its statutes to set up a board for sustainability-related reporting. Politically, the need for a coherent and relevant indicator system such as carbon costs is obvious.

In discussing information requirements and implementation, this paper has implicitly described some of the policy options for central banks and international organisations to support the evolution of a broad-based and consistent system of GHG indicators. The following is a list of policy options resulting from the discussion above:

1) Cooperate with Eurostat and the NSIs in setting up a **rather disaggregated EEIO model** for the euro area, and also for some of the larger countries within it if this is warranted by observed heterogeneity. This would be very effective in creating a joint framework for condensing data at a sectoral level.
2) Set up and maintain a **dissemination platform for carbon cost data** at the level of sectors, enterprises and products. Disclosure standards may oblige producers to use carbon cost data published on that platform for their inputs. These platforms may also name and make available reference proxies for cases where product-level input carbon cost information is not available, especially in the case of imports.
3) Develop and propagate **disclosure standards** and assist in setting them as a basis for comparability and auditing. Those rules can build on the relevant GHG Protocol standards.[18] What inputs to consider and how to evaluate them needs to be determined. In this context, it is necessary to make concrete decisions on the options in Scope 3 accounting, with a view to practicability and informational content. The organisations that support the GHG Protocol, namely the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD), may have a leading role to play here. There are also ISO standards that bear a strong resemblance to the corresponding GHG Protocol standards.[19]
4) Interact with the European Commission and possibly also with the IFRS on potential **disclosure requirements**, especially regarding the CSRD (see Annex 2). In light of the discussion above, possible disclosure requirements should target large companies so as to overcome a threshold that will induce voluntary disclosure by others, and producers of primary goods and import goods so as to ensure valid carbon costs at the front end of the value chain.[20]

17 See the Consultation Paper Draft Implementing Standards on prudential disclosures on ESG risks in accordance with Article 449a CRR, especially paragraphs 40-42 and the corresponding annexes.

18 See, in particular, WRI and WBCSD (2004) as a standard for Scope 1 and 2 emissions, WRI and WBCSD (2011a) for Scope 3 emissions at the enterprise level, WRI and WBCSD (2011b) for corresponding standards for Scope 3 emissions at the product level, and the Technical Guide on Scope 3 emissions in WRI and WBCSD (2013).

19 From the ISO 14060 family of GHG standards; see specifically ISO 14067:2018 on GHG reporting at the organisation level and ISO 14067:2018 on reporting at the product level.

20 As already mentioned, the upcoming legislation on the carbon border adjustment mechanism and the enhancement of the scope of the carbon emissions trading systems are beneficial in this respect.

It would be helpful if financial and environmental disclosure auditing could be carried out in synchronicity.

These are largely the same options that are available with respect to any other meaningful system, but the system presented in this paper is useful in showing how these policy measures fit together and how they interact.

A simplified solution would aim at producers to disclose carbon costs only for a targeted subset of products, eg from parts of the manufacturing sector. This is easier to initiate, but the simplicity comes at a cost. For many input goods, carbon cost coefficients need to be estimated permanently, as even in the steady state there are no values from input providers. Result 3 would not hold. Even in this case, though, valuable granular information would come from producers using their private knowledge on technology and input composition. This is perhaps the most important feature of a system of carbon costs.

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Annex 1: IO models potentially useful for generating proxy carbon costs for input goods

It was argued in Section 3.1. that the total emission intensity of a sector, as calculated from an input-output model, can be used as sector level proxy for input carbon costs on the right hand side of eq (1), if product level information is missing. This Annex looks closer at IO models as a source for emission data.[21]

The System of Environmental Economic Accounting (SEEA) is a multipurpose conceptual framework that describes the interactions between the economy and the environment, and the stocks and changes in stocks of environmental assets. It is a satellite account of the System of National Accounts (SNA) and uses definitions of sectors, industries, time and space consistent with the National Accounts. The framework is a United Nations system. Many countries, including Germany, maintain reporting systems that conform to SEEA standards. In the following, we refer to the SEEA Central Framework adopted in 2012 in United Nations (2014). The SEEA is divided into three areas. First, the *physical flow accounts* describe flows of material between the environment and the economy and its sectors and industries, very much in the same way as flows of goods and services and funds are described in the National Accounts. Additionally, the *environmental activity accounts* identify economic transactions within the SNA that may be considered environmental, such as environmental protection. Finally, the *asset accounts* focus on the recording of stocks and flows associated with environmental resources of many kinds. For the purpose of this analysis, it is the physical flow accounts that are relevant.

These accounts depict the flow of designated substances from the environment to the economy and its sectors and industries, and vice versa – among them, of course, carbon dioxide and other greenhouse gases. Importantly, the accounts are disaggregated by industry in a way that is consistent with the supply and use tables and standard input-output tables as part of National Accounts. On the first level of analysis, the direct emissions of industries are recorded. This makes it possible to look at the emissions of industries and hold them against, for example, their value added. This gives us a first impression of the carbon impact of industries, not just in terms of absolute size, but also in terms of intensity. Second, using the machinery of supply and use tables and input-output analysis, it is possible to calculate the carbon impact of *final demand as well as of its components* – consumption, investment, imports and exports by industry. This calculation fully reflects the industry interlinkages that are discussed above, using the same analytical apparatus. The matrix of industry interlinkages used in input-output analysis corresponds to the matrix **A** in section 2, albeit at an industry level. This is of high analytic value: the direct carbon emissions of electricity production may be of interest in and of themselves, but to the degree that electricity feeds as an input into the production of other goods of final demand, the emissions need to be attributed to these goods. As an example, in Destatis (2019), Tables 2.1.1. and 3.1.1. show the carbon content of final demand in Germany for the years 2013 to 2015, both in total and for 49 industries and product groups. Similar tabulations exist for the final demand components import, export, consumption and

[21] See footnote 10 for references on IO models for industrial ecology.

investment separately. What is more, the publication also gives estimates of carbon content by industry for imports from all major trading partner countries.[22]

The OECD Inter-Country Input-Output (ICIO) tables are the basis for the Trade-in-Value-Added (TiVA) project. They have been successfully employed to compute the carbon content employed in final demand and in international trade, see Wiebe und Yamano (2016) and Yamano and Guilhoto (2020). Partly building on the ICIO tables, Eurostat has made accessible a new database, the 'Full International and Global Account for Research in Input-Output analysis' (FIGARO).[23] Since May 2021, the FIGARO tables are part of the annual production process. They link data on national accounts, business, trade and labour markets for the EU member states and its main trading partners. The relationship between the EU countries, the United Kingdom and the United States are depicted at a level of 64 industries. For the remaining EU partner countries, the data come from the OECD ICIO and cover 30 industries. IO tables are notorious for their long publication lag. Using nowcast methods, FIGARO tables are published with a lag of only 2 years, ie in 2022, tables for 2020 will be available. The data for the two most recent years are at a higher level of aggregation than the rest.

Beyond official statistics, there are Extended Environmental Input-Output (EEIO) models for academic and commercial research that can be used for analysing emissions. They collect information on the physical flows of goods and services from official and private sources and combine them with estimates to get a more disaggregated picture. EXIOBASE is an important academic endeavour. The hybrid version of the multiregional model EXIOBASE 3 is based on physical, not monetary units. The data base features 43 countries, 5 Rest of World regions, 200 products, 164 industries, 39 resources, 5 land categories and 66 emissions. Unfortunately, the time series of the hybrid version only extends to 2011. Ultimately, the EEIO model of Trucost, an environmental consulting agency affiliated to S&P, is based on supply and use tables from the United States Bureau of Economic Analysis. Enriching these with additional breakdowns, Trucost arrives at an EEIO model with no less than 464 sectors.[24] The model helps to estimate firm level emission intensities, see Section 5 for more information on these data.

[22] The entire set of tables can be downloaded here as Excel files.

[23] See the FIGARO website and Remond-Tiedrez and Rueda-Cantuche (2019). To the knowledge of the author, FIGARO has not yet been used to compute emission intensities.

[24] See Trucost (2020). While this is an impressive figure, the issue of whether it is appropriate to use US-based intensities for companies all over the world, even in countries that are far from the technological frontier, is up for debate.

Annex 2: Microdata on emissions – availability today and upcoming EU disclosure requirements

1. Voluntary disclosure

Today, the disclosure of carbon emissions is largely voluntary. In 2001 (revised in 2004), the *GHG Protocol* published standards that are being followed by a growing number of large companies. The GHG Protocol is maintained and supported by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). The latter is an association of private enterprises that is committed exclusively to the topics of economics and sustainability. The GHG Protocol defined three scopes for carbon accounting purposes:[25]

- *Scope 1* – Direct GHG emissions: Direct GHG emissions occur from sources that are owned or controlled by the company,
- *Scope 2* – Electricity (indirect GHG emissions): GHG emissions from the generation of purchased electricity consumed by the company.
- *Scope 3* – Other indirect GHG emissions: Scope 3 is an optional reporting category in the GHG Protocol that allows for the treatment of all other indirect emissions, upstream or downstream. These are a consequence of the activities of the company, but occur from sources not owned or controlled by the company, such as extraction and production of purchased materials, transportation of purchased fuels, and use of sold products and services.

Disclosures of Scope 1 and 2 emissions are binding under the standard. On top of this, the GHG Protocol has issued detailed recommendations regarding Scope 3 emissions, which are optional under the standard; see footnote 9 and the sources cited therein.

As the number of voluntary disclosures grows, platforms have emerged that make those disclosures available to the public. *CDP* (formerly the Carbon Disclosure Project) was founded in 2000 and has evolved into a large and comprehensive database on environmental matters. According to Wikipedia, 2,400 companies worldwide, and 82% of Fortune 500 companies, reported their GHG emissions to CDP in 2009. Most of the disclosing companies follow GHG Protocol standards: in 2016, 92% of the Fortune 500 enterprises that responded to the CDP survey were running programmes based on the GHG Protocol.[26]

CDP data are being sold to firms and universities (at a heavy discount) and form the backbone of what is available from *commercial databases*, among them Trucost and ISS ESG.[27] These companies also collect disclosures directly from websites or non-financial statements and augment them with approximations and estimates to generate a broad information base for their clients, namely institutional investors.

It is interesting to see that 89.1% of the Scope 1 data reported by Trucost as collected from companies originates from CDP. There is thus a clearly visible line running from

[25] See WRI and WBCSD (2004), chapter 4 "Setting operational boundaries".

[26] GHG Protocol website, 14 August 2021.

[27] Trucost is an affiliate of S&P Global. For more information on Trucost environmental data, see section 5. ISS ESG is a consulting company owned by Deutsche Börse.

GHG Protocol standards and via voluntary disclosures by large companies through CDP or non-financial statements through to commercial companies trying to fill data gaps to serve the needs of investors for a wide range of firms. There is readiness to disclose on the one side and there is market demand on the other. Data quality, however, is a big issue if company reports are not standardised and much of the total needs to be estimated using proprietary and partly undisclosed techniques. For investors, it is not easy to use this information to make proper distinctions at the company level. For policymakers, meanwhile, it is impossible.

2. Upcoming disclosure requirements

The current EU legislature on environmental disclosure is moving forwards on two avenues: the Taxonomy Regulation track and the Non-Financial Reporting Directive track.

Taxonomy Regulation 2020/852[28] of 18 June 2020 is designed to establish a framework for facilitating sustainable investment. Article 8 of the Regulation obliges non-financial firms to disclose the proportion of their activity (in terms of turnover) that is aligned to environmental purposes under the "Taxonomy", in order to develop criteria for whether certain investment qualify as sustainable or not. In material terms, Article 8(4) refers to associated regulations (delegated acts) that are to be adopted separately. These are commonly known as "Article 8 delegated acts":

- The *Disclosure Delegated Act of 6 July 2021* further specifies the disclosure obligations under Article 8 of the Taxonomy Regulation. It obliges non-financial and financial undertakings to disclose in non-financial statements what part of their activities is aligned to certain environmental goals. The Act defines key performance indicators (KPIs) in terms of turnover, capital expenditure and operational expenditure. It has five annexes.
- The taxonomy that classifies what activities are "aligned" is described separately in two annexes of the *EU Taxonomy Climate Delegated Act of 4 June 2021*. These annexes introduce technical screening criteria for two of the six environmental objectives specified in the Taxonomy Regulation. They determine the conditions under which an economic activity qualifies as contributing substantially to (1) climate change *mitigation* (Annex 1), or (2) climate change *adaptation* (Annex 2). They also give criteria for determining whether that economic activity causes no significant harm to any of the other environmental objectives. The economic activity is described briefly and the description is supplemented with NACE codes. Only a subset of economic activities are listed with criteria that would qualify them aligned. This is clear to see when looking at the activities listed under manufacturing or energy.

The Taxonomy Regulation and the two delegated acts are one single piece of legislation. Four more annexes with technical criteria for the other environmental objectives of the Taxonomy Regulation – sustainable use and protection of water and marine resources, transition to a circular economy, pollution prevention and control, protection and restoration of biodiversity and ecosystems – will follow separately.

In a rather radical way, the Taxonomy Regulation describes the world as black and white: activities are either aligned or not aligned. There is nothing in between.

[28] Links to all Taxonomy Regulation legislation and important metadata can be found on a dedicated European Commission webpage.

Ultimately, companies, investors and banks have to report the percentage of aligned activities. For our purposes, it is important to note that there are no GHG disclosure requirements, and the taxonomy does not refer to GHG intensities for threshold values, either in absolute terms or regarding best practices, as such comparisons cannot currently be made.

Important change is often incremental, and sometimes less environmentally friendly options may be unavoidable. Quite often, it may be worthwhile to choose carefully between existing options. The taxonomy does not provide any guidance in such circumstances.

A second track of reporting obligations, associated with the *Non-Financial Reporting Directive (NFRD)*, may in the long run be a better candidate for closing this gap. The NFRD, Directive 2014/95/EU of 22 October 2014,[29] concerns the disclosure of non-financial and diversity information by large undertakings and groups. The Directive asks large companies for a rather encompassing statement on ESG issues, but does not go into any details in terms of what should be reported and according to what standards. Essentially, large companies and the head companies of large groups are supposed to report information on "environmental, social and employee matters, respect for human rights, anti-corruption and bribery matters, including: (a) a brief description of the undertaking's business model; (b) a description of the policies pursued by the undertaking in relation to those matters, including due diligence processes implemented; (c) the outcome of those policies."

The NFRD is considered rather ineffective, as companies are mostly free to choose what to report and the metrics and format that they use. A new piece of legislation means to change this. On 21 April 2021, the Commission adopted a proposal for a *Corporate Sustainability Reporting Directive (CSRD)*,[30] which would amend the existing reporting requirements of the NFRD. The proposal:

- extends the scope to all large companies and all companies listed on regulated markets (except listed micro-enterprises);
- requires the audit (assurance) of reported information;
- introduces more detailed reporting requirements, and a requirement to report according to mandatory EU sustainability reporting standards.

Importantly, it requires companies to digitally "tag" the reported information to make it machine readable.

As it is, however, the CSRD proposal is still an empty legislative shell. It specifies who is subject to reporting requirements and the reporting process, but not what to report. Much like the Taxonomy Regulation's delegated acts, the content of the reporting obligations will be defined separately. The contents are currently being prepared by the European Financial Reporting Advisory Group (EFRAG), an EU funded non-profit organisation. A first draft of the reporting standards is expected by mid-2022. It will then be submitted for consultation. To outsiders, it is not yet readily apparent what the specifics of the reporting standards will be. Given the scope of companies it covers, the audit requirements and the type of information to be

[29] Here is a link to the NFRD, and to a press release on the reform.

[30] Here is a link to the CSRD proposal, and to a press release on the need to review the NFRD.

disclosed, the CSRD is in an ideal position to incorporate GHG emissions reporting obligations.

Carbon costs

Towards a system of indicators for the carbon impact of products, enterprises and industries

Dr. Ulf von Kalckreuth, Principal Advisor, DG Statistics, Deutsche Bundesbank

International Conference on Statistics for Sustainable Finance

Paris, 15 September 2021

Carbon costs – the vision

- The price system does not fully account for resoure use. We need **granular data on carbon use, direct and indirect.**
- Imagine that for every good and service, **all direct and indirect carbon emissions in the course of production** are known.
- Carbon costs depend on **direct emissions**, the quantity of **inputs** and **their carbon costs**!.
- A secondary price system, indicating the use of carbon on every stage of production.
- Producers, investors, consumers and political authorities would have the information needed for decision making. Competition among producers may induce rapid adjustment!

The paper…

… introduces a consistent system of indicators for the **carbon impact of industries, companies, products and activities**

… works out **3 views**: a cost equation, an IO reduced form and a GHG Protocol representation

… shows how the system of indicators can be **generated in a largely decentralised way.** Carbon cost is like a price tag, can be handed over the stages of the value chain!

… points out the **elements of a working solution. Start with top down estimates, then boot the system bottom up**

… discusses **policy options for central banks**

(1) Cost equation

Consider the *bill of material* (BoM) of product *k*, with r_{ik} being the quantity of good *i* embodied in the production process:

$$\mathbf{r}_k = (r_{k1} \quad r_{k2} \quad \dots \quad r_{kK})'$$

Let d_k be the amount of carbon directly emitted and c_i be the carbon cost of input *i*

Direct emissions

Indirect emissions

Quantity structure of inputs

Then the carbon cost of good *k* is given as the **sum of direct and indirect emissions**:

$$c_k = d_k + \mathbf{r}_k{}'\mathbf{c} = d_k + \sum_i r_{ki}\, c_i \tag{1}$$

"Price" structure of inputs

If the c_i is known, we can calculate the carbon cost of product k directly.

(2) IO reduced form

If the c_i are unknown, the equation is recursive. We can solve for the carbon content of all goods simultaneously. Let

$$\mathbf{R} = (\mathbf{r}_1 \quad \mathbf{r}_2 \quad \dots \quad \mathbf{r}_K)$$

be the matrix of the BoMs for all produced goods. With **d** the vector of direct emissions for products 1,…, *K*, we may write:

$$\mathbf{c} = \mathbf{d} + \mathbf{R}'\mathbf{c}$$

We do not need to compute this solution. It is enough to know that it exists and we can let decentralised information processing do the work!

and solving for **c** yields

$$\mathbf{c} = (\mathbf{I} - \mathbf{R}')^{-1}\mathbf{d} \qquad (2)$$

Carbon costs of all goods

Leontief inverse, reflecting interlinkages

Direct emissions for all goods

(3) GHG Protocol representation

Given the widespread use of the Greenhouse Gas (GHG) Protocol emission classes in environmental reporting, it is useful to rephrase the definition of carbon cost.

In the production of good *k*, let $sc1_k$ and $sc2_k$ be Scope 1 and Scope 2 emissions, and $sc3u_k$ be upstream Scope 3 emissions (cradle to gate). Then we have:

$$c_k = sc1_k + sc2_k + sc3u_k. \tag{3}$$

Carbon cost is equal to the sum of Scope 1, Scope 2, and upstream Scope 3 emissions!

This gives us the chance to compute *firm level* carbon costs from emissions data

Company level carbon costs – some descriptives

Level data highly skewed

Company level GHG emission intensities and carbon costs

Trucost environmental data, 2019, world-wide

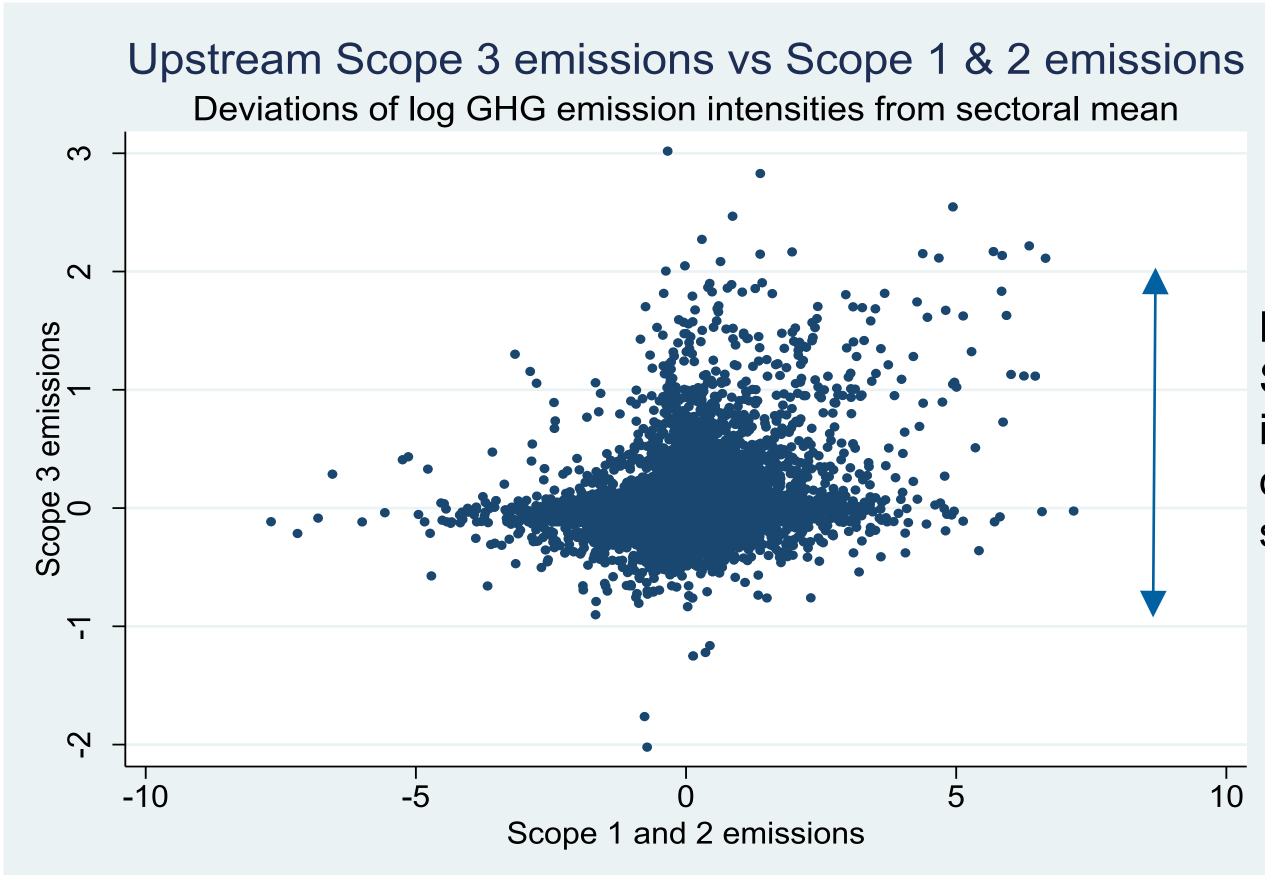
	Mean	Median	Std Dev	# Obs
Intensity levels				
Scope 1 & 2	338.56	39.33	2034.17	19,405
Scope 3 upstream	160.29	97.70	197.07	19,405
Carbon cost	498.84	169.84	2073.89	19,405
Log intensities				
Scope 1 and 2	3.794	3.672	1.790	19,405
Scope 3 upstream	4.577	4.582	0.990	19,405
Carbon cost	5.150	5.135	1.266	19,405

[1] Emission intensities are given as tons of CO2 equivalents, normalised by company revenue in millions of USD. Scope 1 and 2 emissions are direct emissions plus purchased electricity, heat and steam. Scope 3 upstream emissions are indirect emissions that result from intermediate inputs. Carbon cost is defined according to equation (3) as the sum of Scope 1, Scope 2 and upstream Scope 3 emissions. All data are reported unweighted.

Sources: Trucost environmental data, own calculations.

Logs nicely behaved. Scope 3 upstream emissions large contribution!

Company level carbon costs – checking information content



Logs of upstream Scope 3 emission intensities, deviations from sectoral means

Computing carbon costs

To evaluate inputs, we need values for **carbon costs on a product level**.

- Ideal case: Carbon costs for input goods are available from input provider. Carbon costs can be **computed** on the basis of equation (1) and cost accounting allocation models

− **We may approximate input carbon costs** using
- sectoral data from SEEA and EEIO models
- granular data from company level data of provider
- granular carbon costs of reference products

− Disclosed carbon costs and data for proxy valuations can be **disseminated centrally!** It is important that the producer uses her proprietary information!

A detour: Physical flow account of SEEA and EEIO models

- SEEA: "Standard of Environmental Accounting". A UN Standard for aggregate statistics on environmental issues. The physical flow account yields absolute values and intensities for direct and indirect emissions by sector, on the basis of IO models for the whole economy.

- Physical flow account for Germany shows the carbon content of final demand for 49 sectors

- EEIO models: specific IO models for modelling the use of ressources and emissions. The Trucost EEIO model yields carbon intensities for **464 sectors** (US based)

Eq (2) justifies the use of sectoral carbon intensities from SEEA and EEIO models as a first level estimate for carbon costs of inputs!

Top down and bottom up

Producers do not need to know the carbon costs of the whole economy, **only those of their own providers** (or estimates thereof), just as for **cost accounting** we do **not need to know the entire price system, just what our providers charge.**

If all producers give a fair estimate of eq (1) using the information they have, i.e.

- Direct emissions,
- Bill of Material (BoM),
- Carbon costs of input providers if available, estimates if not

and if this information is disclosed and used by all participants alike, in equilibrium the resulting system of carbon costs **will necessarily correspond to the solution given by eq (2)!**

Jumpstart the system with proxies and boot it bottom up!

Is there scope for voluntary disclosure?

It is conceivable to make disclosure compulsory. However, there is a path that leads to **voluntary disclosure by (almost) all firms:**

− Producers with low CC (relative to peer group) will have an **incentive to disclose.** With a low CC, **they can charge higher prices.**
− This generates a **signal value** for the **decision not to disclose**
− Can be **reinforced** by **disseminating disclosed carbon costs on a central data platform**
− Can be **reinforced further** by **calculating sector averages conditional on not disclosing**
− With many companies disclosing, those that do not disclose will **be looking really bad**.

To get this mechanism going, we may need to overcome a **threshold level of disclosures.**

How to get there?

- We need **auditing** to make sure that the carbon costs is a fair estimate, using the information on direct emissions and production interlinkages existing on the company level.

- **Centralised platforms** can make available for everybody the existing information
  - on industry averages (also reduced form from EEIO data)
  - on carbon costs on a product and on the company level, if available

In addition, platforms can compute estimated carbon content for firms of a given industry that do not disclose their CCs**,** from the known industry averages and the known CCs of the firms that do disclose. **This will give a strong incentive for disclosure!**

These measures will make carbon costs informative, an **effective instrument in competition.**

To sum up

- Simple concept: on every stage, the **cumulated carbon content** is computed. This is passed as carbon costs to the next stage.
- Starting with estimates, the **system converges** to the values given by the solution
- Information processing **mostly decentral**. Producers only need to know their technology and the carbon costs of their input. A platform is needed that communicates disclosed carbon cost
- There is a mechanism that makes **disclosure the outcome of economic incentives**
- The system will yield **encompassing and highly granular information.**
- **And central banks and international organisations may have an important role!**

Policy options for CBs and international organisations

1. Co-operate with Eurostat and the NSIs in setting up a **rather disaggregated EEIO-model for the Euro Area**, and also for some of the larger countries if this is warranted by observed heterogeneity.
2. Set up and maintain a **dissemination platform for carbon cost data** on the level of sectors, enterprises and products.
3. Develop and propagate **disclosure standards** and assist in setting them, as a basis for comparability and auditing. Those rules can build on the relevant GHG Protocol standards.
4. Interact with the EU Commission and with the IFRS on **disclosure requirements**, especially regarding the CSRD. Possible disclosure requirements should target large companies, as well as producers of primary goods and importers.

Reserve slide

Carbon costs – the three perspectives

Eq (1) is the definition of carbon costs. Carbon costs result from direct emissions and the carbon costs of other inputs. The system is recursive

$$c_k = d_k + \mathbf{r}_k{}'\mathbf{c} = d_k + \sum_i r_{ki}\, c_i \qquad (1)$$

Eq (2) gives the solution. Under standard regularity conditions, it is unique.

$$\mathbf{c} = (\mathbf{I} - \mathbf{R}')^{-1}\mathbf{d} \qquad (2)$$

Eq (3) shows how carbon costs relate to the standard GHG protocol definitons:

$$c_k = sc1_k + sc2_k + sc3u_k. \qquad (3)$$

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Application of text mining to the analysis of climate-related disclosures[1]

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[1] This presentation was prepared for the conference. The views expressed are those of the authors and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

Application of text mining to the analysis of climate-related disclosures[1]

Ángel Iván Moreno and Teresa Caminero[2]

Abstract

In this article we apply text-mining techniques to analyse the TCFD recommendations on climate-related disclosures of the 12 significant Spanish financial institutions using publicly available corporate reports from 2014 until 2019.

In our analysis, applying our domain knowledge, first we create a taxonomy of concepts present in disclosures associated with each of the four areas described in the TCFD recommendations. This taxonomy is then linked together by a set of rules in query form of selected concepts. The queries are crafted so that they identify the excerpts most likely to relate to each of the TCFD's 11 recommended disclosures. By applying these rules, we estimate a TCFD compliance index for each of the four main areas for the period 2014-2019 using corporate reports in Spanish. We also describe some challenges in analysing climate-related disclosures. The index gives an overview of the evolution of the level of climate-related financial disclosures present in the corporate reports of the Spanish banking sector. The results indicate that the quantity of climate-related disclosures reported by the banking sector is growing each year. Besides, our study also suggests that some disclosures are only present in reports different than annual and ESG reports, such as Pillar 3 reports or reports on remuneration of directors.

Keywords: sustainability, sustainability data gaps, text mining, TCFD, Taxonomy and Ontology Management

JEL classification: C81, G32, Q54

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2 All preceding authors work at the Financial Innovation Division of the Bank of Spain.

Contents

1. Introduction

The European Directive 2014/95/UE, also called the non-financial reporting directive (NFRD), represents an important milestone towards improving the current corporate reporting to include not only the tangible assets but also the intangible assets, such as the communication, the culture the brand and the reputation, which require non-financial indicators, besides the traditional financial indicators (Instituto de auditores internos de España, 2018). Recent studies indicate that the total value of the intangible assets can be greater than the value of the tangible assets (Brand Finance Institute, 2017). Climate-related disclosures are one type of non-financial disclosures that investors have been pressing companies to include in their reports. Although initially this might have been mainly driven by an ecological activism caused by growing awareness of the impact of financial investments on the deterioration of the Earth, it also soon became clear that climate change was a source of risks as well as opportunities. (FIR -Forum pour l'investissement responsible, 2016)

This interest on the financial impact of climate change prompted the G20 Finance Ministers and Central Bank Governors, in their Meeting in Washington in April 2015, to ask the Financial Stability Board (FSB) to "convene public- and private- sector participants to review how the financial sector can take account of climate-related issues" (G20 Finance Ministers and Central Bank Governors Meeting, 16-17 April 2015). Underscoring this need, in September of the same year, Mark Carney, Chairman of the Financial Stability Board (FSB) at the time, performed a historic speech (Carney, 2015) where he stressed the importance of company disclosures so that "better information – about the costs, opportunities and risks created by climate change – can promote timely responses" and introduced the Climate Disclosure Task Force (CDTF), later known as the TCFD (Task Force on Climate-related Financial Disclosures).

This speech acknowledged that Central Banks, in their mandate to protect financial stability, should consider the financial risk that climate factors create. It also made clear that climate-related corporate disclosures were key in assessing these risks.

In the financial sector in particular, in an analysis published in 2018, the Bank of England identified three broad categories in which banks were responding to climate-related risks: as being "responsible", focusing in the Corporate Social Responsibility (CSR) aspect to reduce reputational risk; as being "responsive", where climate change is viewed only from a short-term financial risk perspective and as being "strategic"; taking a long-term view of the financial risks involved (Bank of England, 2018). Although the report focused on banks, these three categories could also be applicable to other sectors.

In Spain, corporate reporting is mainly regulated by the "Ley de Sociedades de Capital". Accordingly, most corporations (depending on their type, the requirements may vary) need to produce three main types of reports[3]: Annual Financial Statements, Corporate Governance Report and Management Report. The Management Report and the Annual Financial Statements are often put together in one single document. Listed companies are also required to create an Annual Report on Remuneration of

3 Together with an Audit Report

Directors. As part of the Basel Framework[4] requirements, internationally active banks need to produce an additional prudential report following the Pillar 3 standard. In their Action plan for Sustainable Finance, the European Banking Authority (EBA) emphasized the need to disclose Environmental, Social and Governance (ESG) risks in this Pillar 3 report (EBA, 2019). In particular, climate change is referred to as part of the environmental risk factors on which the EBA will especially focus in the first phase of the action plan.[5]

The Annual Financial Statements are frequently produced in XBRL[6] format, as well as in pdf format, but they are often also part of a document normally called Annual Report which is meant for shareholders and other interested parties. This document is typically a colourful brochure that combines text, tables, pictures and charts and which also includes non-financial information. It sometimes follows a framework defined by the International Integrated Reporting Council (IIRC), which advocates for a single report where the financial and non-financial information is integrated in a cohesive way.

Before the transposition of the NFRD European Directive, there were no mandatory disclosures on many non-financial topics, including climate change, although many companies voluntarily created a separate ESG or CSR Report which served both as a marketing tool for investors and as a way to report non-financial information. While the mandatory reports are placed in the Commercial Register, the National Stock Market Commission (CNMV) or, in the case of the Pillar 3 report, at the Banco de España, there is no obligation to register the ESG reports in a centralized way. The NFRD Directive allows for publication of these reports in the respective corporate web sites. This actually means that the best way to find the main company reports that potentially contain climate-related disclosures is retrieving them from each individual corporate site.

There are several Spanish regulations related to the NFRD Directive, but for the purpose of this study it is worth mentioning three:

- Ministerial Order ESS/1554/2016, which, since the NFRD Directive allows for a separate report for the non-financial disclosures, establishes a voluntary procedure that allows publishing the ESG reports in a centralized way. This publicly available database was eventually called "Memorias de Responsabilidad Social de las Empresas" (MEMRSE[7]) and constitutes the Spanish Sustainability Register

4 The Basel Framework is the full set of standards of the Basel Committee on Banking Supervision (BCBS), which is the primary global standard setter for the prudential regulation of banks. The membership of the BCBS has agreed to fully implement these standards and apply them to the internationally active banks in their jurisdictions. (BIS, 2020)

5 Despite Climate Change being considered mainly an Environmental factor, both the EBA Action Plan and the European Commission Action Plan (European Commission, 2018) highlight that "Environmental and social considerations are often intertwined, as especially climate change can exacerbate existing systems of inequality. The governance of public and private institutions […] plays a fundamental role in ensuring the inclusion of social and environmental considerations in the decision-making process."

6 XBRL is the open international standard for digital business reporting, based on the XML standard and managed by a global not for profit consortium, XBRL International.

7 https://expinterweb.mitramiss.gob.es/memrse/entrada/listadoMemoriasPublicadas.action

- 11/2018 Act, with reference BOE-A-2018-17989, which is the main law that transposes the NFRD directive. This enforces a specific set of non-financial disclosure for certain corporations, being applicable starting in the 2018 reporting period.
- Draft bill of Climate Change and Energy Transition, according to which the Spanish Macroprudential Authority Financial Stability Council (AMCESFI, for *Autoridad Macroprudencial Consejo de Estabilidad* Financiera)[8] will have to evaluate every two years the climate change risks for the financial sector.

According to the Internal Auditors Institute (2018) the five main standards for non-financial reporting that Spanish Corporations follow are: Global Reporting Initiative (GRI); Progress reports of the United Nations Global Compact; CDP (formerly Carbon Disclosure Project) reports; Sustainability Accounting Standards Board (SASB) -although this is mainly used in the US as per recommendation of the Securities and Exchange Commission (SEC) - and the IIRC framework.

The *KPMG Survey of Corporate Responsibility Reporting 2017* identified that 77% of the top 100 Spanish Corporations use the GRI standard as a reference for their ESG reports. Besides, according to the same report, more and more companies are reporting following the IIRC framework.

Although the recommendations of the TCFD are meant to be considered as part of the financial reporting, in practice they seem to be included in the ESG reports (KPMG 2017 and Marqués Sevillano and Romo González 2018). According to a recent report on practices among financial firms (IIF, 2019), the type of documents where companies publish climate-related financial disclosures includes annual reports or climate position papers; ESG or CSR reports; integrated reports or Global Reporting Initiative (GRI) documents; and standalone TCFD reports. It is worth noting that in a 2017 response to the TCFD Report Consultation (GRI, 2017), GRI acknowledged that 8 out of the 11 recommended disclosures corresponded, at least in part, to disclosures already established in the GRI Standards, which would explain why companies might try to follow the TCFD recommendations in their sustainability reports. This overlap also means that companies following GRI in their disclosures were probably aligned with some of the TCFD recommendations even before 2017.

The multiplicity of standards and recommendations and the fact that there is still no XBRL taxonomy for ESG reporting, which would make this data computer-readable, means that analysts have to go through usually lengthy pdf documents to extract the key information they require for their analysis, whether it is for supervisory, credit assessment, investment or other purposes.

There are many ESG/CSR reports studies in the literature, such as the already mentioned KPMG *Survey of Corporate Responsibility Reporting 2017*. Some focus on sustainability or climate, such as Blacksun's study on the FTSE 100 ("The Ecosystem of Authenticity") or the Carbon Disclosure Standard Board (CDSB) report "First Steps: Corporate climate & environmental disclosure under the EU Non-Financial Reporting Directive". There are also studies on environmental disclosures specific to Spanish

8 The AMCESFI is an inter-agency collegiate body attached to the head of the Ministry of Economic Affairs and Digital Transformation and participated by high-ranking officials from the said Ministry and the three national authorities with prudential regulatory and supervisory responsibilities for the Spanish financial system: the Banco de España, the Comisión Nacional del Mercado de Valores (CNMV, National Securities Markets Commission) and the Dirección General de Seguros y Fondos de Pensiones (Ministry's Directorate General for Insurance and Pensions Funds). (Banco de España, 2020)

companies (Echave & Bhati, 2010) or GRI disclosures of Mediterranean countries (Tarquinio, Raucci, & Benedetti, 2018). But most of these studies are based on manual work of reviewing the reports. A computer-aided study was also performed in 2008 (Doran & Quinn, 2008) where they basically looked for the terms "climate change", "global warming" and "greenhouse gas" in the SEC 10K filings. On top of that, they also performed a manual analysis. El-Haj, et al. (2019) in their analysis of computational linguistics (CL) applied to the study of financial discourses, suggest using a Natural Language Processing (NLP) technique called Named entity recognition (NER) which they define as "an information extraction task that isolates and then classifies named entities into predefined categories such as person names, locations and organizations", identifying it as one of the tools to gain traction in mainstream accounting and finance research and which they believe "offer promising ways to enhance the study of meaning in financial discourse". The simplest NER method they describe is using "handcrafted lists" or "bag of words" to detect these entities. A list-based approach was followed by Kravet (Kravet, 2013) to detect risks in 10-K filings using keywords such as "can", "cannot", "could", "may" or "might".

NLP has been broadly used in financial research and, to a lesser extent, in central bank research, with a special focus on unsupervised techniques and applications related to sentiment analysis, topic modelling and complexity analysis (Bholat, Hansen, Santos, & Schonhardt-Bailey, 2015). Supervised machine learning techniques for NLP applied to finance are less found in the literature and most of the studies are focused on sentiment analysis. Despite the significant body of work around financial NLP applications, as A. Luccioni indicates in her finance section of the Climate Change AI paper (Rolnick, Donti, Kaack, Kochanski, & Lacoste, 2019), the field of climate finance has been largely neglected within the scope of financial research. Luccioni also argues that machine learning techniques can play a central role to improve this field. Together with H. Palacios they proposed an idea for a study on climate disclosures using state-of-the-art NLP tools (Luccioni & Palacios, 2019), although at the point of this writing this proposal has not been further developed. The growing importance of this type of disclosures, together with the inherent difficulty of identifying them due to their heterogeneity and dispersed characteristic, seems to make the actual task of gathering these disclosures worthy of some kind of automation.

In their 2018 and 2019 (TCFD 2018 and 2019) Status Reports, the TCFD also made use of supervised machine learning techniques to identify areas of the corporate reports potentially containing information related to each one of 11 recommended disclosures related to the four recommendations (see Figure 1 for a summary of the recommendations and recommended disclosures). The process required an initial labelling of passages from 150 companies to train a statistical model. Once trained, given an excerpt, the model would assign it a likelihood of being aligned with a recommended disclosure. By carefully adjusting the threshold, they created an index that allowed monitoring the level of compliance with the recommendations. In their 2019 Status Report they evaluated reports using AI from 2016 to 2019, including 104 banks of different jurisdictions and sub-industries, without giving additional details regarding the type of AI approach they employed.

The present study focuses on Spanish financial institutions, and in it we analyse 330 reports of the 12 significant Spanish institutions[9] to automatically estimate a TCFD compliance index. Instead of using a statistical model, we use a rule-based model. The index is built based on search queries using key concepts to identify excerpts where the different recommendations are likely to be followed. These key concepts are part of a taxonomy initially created using the Spanish Sustainability Register. It was later adapted to fit some specificities of the banking sector reports.

Recommendations and Supporting Recommended Disclosures

Figure 1

Governance	Strategy	Risk Management	Metrics and Targets
Disclose the organization's governance around climate-related risks and opportunities	Disclose the actual and potential impacts of climate-related risks and opportunities on the organization's businesses, strategy, and financial planning where such information is material.	Disclose how the organization identifies, assesses, and manages climate-related risks.	Disclose the metrics and targets used to assess and manage relevant climate-related risks and opportunities where such information is material.
Recommended Disclosures	**Recommended Disclosures**	**Recommended Disclosures**	**Recommended Disclosures**
a) Describe the board's oversight of climate-related risks and opportunities.	a) Describe the climate-related risks and opportunities the organization has identified over the short, medium, and long term.	a) Describe the organization's processes for identifying and assessing climate-related risks.	a) Disclose the metrics used by the organization to assess climate-related risks and opportunities in line with its strategy and risk management process.
b) Describe management's role in assessing and managing climate-related risks and opportunities.	b) Describe the impact of climate-related risks and opportunities on the organization's businesses, strategy, and financial planning.	b) Describe the organization's processes for managing climate-related risks.	b) Disclose Scope 1, Scope 2, and, if appropriate, Scope 3 greenhouse gas (GHG) emissions, and the related risks.
	c) Describe the resilience of the organization's strategy, taking into consideration different climate-related scenarios, including a 2°C or lower scenario	c) Describe how processes for identifying, assessing, and managing climate-related risks are integrated into the organization's overall risk management.	c) Describe the targets used by the organization to manage climate-related risks and opportunities and performance against targets.

Source: TCFD (2017)

To analyse the reports, we leverage NLP techniques using NER for information extraction. The NER method we use is based on a lexicon-based taxonomy that goes beyond the simplest "bag of words", taking into account lemmatization and regular

[9] As of 2020. Banks considered significant are under the ECB's direct supervision. To qualify as significant, banks must fulfil at least one of the criteria set out in the SSM Regulation and the SSM Framework Regulation regarding size, economic importance, cross-border activities or direct public financial assistance.

expressions[10]. We then use the recognized entities in a second step following a rule-based approach to query the documents in order to create a compliance index based on the matches. The rule-based approach has the benefit of being easy to understand as well as being flexible in calibrating the model, since rules are easier to modify than a training set of labelled data. Besides, although we did not use a statistical model for the NER process, using a statistical model is still possible and it would allow us to have a hybrid model (a combination of a rule-based model and a statistical model). Finally, the, automatic labelled data can easily be repurposed for helping the analysts identify specific topics within the domain, similarly to the 'human-in-the-loop' approach proposed by Luccioni and Palacios (2019). Specifically, when organizing related supervisory activities, this can contribute to a more efficient use of the available resources.

This approach is also similar to the one used for email surveillance for compliance purposes. In 2018 the Office of Compliance Inspections and Examinations (OCIE), which conducts the SEC's National Exam Program published a Risk Alert (OCIE, 2018) where it highlighted some examples of practices that would assist in complying with the regulation. Within these examples was to have the ability to "compare postings to a lexicon of key words and phrases". Some examples of key words that are typically used are "can't talk", "political", "tip" or "in exchange" (NAIC, 2018). The idea is that the presence of those key words in an email could be an indicator of employee misconduct. The lexicon can be organized into categories and additional rules might be used to have further information on the type of potential misconduct being identified. Although this approach can be prone to a significant number of false positives, it has the benefit of being easily interpretable, which is important in highly regulated environments.

The approach followed in this paper is also commonly used in enterprise search engines and is closely related to the technology referred by Gartner as "Enterprise Taxonomy and Ontology Management" (Gartner Inc 2016 and 2017). This paper also demonstrates that the current state of the art of the technology allows for research projects of intermediate size data using office-level personal computers.

In the following sections, first, we describe the selection process of the ESG reports available in the Spanish Sustainability Register. We used these reports to create the initial taxonomy, although we did not perform any additional analysis with them due to several inconsistencies. We then describe the selection process for the Bank reports, which we used to further enhance the taxonomy. The reports used in the analysis were not limited to Annual Reports and ESG reports, but were enriched with both national and banking-specific reports. These were as well the subject of our actual analysis of the financial institutions disclosures. Next, we define the rules to be used in the compliance index, also briefly describing the computer-aided process used to identify the text excerpts where the key areas of interest are located. Finally, we review some of the manual findings and challenges involved in analysing sustainability reports, and we evaluate the results of the calculated compliance index for the period 2014-2019.

[10] Regular expressions (aka regexes) are a sequence of characters that define a search pattern. Regexes have far more capabilities than the usual wildcard characters and have a standard textual syntax for representing patterns for matching text.

2. Methodology

The Spanish Sustainability Register

Although any company is allowed to submit their ESG Reports to the Spanish Sustainability Register, we decided to select only those companies under the definition of "Sociedades de Capital" which in Spain corresponds to "Sociedades de responsabilidad limitada", "Sociedades anónimas" and "Sociedades comanditarias por acciones" with more than 250 employees[11]. We did not exclude those companies that explicitly indicated that their ESG report did not contain environmental topics when they uploaded, since their ESG reports did not support that claim. This resulted in 118 reports of 53 companies for a period spanning from 2013 to 2018.

We found that the name of the reports can be misleading, since they can have names such as "Value Creation Report" or even "Annual Report" when they are actually ESG Reports. We can also find reports with the title "Progress Report" in reference to the United Nations Global Compact[12]. In any case, although Sustainability Reports typically use the GRI standards as a reference, there is no clear distinction between the content of ESG Reports, CSR Reports and Sustainability Reports besides the title given to them, which not always is fully aligned with the actual content. Therefore, we will refer to them globally as ESG Reports. In fact, in their latest review of their "Good Governance Code of Listed Companies", the CNMV has replaced the term CSR with ESG (CNMV, 2020). Out of the companies reviewed, only a single one had a specific "Non-financial disclosures report". The remaining corporate reports that we used were either ESG Reports (37 companies) or Integrated Reports (15 companies).

The reports present in this Register were scarce, some companies did not upload them for most of the years, and even there were reports not matching the claimed description. This made this source of information unfit for a broader analysis, but it was still useful for the creation of an initial taxonomy. Since the process involved a manual review of specific sections of interest, it also uncovered some challenges and issues related to ESG reporting. The main ones are described later in the paper.

Banks reports selection

After an initial taxonomy was created using the Sustainability Register as a baseline, this baseline was adapted with reports from the 12 significant Spanish financial institutions. In their 2018 Status Report, the TCFD evaluated the compliance with their recommendations by focusing on sustainability reports and financial filings of each company. It was further acknowledged that there was no single report where all disclosures could be found. They also included integrated reports, annual reports, "and other relevant documents" as needed, using reports of a previous year if the ones for 2017 were not available. In our analysis, to be able to compare disclosures

[11] This in line with the 11/2018 act, which, as mentioned in the introduction, is the main law that transposes the NFRD directive.

[12] The United Nations Global Compact is a call to companies everywhere to align their operations and strategies with ten universally accepted principles in the areas of human rights, labour, environment and anti-corruption, and to take action in support of UN goals and issues embodied in the Sustainable Development Goals (UN Global Compact, 2018).

coming from similar sources between financial institutions, only reports with a yearly frequency were selected. This means that documents such as policy reports and web-only content that was not annualized was not part of the study. This is in line with the TCFD recommendation that the disclosures should be issued "at least annually" (TCFD, 2017). This also leaves out policy documents or other documents which are not updated annually and might be referenced in the main reporting document. Thus, the types of reports we used were:

1. Integrated Reports, Annual Reports or alternatively, Financial Statements, including the mandatory Management Report. These were categorized collectively as "Annual Reports".

2. ESG Reports. "ESG" is considered in the general sense, as mentioned in the previous section, which means that there were institutions that had more than one ESG Report for a given year.

3. Corporate Governance Reports

4. Reports on Remunerations of Directors

5. Pillar 3 reports

Note that not all of them are mandatory and the minimum number of reports available for a given year can be as low as three (Financial Statements, Pillar 3 Report and Corporate Governance Report). In total 330 reports from the 12 significant banks were considered for the period between 2014-2019, having at least 3 reports for each institution and year.

These reports were manually retrieved from the corresponding corporate web sites. Whenever a mandatory report was not found in the corporate web site, it was retrieved from the CNMV web site. Once downloaded, the reports were classified, and they were processed in the same way as the ESG reports of the MEMRSE database. Besides, they were also analysed to adjust the taxonomy as described in the following section.

Taxonomy creation

To help with the creation of the taxonomy, we followed the workflow shown Figure 1. First, we processed the pdf documents in order to extract their textual content. This was performed in a two-step process: first, using a commercial tool called *Kofax Power PDF Advanced* the pdf documents were turned into *MS Word* documents. Then, using a Python script, the *Word* documents were processed to extract the text and to partition it into excerpts. The intermediate *Word* step allowed for identification of paragraphs, tables and bullet points. The script treated each paragraph and bullet point as an excerpt. It also considered as an excerpt every table by itself, as well as any text content identified as a text box by the conversion tool. The script applied some additional heuristics to perform tasks such as trying to identify titles to consider them part of the next contiguous excerpt.

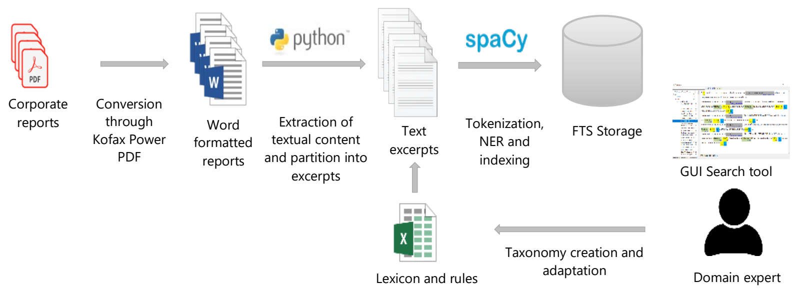
Within this study, we also developed a tool to be able to perform full text search (FTS) on the set of excerpts. The tool tokenized[13] and indexed all excerpts and allowed quickly finding all instances where a given word was used. The number of resulting

[13] The process of tokenization is used in NLP to identify each individual lexical item present in a text, and it typically refers to demarcating the words within a text.

excerpts for the total of the 330 corporate reports of the 12 significant institutions was close to 570.000.

Representation of the workflow of our approach

Figure 2



Source: Own elaboration

By using the FTS technique and manually reviewing the matching sections within the corporate reports, a taxonomy of concepts was created with the TCFD recommendations in mind. This way, for **Governance**, some of the specific concepts identified were: *board*[14,] *management*[15], *sustainability committee*, *remuneration* and *periodicity*. For **Strategy**, some specific concepts were: *climate scenarios* and *temperature increment*. For **Risk Management**: *climate change risks*, *transition risks* and *physical risks*. For **Metrics and Targets**: *scope*, *CO_2 emissions* or *CO_2 units*. There were also other general concepts that could be used in any of the categories in combination with other concepts, such as: *climate change*, *sustainable* or *value*. The latter was used to identify numerical quantities, and it is an example of a concept where a regular expression pattern is more effective than a list Table 1 shows the main concepts used in the different recommendations.

Each of the concepts was then linked to a lexicon created from the actual reports also adding potential variants using our own domain knowledge. For example, for directors, the list contained, among others, the Spanish equivalent of Chief Executive Officer or general manager. Table 2 shows a sample of the actual Spanish content of three of the concepts of the taxonomy.

The purpose of the lexicon was to label the excerpts accordingly. To simplify the process, a given word could only have one label. If a given sequence of words was present in a concept and a subsequence of these was present in another concept, the longest sequence always prevailed. For example, in relation to the *CO2 emissions* concept, which included "emisiones de CO2" (Spanish for *CO2 emissions*). There was

14 Board of Directors or Board refers to a body of elected or appointed members who jointly oversee the activities of a company or organization (TCFD, 2017). In Spain this is known as "Consejo de Administración"

15 Management refers to those positions an organization views as executive or senior management positions and that are generally separate from the board (TCFD, 2017). In Spain this is referred as "alta dirección" or simply "dirección".

another concept called *emissions,* which among others, included the word *emisiones* (Spanish for *emissions*). If "emisiones de CO2" appeared in an excerpt, it would never be labelled as simply *emissions*, since there is a concept (*CO2 emissions*) with a longer sequence of matching words.

Main concepts used in each of the 11 recommended disclosures

Table 1

Recommendation	Recommended Disclosure	Sample of concepts used
Governance	a. Board Oversight	board, remuneration, periodicity, follow-up
	b. Management's Role	management, remuneration, periodicity, follow-up, sustainability committee
Strategy	a. Risks and Opportunities	climate change risks, opportunities, transition risks, physical risks, lending, mortgage, green loans, short, medium, long, extreme climate, cost reduction
	b. Impact on Organization	standards, strategy, impact, reputational risks, reporting standards, technology use, renewable energy
	c. Resilience of Strategy	climate scenarios, temperature increase
Risk Management	a. Risk ID & Assessment Processes	climate change risks, opportunities, transition risks, physical risks, processes, reporting guidelines, legal risk, reputational risk, financial risk, regulation, international agreements
	b. Risk Management Processes	risk response, materiality, carbon pricing, litigation, extreme climate, renewable energies, transition costs
	c. Integration into Overall Risk Mgmt	Integrated management, identification, risk management control system
Metrics and Targets	a. Climate-Related Metrics	reduction, CO2 emissions, waste, energy consumption, water consumption, fuel consumption, renewable energy, value
	b. Scope 1,2,3 GHG Emissions	Scope, CO2 emissions, CO2 units, intensity
	c. Climate-Related Targets	target, reduction, CO2 emissions, waste, energy consumption, water consumption, fuel consumption, renewable energy, value

Source: Own elaboration

In order to reduce the number of errors due to ambiguities, a special *not applicable* category was created. This was deemed necessary as there were words that could be used within an applicable concept as well as within a concept not useful for the current analysis. Often including one or two of the surrounding words was enough to distinguish the meaning. For example, climate was initially part of the lexicon related to the climate change concept, but soon it became clear that in the reports there were more usages of *climate* in a different sense (*working climate, climate survey, organizational climate or political climate*). This resulted in only considering climate in combination with other words in order for it to be applicable to the climate change concept (e.g. *climate change* or *energy and climate*).

Sample of the actual Spanish content of three of the concepts of the taxonomy

Table 2

CO2 emissions	Climate change risks	management
emisiones de co2	riesgos de cambio climático	director ejecutivo
niveles de carbono emitido	riesgos del cambio climático	comité de dirección
emisiones de carbono	riesgos derivados del cambio climático	dirección general

Source: Own elaboration

Additionally, often the actual text of the GRI requirements is also included in the ESG reports. To prevent identifying the actual text of a GRI reporting requirement as the text to comply with the requirement, verbatim sentences of the actual requirements were included as part of the *not applicable* concept. A similar situation happened with other mandatory reports that included the disclosure requirement as part of the report (e.g. Remuneration of Directors Report).

The lexicon was further lemmatized and lowercased, to consider this way minor variations of the terms. The excerpts were then automatically processed using Python and labelled according to the defined taxonomy.

Rules definition

To define a taxonomy of named entities for the NER model, we started from the 11 TCFD recommended disclosures. Since they are quite broad in their scope, we further divided those disclosures into 91 fine-grained disclosures using our own domain knowledge based on the examples and guidelines described by the TCFD (TCFD, 2017). For each of these fine-grained disclosures, we defined a rule to determine if the disclosure was present in any of the corporate reports. The output of each rule was a value between 0 and 3. A zero value indicated that the disclosure was not found, while a value of three meant that there was a high probability that the disclosure was properly reported. Values 1 and 2 indicated a lower degree of certainty that the disclosure was either present or properly reported. For example, within the "Board Oversight" recommendation, one of the potential specific disclosures was information on how frequently there was a follow-up with the Board with the corresponding committee or similar on climate-related topics. The rule associated with this disclosure had three queries with varying level of precision in mind. If there was a match with the first query, it was evaluated as a "3", if it was the second query or third query that matched, it was evaluated as a "2" or "1" respectively. In the instance of no match, it resulted in a "0".

Table 3 shows this sample case where the three rules show a decreasing progression of specificity in their search concepts. Note that in the event of matching multiple queries for a given specific disclosure, only the maximum value was taken into account. It was also perfectly possible that the same excerpt would account for two different specific disclosures. This was considered acceptable, so the corresponding score was assigned to the different disclosures according to the resulting value of the rule. It is important to highlight that the number of matches did not influence the result. The rules would assign the same score regardless if there was one or multiple excerpts that matched.

Sample case of three rules with a progression of flexibility in their search concepts

Table 3

Recommendation	Recommended disclosure	Specific disclosure	Query	Value
Governance	Board Oversight	Follow-up frequency with the Board	**board** AND **periodicity** AND **sustainability_committee**	3
			board AND **periodicity** AND **climate_change**	2
			board AND **periodicity** AND (**sustainable** OR **esg**)	1

Source: Own elaboration

The 4-level scoring system allowed for a greater granularity than a binary approach (the disclosure is present or not present). Besides, since each recommended disclosure actually can refer to a diversity of specific disclosures, the rule approach gives the possibility to additionally create a weighting schema, which we did not use in this paper, to modulate the importance of specific disclosures.

The queries were defined using a very simple query language based on a combination of concepts from the taxonomy. The concepts could only be combined using the boolean operators AND, OR and NOT. Parentheses were allowed to group operators together.

After several iterations and reviews, eventually, 205 queries were defined, using a total of 81 different concepts. These queries were used to identify 91 different fine-grained disclosures, each one linked to one of the 11 recommended disclosures. Not all specific disclosures had 3 queries. Some of them had only 1 or 2. Table 4 shows the number of specific disclosures and number of queries for each of the recommended disclosures.

As an example of one of the ideas that was used to guide the levels is the differentiated concepts of *climate_change* and *sustainable*. The first one was related to the explicit mention of climate impact, while the second one was more related to the impact to the environment and natural resources. Besides, the word "sustainable" with the meaning of "able to be maintained" in phrases like "sustainable growth" or "sustainable in time" was considered part of the *not applicable* category. Frequently, the rules were designed so that the relation of a disclosure with *climate change* was evaluated with a higher score than when it appeared only in relation with *sustainable*.

This approach is similar to but slightly more flexible than the one used by TCFD in their manual review where, for the Governance recommendation, they considered that "if a company described board or management responsibilities related to sustainability or ESG programs, but did not explicitly state that those programs included climate-related issues, the company's disclosure was not considered as aligned with the recommended disclosures". (TCFD, 2018).

Number of specific disclosures and queries for each of the recommended disclosures

Table 4

Recommendation	Recommended disclosure	# Specific disclosures	# Queries
Governance	a. Board Oversight	8	19
	b. Management's Role	13	34
Strategy	a. Risks and Opportunities	11	24
	b. Impact on Organization	16	24
	c. Resilience of Strategy	1	3
Risk Management	a. Risk ID & Assessment Processes	6	13
	b. Risk Management Processes	11	20
	c. Integration into Overall Risk Mgmt	3	7
Metrics and Targets	a. Climate-Related Metrics	7	18
	b. Scope 1,2,3 GHG Emissions	8	24
	c. Climate-Related Targets	7	19

Source: Own elaboration

To calculate the index for each recommended disclosure, the average scoring of the specific disclosures was calculated and scaled to a number between 1 and 10. This value was then averaged across all the institutions to obtain the total score. The results can be seen in Figure 3 and are discussed later in the paper. Besides calculating the score, we also analysed the percentage of times each report type was used for scoring. Figure 4 shows a chart with this information. Whenever multiple reports matched the corresponding query, a precedence list was followed to create the chart, so that only one document was accounted. This means that only the first matching document of the following list was used in the chart: Annual Reports, ESG Reports, Corporate Governance Reports, Remuneration of Directors Report and Pillar 3 Reports.

3. Evaluation of manual review findings

Although the ESG reports can follow a reporting standard (as mentioned before, in Spain this is commonly the GRI standard), they are typically not audited at the same level as the Financial Statements, if audited at all. The Non-Financial Disclosures (NFD) reports are often audited through what is known as "limited assurance engagement". This is the lower level of the two levels defined in the NIEA 3000 standard, which is the standard adopted by the Instituto de Censores Jurados de Cuentas de España (ICJCE, 2019).[16]

Among the different problems we have found while manually reviewing the reports of the MEMRSE database, it is worth mentioning:

16 This lower level is targeted towards reducing the risk to an "acceptable level" to allow expressing the opinion of the auditor in a negative form. The higher level is targeted towards reducing the risk to a "reasonable level" to allow expressing the opinion of the auditor in a positive form.

- The ESG reports too often contain marketing wording. Quoting Richard Howitt[17]'s comment in the foreword of the 2019 Research Report (Alliance for Corporate Transparency, 2020): The major extractives company who sets its objective as "The wellbeing of our people, the community and the environment is considered in everything that we do," exposes 'warm words' rather than concrete targets, which are espoused in too much of today's reporting. This means that queries used to identify specific disclosures needed to be carefully crafted to actually find the appropriate excerpts.

- It is not uncommon to find that a value for CO2 emissions reported one year is different from the one that appears as reported for that year in the report of the following year. For, example, a company may report 112 t of CO2e in 2014. When looking at the report of 2015 the emissions of 2014 may appear as 113 t of CO2e. Greenhouse Gas emissions (GHG) calculation is not an easy task, especially for big companies, and information required to perform the calculation might be delayed at the time of publishing the report, thus causing minor variations of the actual value. However, this change should be explained somehow in the report where the new value is reported. This would avoid confusion and would also allow stakeholders that actually keep track of those values to update their records accordingly. Unfortunately, more often than not, this clarification is not present. In any case, the objective of this semi-automated analysis was not to identify these errors, but whether the information was reported.

- As also identified by the TCFD (TCFD, 2018), companies often do not describe the reasons for a given climate-related project, making it difficult for investors to understand the relevance of this project in relation to the company strategy. For example, when a company states that it "has multiplied its sustainability projects" without further information, leaving aside the fact that there is no information of which of these projects is related to climate-change, it is also not clear the benefit of these projects to the organization, with each project even potentially having a different strategic objective.

- There are instances where the climate related context is not fully contained in a given section, especially with risk management (TCFD, 2018). Since sections are typically further divided into excerpts, this situation would prevent the technique used in this paper from identifying those disclosures.

On top of that, we have to consider some of the technical problems presented by typical ESG reports, among others:

- Since the reports are meant to be read by people, numerical information is often provided in the form of charts or infographics. This representation, although visually appealing and sometimes easier to understand, is difficult to transform into a cohesive textual excerpt that could be further processed by a machine. Extraction and Optical character recognition (OCR)18 tools might be able to identify the text pieces embedded in the images, but since the relationship between these text pieces is a spatial one, it will be lost when

[17] MEP with responsibility for parliamentary negotiation of the Non-Financial Reporting Directive in 2014. Chief Executive Officer, International Integrated Reporting Council (2016-2019)

[18] Optical Character Recognition is the process of converting images of text into machine-encoded text.

only considering the text itself, often losing the context of each individual text piece.

- Tables are also another common format to disclose numerical information. Similarly to infographics, companies tend to create visually appealing tables. The more imaginative and aesthetically designed a table is, the more challenging it is for a machine to identify it as a table. Sometimes, due to the distinct visual and spatial differentiation of the row or column headers in relation to the rest of the table, the Kofax conversion tool identified the headers and the body as independent elements and represented them in Word as two different tables, as a text-box and a table or even an image and a table. Although we added some hand-crafted rules to the processing script to cover some cases, this could cause the original table to end up divided into two excerpts, with the header in one and the body in another. Since each excerpt was treated independently by the rules, this also meant that the body of the table was deprived of the context implied in the headers.
- The pdf format is meant to be a description of a fixed-layout document as opposed to a reflowable format. Consequently, page breaks are clearly delimited. This often causes paragraphs to be broken even in mid-sentence. Although some heuristics were used to reduce this problem, there were always cases where a paragraph ended up divided into two excerpts. This problem was compounded whenever tables were involved since it was difficult to detect whether there were actually two tables or one continuous table across two pages.

4. Evaluation of TCFD Compliance Index

The resulting value of the compliance index is shown in the chart of Figure 3. The bars represent the aggregated index for each *Recommended disclosure* while the lines show the range of values of the 12 institutions with marks signalling the index of each individual bank. The vertical areas highlight the limits of the 4-level scoring mechanism used in the analysis.

Figure 4 shows the distribution of report types where the disclosures were found. Only one report per disclosure is accounted for, following the priority indicated in the legend. The length of the bar represents the percentage of specific disclosures actually found in the reports for all banks, regardless the score obtained for each specific disclosure.

Governance Observations

a) Board Oversight

The rules used in this recommended disclosure were aimed to identify those excerpts with the presence of the *board* concept together with *climate change* related concepts, including concepts such as *periodicity*, *risks*, *remuneration* and *sustainability committee*. The chart in Figure 3 shows a progressive improvement of reporting from the apparently lowest level of 2015. Both 2014 and 205 have an aggregated score below the first scoring level, both in terms of number of specific disclosures and in terms of the score obtained by the defined rules. There seems to be more and more involvement of the respective Boards in climate-related issues. As can be seen in the chart of Figure 4, while Annual Reports and ESG Reports contain the largest amount of specific disclosures for other recommended disclosures, in this case, Corporate Governance, Pillar 3 and, increasingly, the Remuneration of Directors reports display a similar proportion of specific disclosures. As mentioned in a previous section, the fact that the rules use a flexible scoring in relation to the *Climate change* concept to accommodate the *Sustainable* concept, probably has the effect of showing a higher compliance level than what would be expected from the analysis performed by the TCFD in their Status reports.

b) Management Oversight

The rules used in this recommended disclosure were aimed to identify those excerpts with the presence of the *management* concept together with most of the concepts included in the previous disclosure with minor variations. The results displayed in Figure 3 do not seem to have a clear trend, probably because the Spanish reporting regulation is more focused on Governance disclosures at the Board level than at the Management levels. This is supported by the fact that the CNMV's *Code of good Governance* focuses on disclosures related to the Board (CNMV, 2020). Overall management oversight ranks as the second lowest scored disclosure, with the aggregated score not surpassing the first level in any of the analysed years.

Strategy Observations

a) Risks and Opportunities

The rules used in this recommended disclosure were aimed to identify those excerpts with the presence of the general *risks* and *opportunities* terms in relation to *climate change* considering *short, medium* and *long* terms, including *transition risks* and *physical risk*, as well as specific risks and opportunities such as *extreme climate*, *cost reductions, lending* risks and *green products*. As with Board Oversight, the results in Figure 3

show a progressive improvement of reporting, but with a lowest located in 2014, also both in terms of number of specific disclosures and in terms of the score obtained by the defined rules. The lower margin also has an ascending trend, pushing the scores to the right side of the chart. In the chart of Figure 4 it is noteworthy the increased proportion of specific disclosures found in Pillar 3 reports, which should not come as a surprise since one of the main purposes of Pillar 3 reports is to provide stakeholders with information on the bank's material risks

b) Impact on Organization

The rules used in this recommended disclosure followed a variety of patterns. There were rules aimed to identify the presence of the *risks* concepts in relation to *climate change* and *impact, strategy* or *objectives,* with a specific rule for *reputational risks*. There were also rules to find references to *climate change reporting standards*. Finally, there were rules to find specific impacts such as *technology use* or *renewable energy usage* in relation to *climate change*. The chart in Figure 3

shows a trend very similar to Board Oversight, with a lowest located also in 2015. As seen in Figure 4, Pillar 3 reports keep gaining importance in this area. As with the previous disclosure, the lower margin has an ascending trend, making the total score very close to the edge of the third lane. We interpret this as indicating that banks are increasingly reporting that climate-change issues are causing an impact in their organization such as adapting using new technologies or performing specific actions to reduce their reputational risk.

c) Resilience of Strategy

This recommended disclosure had only one rule, albeit with 3 queries, focused on identifying reporting of *climate scenarios* on *temperature increase*. The chart of Figure 3 shows that no institution reached level 3, and most were at level 0, although there is a clear progression towards levels 1 and 2. Note that level 2 indicates a lower certainty that the information was actually disclosed, not necessarily that the information was disclosed with lower quality, but in any case this makes this disclosure the lowest scored of all.

Risk Management Observations

a) Risk ID & Assessment Processes

The rules used in this recommended disclosure were aimed to identify those excerpts with the presence *risks* and *processes* in relation to *climate change*. Also references to *regulation,* specific risk-related *reporting frameworks* and *international agreements* together with *climate change*. As seen in the chart of Figure 3, this area shows a slow growth from an already moderate level, with the lowest scores also moving to the right. The chart of Figure 4 shows that Pillar 3 reports are gaining importance progressively in this area. Corporate Governance reports seem to be identified as a source of this disclosure in the early years, but their overall weight decreases in the last years.

b) Risk Management Processes

As per the TCFD Annex (TCFD, 2017), both this recommended disclosure and disclosure a) of the Strategy recommendation are referred to the same table of “Examples of Climate-Related Risks and Potential Financial Impacts”. This means that disclosures in these two areas will very likely share similar concepts, being sometimes difficult to establish a clear differentiation between the two. Besides, there is also an overlap between this recommendation and the previous one. In fact, in their overall observations of their 2018 Status Report, the TCFD actually merged these two recommendations. In any case, the rules used in this recommended disclosure were aimed to identify those excerpts where concepts such as *risk_response* or *materiality* in relation to *climate change* were present. There were additional rules aimed to find references to *carbon pricing, litigation* and *transition costs,* always linked to *climate change*. As shown in the chart of Figure 3, there is an upward trend in this disclosure, with the lowest score also increasing its value, while the chart of Figure 4 shows that close to a third of excerpts are found in Pillar 3 reports.

c) Integration into Overall Risk Management

The rules used in this recommended disclosure were aimed to identify those excerpts with the presence of *climate change* in relation to the *integrated management* concept and *risks* or *risk control system*. This was the recommendation with the second lowest number of rules, being difficult to identify a wider variety of concepts that could fit into this recommended disclosure Figure 3 shows that, as with most disclosures, we find an upward trend, this time also with a minimum in 2015. It is not until 2018, that the aggregated score goes above the first level. As per Figure 4, Pillar 3 reports seem to start including this recommended disclosure from 2017.

Metrics and Targets Observations

a) Climate-Related Metrics

The rules used in this recommended disclosure aimed to identify common metrics such as *renewable energy*, *emission reduction*, *waste*, *energy consumption*, *water consumption* or *fuel consumption*. Excerpts with actual *values* were evaluated higher, but it is difficult to determine whether the *values* were always actually related to the metrics. Figure 3 shows that this is the recommended disclosure with the highest score overall.

b) Scope 1, 2, 3 GHG Emissions

The rules used in this recommended disclosure tried to differentiate between the 3 different *scopes* and between raw *emissions* and *intensity* of *emissions*, also giving more weight to the excerpts where actual *values* were reported. Due to the limited breadth of the rules, there were actually banks that had the highest possible score in this disclosure. Figure 3 shows that the trend from 2014 to 2019 is also upward, with the exception of 2017. The first level is only surpassed in 2016, 2018 and 2019. As seen in Figure 4, this disclosure appears mainly in excerpts of Annual Reports and ESG Reports.

c) Climate-related Targets

The rules used in this recommended disclosure are very similar to the ones in the Climate-Related Metrics disclosure, but with the addition of the *target* concept. Figure 3 shows that, while the trend of the values is mostly kept, the actual values suffer a steep drop compared to the previous recommended disclosure because of this, which seem to indicate that institutions are much keener to report on the climate-related metrics than on the targets. The drop seems to be more intense for 2014 and 2015. Only in 2018 and 2019 they are slightly above the first level, making this disclosure the third lowest scored. Pillar 3 reports have a residual relevance in this disclosure, while for the metrics disclosure their weight was significant.

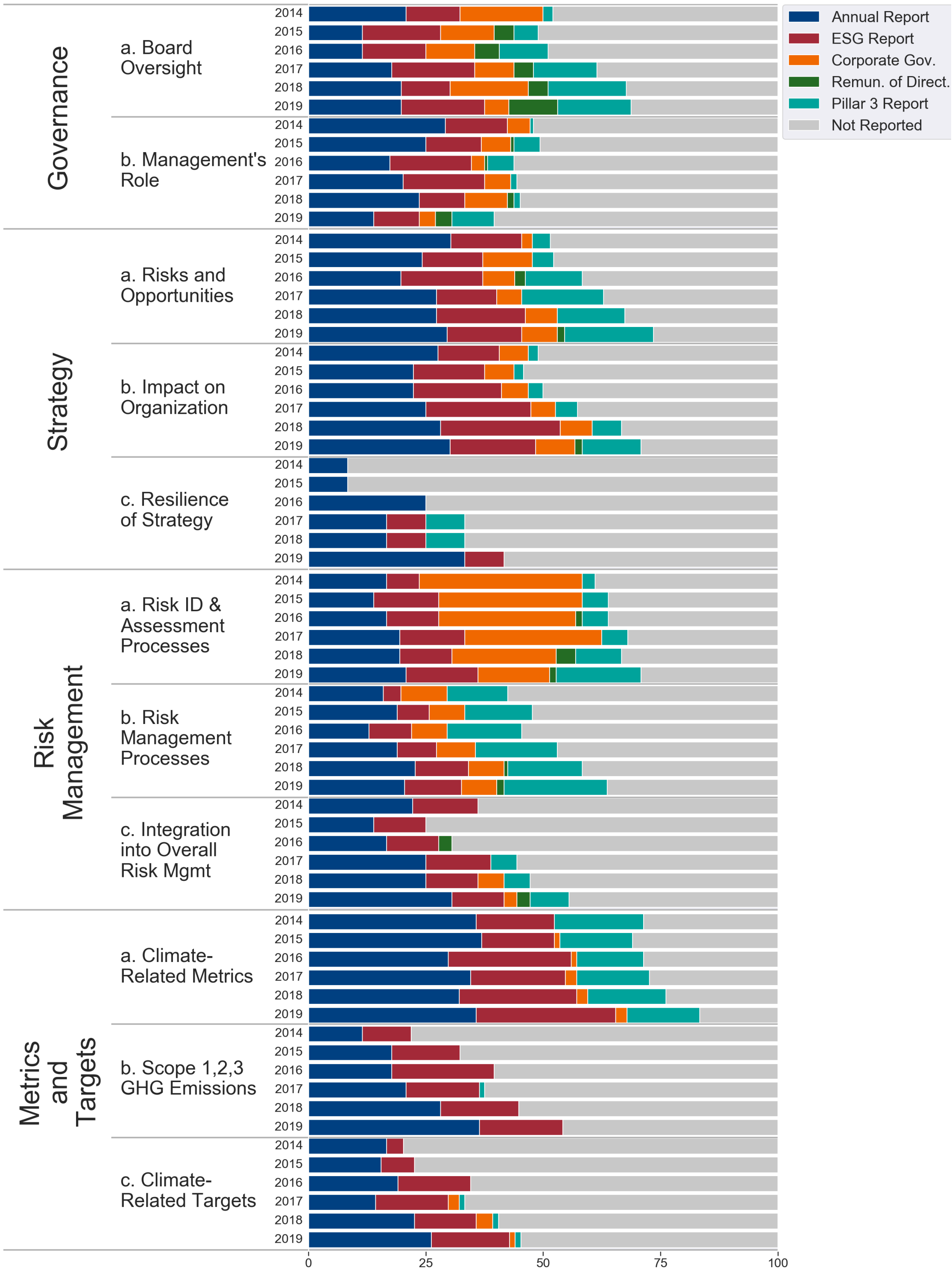
Estimated Compliance Index for the recommended disclosures. The bars represent the aggregated index while the lines show the range of values of the 12 institutions with marks signalling the index of each individual bank. The vertical areas highlight the limits of the 4-level scoring mechanism used in the analysis.

Figure 3

Source: Own elaboration

Distribution of report types where the disclosures were found. Only one report per disclosure is accounted for, following the priority indicated in the legend. The length of the bar represents the percentage of specific disclosures actually found in the reports for all banks, regardless the score obtained for each specific disclosure

Figure 4



Source: Own elaboration

5. Conclusions

In this paper, we used a rule-based NER approach to estimate an index that measures the level of compliance of the climate-related financial disclosures with the TCFD recommendations. We have applied this approach to estimate this TCFD compliance index analysing 330 reports of the 12 significant institutions of Spain using an NLP approach driven by NER.

Identifying the sections of the reports addressing specific climate-related financial disclosures can be seen as a text classification task, with really fine-grained categories. Besides, the number of excerpts that actually relate to a climate-related disclosure within the financial reports is sparse. Finally, some disclosures are much more present than others thus making the categories imbalanced as well. The fine granularity of the categories together with the scarcity and data imbalance present serious difficulties to an automatic text classification algorithm. Adding the fact that the language is not English but Spanish, also limit the availability of resources for a supervised machine learning approach. The approach presented in this paper relies on domain expertise and builds upon the traditional bag-of-words technique to create a rule-based NER model that not only helps analysts identify where potential disclosures are present, but also can be used for text classification purposes. When applied to the identification of climate related disclosures of the 12 significant Spanish banks we showed that banks are progressively improving their climate-related reporting, with three areas where banks seem to be lagging: Management Roles disclosures, Resilience of Strategy disclosures and Climate-Related Targets disclosures. It also showed that Annual Reports and ESG Reports should not solely be considered when evaluating the level of compliance with the TCFD recommendations, since national and sector regulations might indicate the need to include additional corporate reports to be able to have a better picture.

Due to the fact that the reporting documents are typically in pdf format and make extensive use of infographics, charts and, sometimes, graphically edited tables, the extraction of the textual information presents several challenges. This, together with the ambiguity when disclosing certain information and other findings perhaps related to disclosure regulations not being as specific and strict as with financial information, make the task even more challenging.

The use of lexicons and rule-based approaches to text categorization is frequently discarded in favour of machine learning based techniques, although lexicons are still often used in sentiment analysis. In this paper, we have also shown a practical application of a rule-based approach that despite having the traditional problem of the need of domain expertise, it also tries to reduce the complexity problem through the creation of a taxonomy, providing this way higher flexibility and better interpretability. The rule-based model of the NER phase, could be enhanced with a statistical model, resulting in a hybrid model that could reduce the problem of words that have different meanings depending on the context as well as help with the scalability problem inherent to rule-based models. While the performance of a statistical NER model can typically be improved with additional training using annotated data, the performance of a rule-based model requires careful consideration of the existing rules as well as domain expertise. Is it also important to note that, in the case of a statistical model, domain expertise is required as well to be able to properly annotate training data, which can also be time-consuming. Besides, in instances where there is not enough data to train a statistical model, the effort might substantially increase in order to prevent the model from performing poorly, as synthetic data might need to be generated, with contexts where a given set of words is meant to be identified as a certain entity together with contexts where the same set of words is not. Alternatively, the identification of words to be added to the lexicon could also be aided with the application of word2vec techniques to obtain lists of similar words from which the domain expert can choose. This way, the approach described in the paper allows for a progressive improvement as analysts identify shortcomings.

The TCFD compliance index can be further enhanced with additional rules and a weighting schema of the different specific disclosures. Since the TCFD compliance index outlined in this paper has been crafted to identify specific fine-grained disclosures, equally weighted, if a different weighting schema is used or if the index gets enhanced with additional disclosures, results will obviously vary and certain banks might perform differently in comparison, due to the human bias introduced when creating the rules.

The publication of the TCFD recommendations represent an important milestone towards standardization of the climate-related disclosures that are material to organizations. Following Carney's speech, by making sure that organizations provide better information about the costs, opportunities and risks created by climate change, timely responses can also be identified. But as long as climate-related disclosures do not reach the standardization level of financial statements, ideally in a machine readable format, analysts will have to carefully manually review the multiple reports published by corporations. The application of NLP techniques can greatly facilitate this task. Since there are specific corporate reports that are only in the Spanish language, it is important to develop NLP resources that help the advancement of the Spanish NLP applications. The approach presented in this paper can also be used to help building a baseline of training data for a machine-learning model that could overcome the scalability problem

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APPLICATION OF TEXT MINING TO THE ANALYSIS OF CLIMATE-RELATED DISCLOSURES.

Ángel Iván Moreno and Teresa Caminero García

Banco de España
September 14-15, 2021

FINANCIAL INNOVATION DIVISION

BANCO DE ESPAÑA
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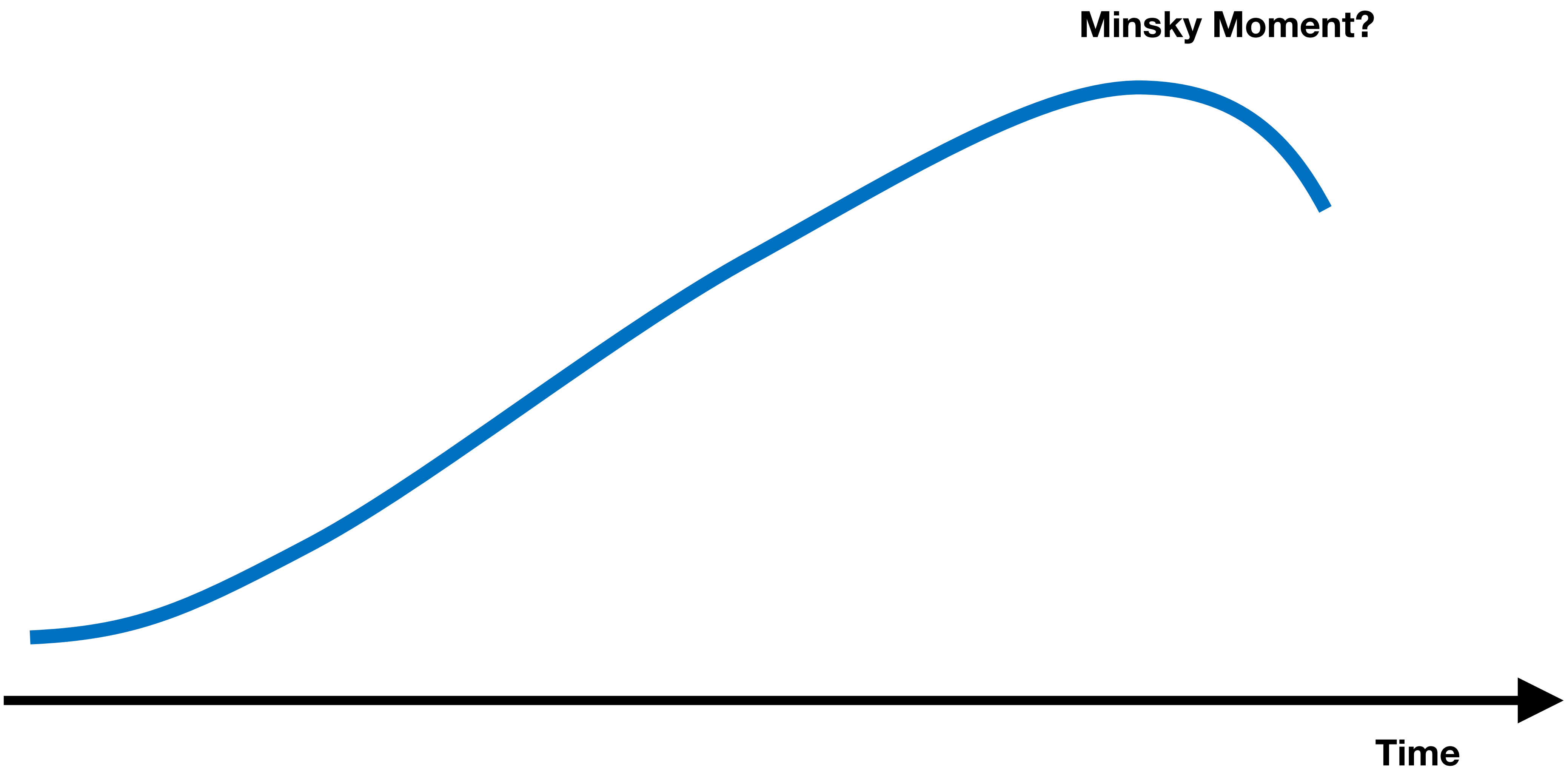
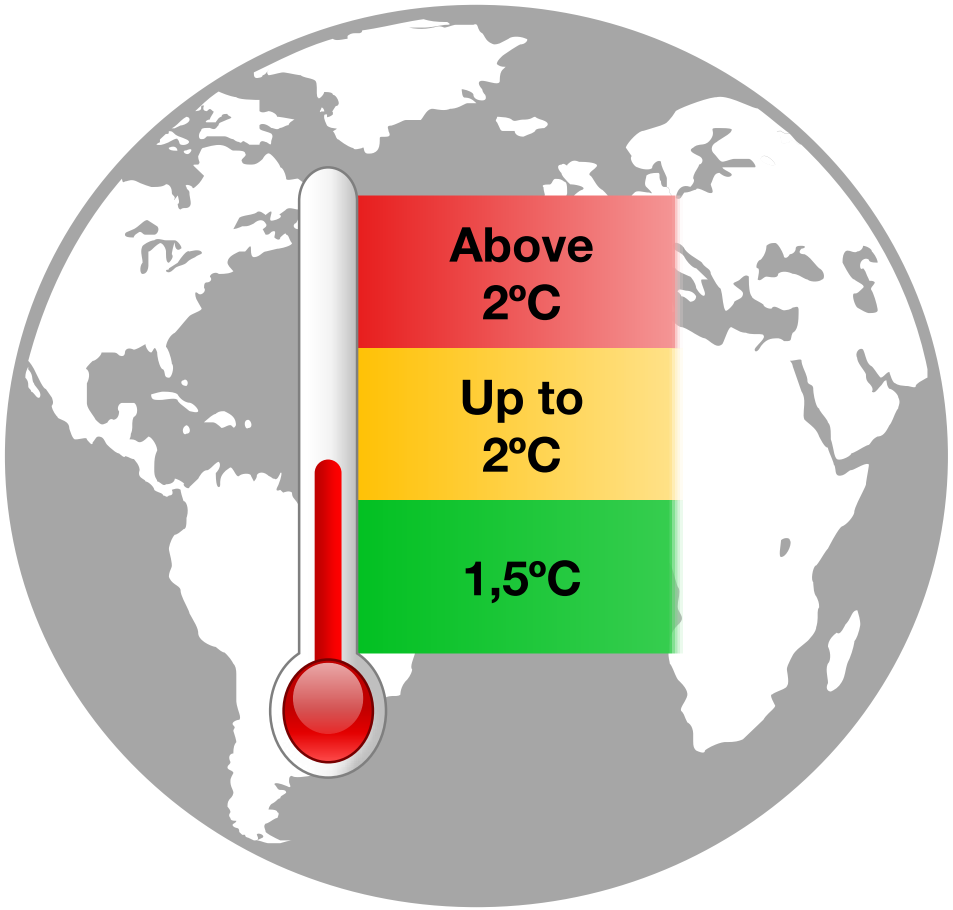
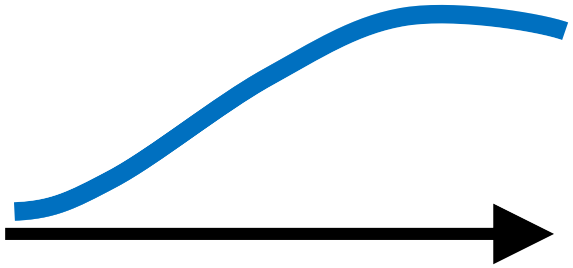
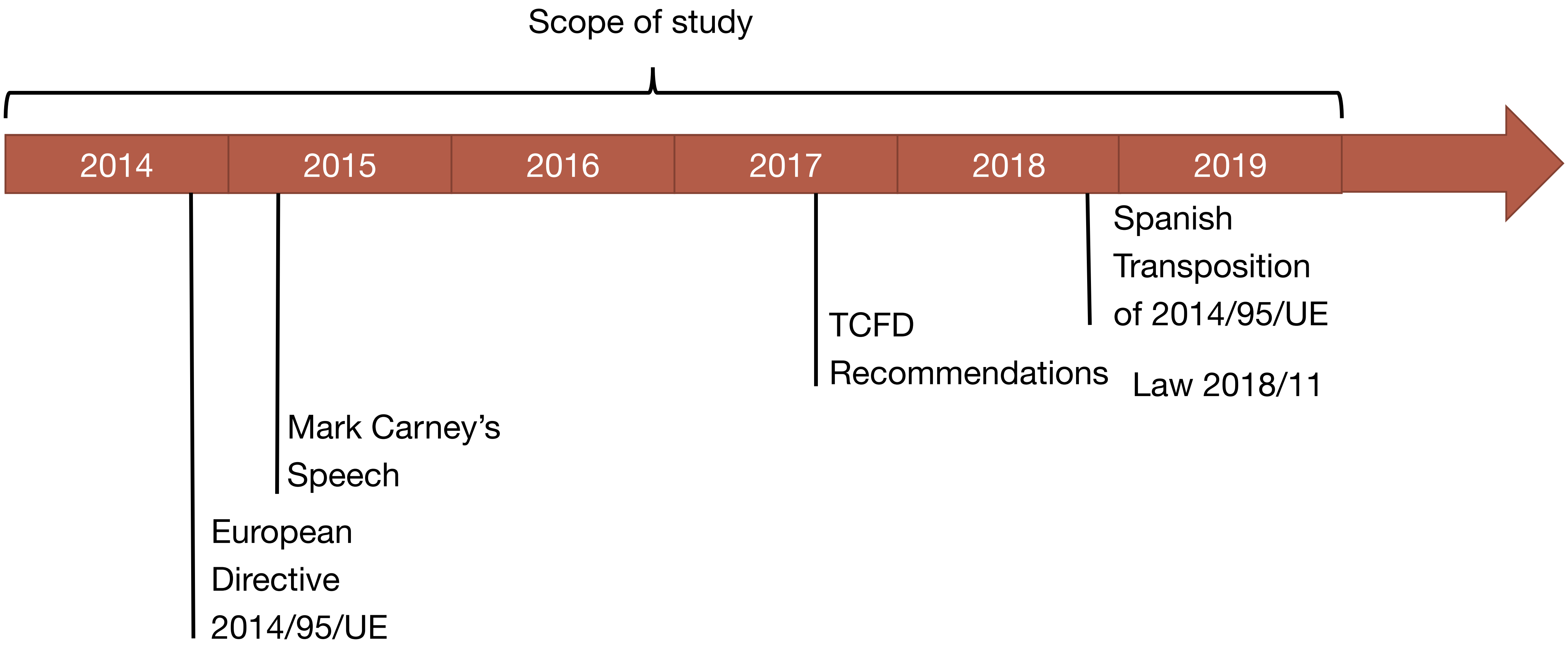


PARIS2015
UN CLIMATE CHANGE CONFERENCE
COP21·CMP11



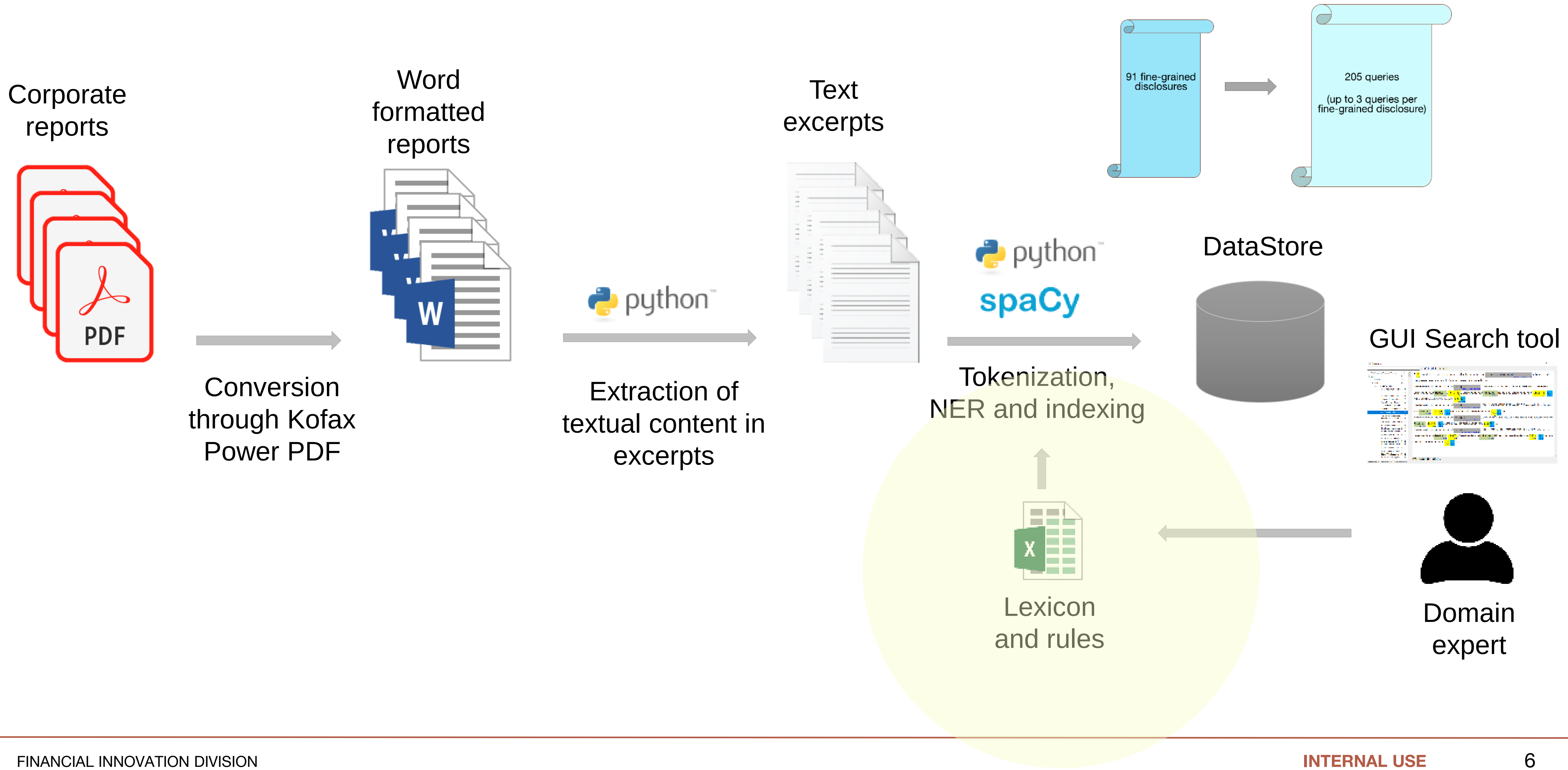


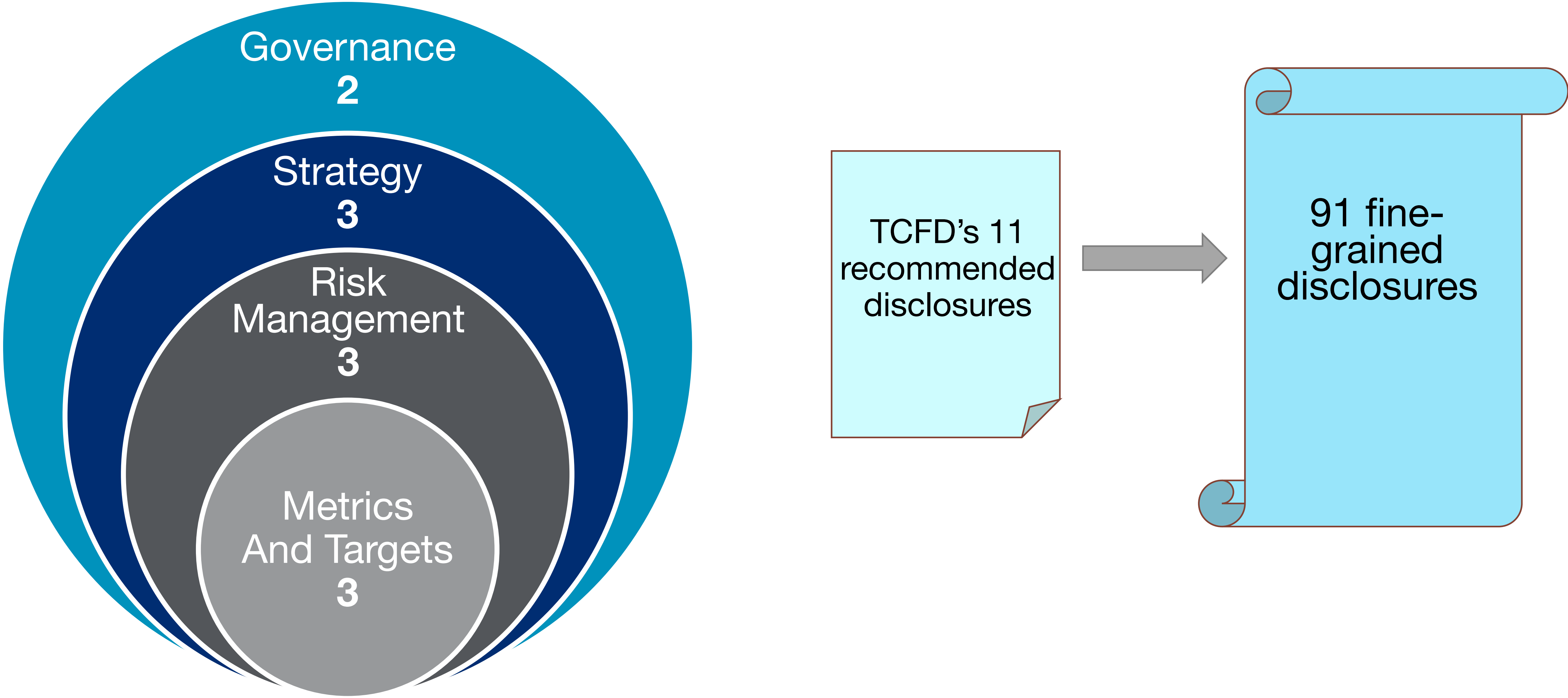

Scope of study
2014
2015
2016
2017
2018
2019
European Directive 2014/95/UE
Mark Carney's Speech
TCFD Recommendations
Spanish Transposition of 2014/95/UE
Law 2018/11

- Technique?
- Mainly Annual Reports and ESG Reports
- English

- Flexible and interpretable method
- Banks
  *Sector-specific *(Pillar 3)*
  *Country-specific
  (Directors' remuneration report)
- Spanish

THE RULE-BASED MODEL




Governance
2
Strategy
3
Risk Management
3
Metrics And Targets
3
TCFD's 11 recommended disclosures
91 fine-grained disclosures

Governance

a) Describe the board's oversight on climate-related risks and opportunities

Describe the frequency of the board's meetings
with a sustainability committee

NAMED ENTITY RECOGNITION (NER)
Fine-grained disclosures

The Board meets monthly with…

NER Model

The Board meets monthly with…

climate-change

sustainability

Rule-based

- Lexicons
- Regular Expressions
- Rules

Machine Learning

RESULTS

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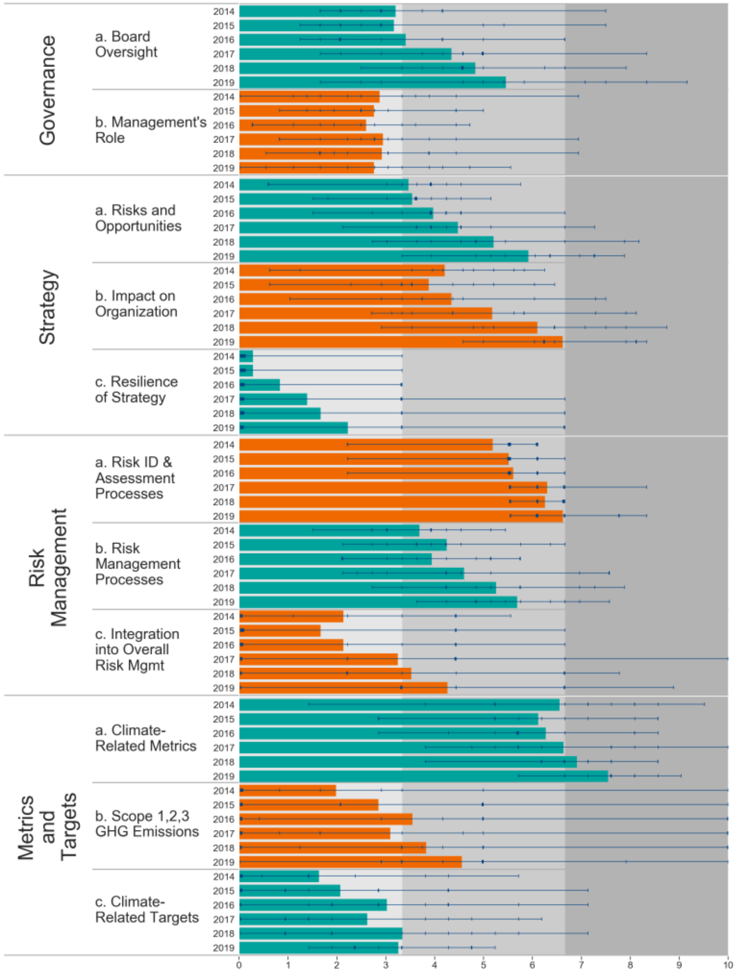
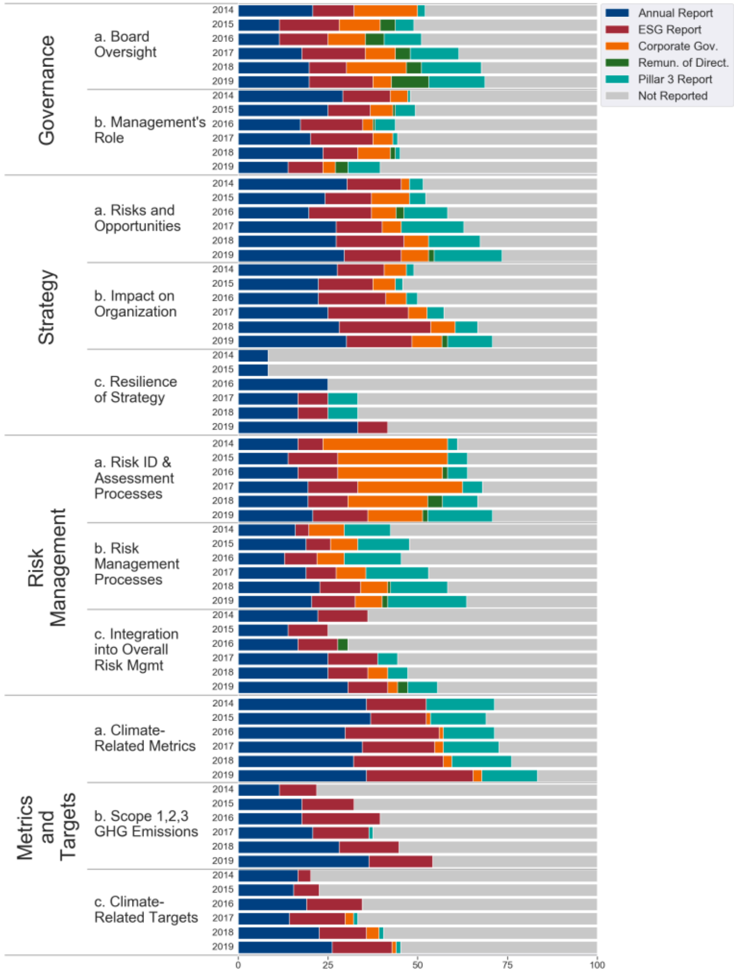
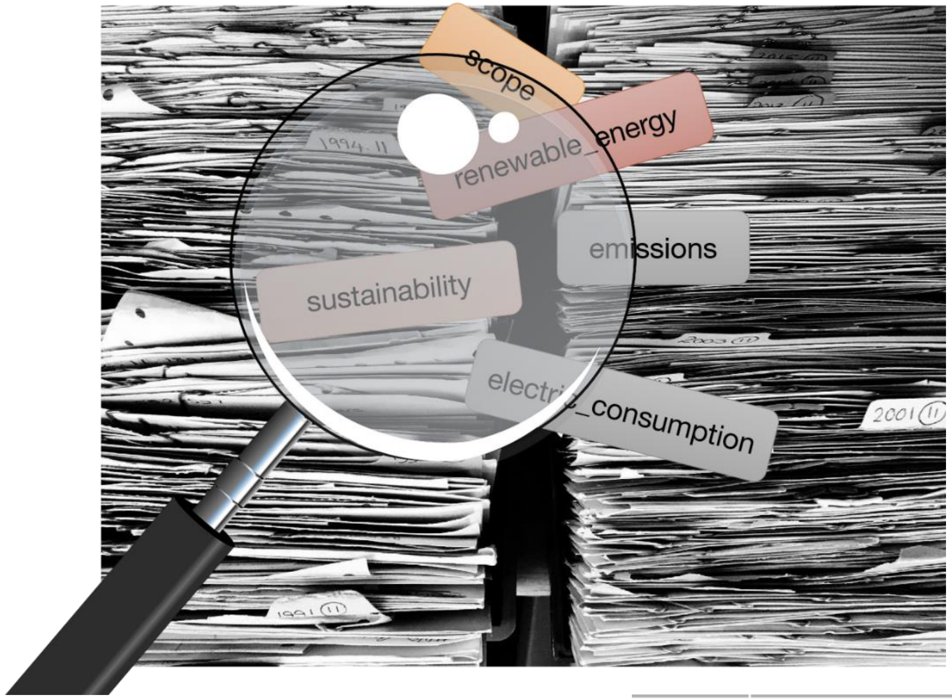
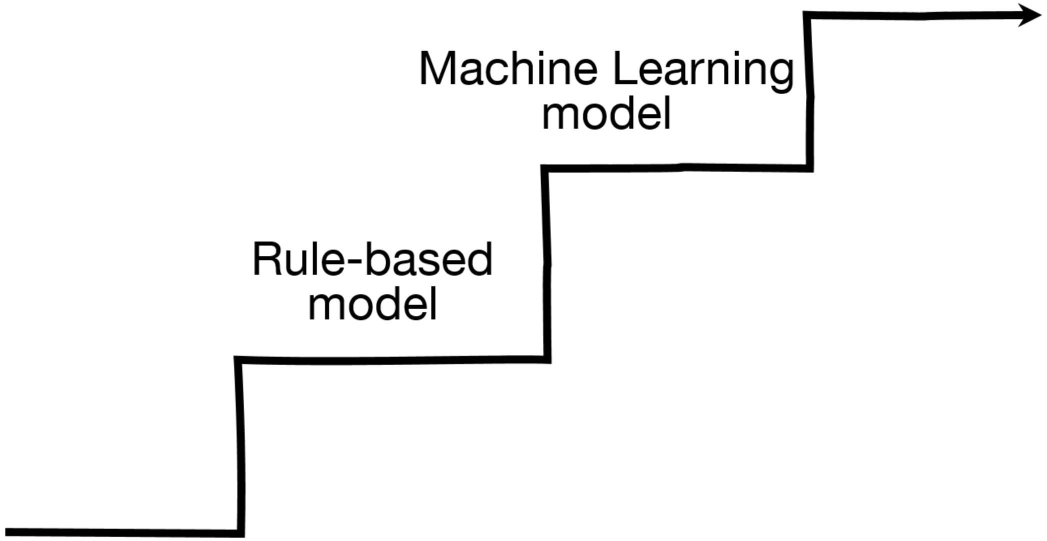
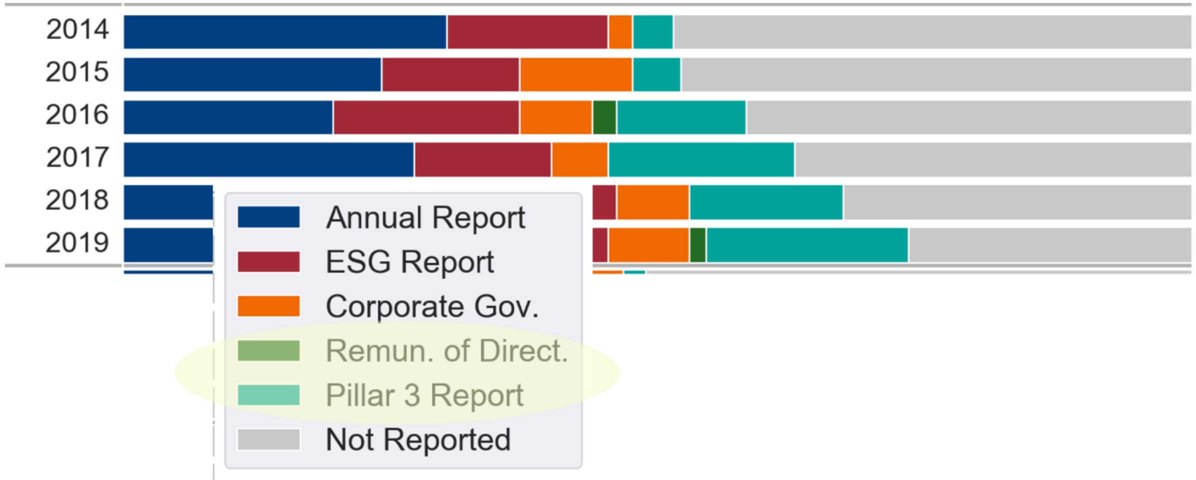




CONCLUSIONS







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Transition versus physical climate risk pricing in euro area financial markets: A text-based approach[1]

Giovanna Bua and Daniel Kapp, European Central Bank;
Federico Ramella, Amsterdam Business School;
Lavinia Rognone, Alliance Manchester Business School, The University of Manchester

[1] This presentation was prepared for the conference. The views expressed are those of the authors and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

Transition versus physical climate risk pricing in European financial markets: A text-based approach

Giovanna Bua (European Central Bank), Daniel Kapp (European Central Bank), Federico Ramella (Amsterdam Business School) and Lavinia Rognone (Alliance Manchester Business School, The University of Manchester)[1]

Abstract

We examine the existence of physical and transition climate risk premia in euro area equity markets. To do so, we develop two novel physical and transition risk indicators, based on text analysis, which are then used to gauge the presence of climate risk premia. Results suggest that climate risk premia for both, transition and physical climate risk, have increased since the time of the Paris Agreement. In addition, we investigate which metrics may be used by investors to proxy a firm's exposure to either physical or transition risk. To this end, we construct portfolios according to the most common firm-specific climate metrics and estimate the sensitivity of these portfolios to our risk indicators. We compare results from these firm-level proxies to much simpler sectoral classifications to see if investors may simply pigeonhole firms into the industry they operate in. We find that firm level information appears to be used as a gauge for transition risk, in particular since 2015, whereas sectoral classifications appear insufficient. However, sectoral classification may be employed to broadly gauge firms' exposures to physical risk.

Keywords: Climate risk premia, Transition risk, Physical risk, Text analysis

JEL Classification: C58, G12, G14, G28, Q51

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Contents

Introduction

As climate change progresses, investors are increasingly reported to reflect climate-related risks in firms' valuations. While this observation may seem obvious in light of the overarching evidence which shows that climate change and the measures taken to combat it represent a source of financial risk, documenting climate risk pricing or the presence of climate risk premia is not trivial - as demonstrated by conflicting results throughout the green finance literature (Bolton & Kacperczyk, 2021a; In et al., 2019; Alessi et al., 2019; Hsu et al., 2020; Pastor et al., 2021b). Several factors might impede investors from allocating capital to firms which serve as a hedge from climate change; for example the lack of agreed-upon metrics for firms' exposure to climate-related risks, alongside the difficulty of identifying and measuring climate risk events over time (Engle et al., 2020). It follows that investors might not be able to easily screen exposed firms, failing to detect climate risky investments (Bolton & Kacperczyk, 2021b). In contrast, there is the possibility that market participants are insensitive to shocks in climate change, which would suggest that they do not perceive these risks as a major source of financial risk. Both scenarios could lead to a mispricing of climate change risks with important consequences for the functioning of the financial sector as such and as a vehicle to transmit climate mitigation policies.

To investigate the pricing of climate risk, we first build two novel physical and transition risk indices exploiting text analysis and then use these to gauge the presence of physical and transition climate risk premia in euro area equity markets over the period from January 2005 to October 2021. We then investigate the impact of these climate risk factors on portfolios constructed according to common firm-specific climate metrics in order to identify which metrics are likely used by investors to proxy for a firm's exposure to either physical or transition risk. As an alternative exposure metric we also use sector classifications and investigate if investors simply pigeonhole firms into the industry they operate in – rather than using firm-level information, as hypothesized by Bolton & Kacperczyk (2021b).

Considering that climate change can affect asset prices through changes in physical risk or transition risk[2] we propose to distinguish between physical and transition risk using a text analysis approach proposed by Engle et al. (2020). To this end, we examine scientific texts on climate change to build two novel vocabularies on physical and transition risk which are able to capture the multifaceted characteristics of these two risk types. We compare the vocabularies with a corpus of news sourced from Reuters News, from which we obtain a Physical Risk Index (PRI) and a Transition Risk Index (TRI). The approach is based on the idea that investors use newspapers as a source of information to update beliefs about gyrations in climate

[2] Physical risk materialises in the form of financial losses/increased costs from the impact of chronic (gradual shifts in, e.g., wind and precipitation, and longer-term, e.g., sea levels, desertification, and ocean temperatures changes) and acute (extreme weather such as floods, droughts, and wildfires) physical events. Exposed companies can be affected through damaged assets and disruption of business operations. Transition risk arises from the costly adjustment towards a low-carbon economy and it is typically prompted by changes in climate and/or environmental policy, technological advances, and/or shifts in public preferences (ECB, 2019; NGFS, 2020). Transition risk is usually of most concern for companies with large dependencies on energy and fossil fuels and, depending on how fast and orderly the process of decarbonization occurs, its impact may worsen over time with the potential to cause large swings in asset prices and "stranded" assets.

change risks and supposes that news coverage on climate change intensifies if as climate risks rise (Engle et al., 2020).

We find that PRI and TRI spike during days where the discussion on either risk type increases substantially. Results show that PRI captures multiple aspects of physical risk, allowing for instance to detect unexpected news concerning rising sea levels, heat waves, permafrost thawing, floods, adaptation measures. The TRI is able to detect news regarding the introduction of new regulation to curb greenhouse gas (GHG) emissions as well as news discussing the importance of technological advances to a climate-neutral economy, among others.

To assess the presence of climate risk premia for physical and transition risk in the crosssection of European stock returns we adopt a standard portfolio sorting approach covering the period January 2005 to October 2021, which we further divide in two sub-periods, before and after 2015. This is in line with recent studies that document an increase in the importance of climate risks since the time of the Paris Agreement (Bolton & Kacperczyk, 2021a; Goldsmith- Pinkham et al., 2021; Krueger et al., 2020; Painter, 2020). We perform time series regressions of equity returns on climate risks, controlling for Fama French factors known to drive returns, and gauge equity market sensitivities to carbon risk. The resulting loading on the risk factors, i.e. the transition and physical risk betas, are our firm-level indicators of climate risk exposure. Stocks which depict a positive climate risk beta tend to appreciate when investors are concerned about climate risk. Since investors can be expected to want to hedge against climate risk, they should be willing to accept lower expected returns for equities that appreciate when climate risk increases (high beta portfolios). In turn, this means that 'climate risky' stocks should trade at a discount and offer higher expected returns. A low-minus-high transition (physical) climate beta portfolio should therefore earn positive excess returns in case a climate risk premium existed. Results indicate the emergence of both, a physical and transition climate risk premium since 2015.

To test which exposure metrics may be used by investors to proxy firms' exposure to physical or transition risk, we then include the constructed climate risk series into a Fama & French (2015) five factors asset pricing model. Firms are sorted according to their GHG emissions levels, GHG emissions intensity, Environmental (E) scores, and Environmental, Social, and Governance (ESG) scores, with returns being aggregated into green and brown portfolios. Second, we conduct a sectoral analysis by aggregating returns of firms belonging to the same sector (NACE Rev. 2 classification). Overall, we find that firm level information appears to be used as a gauge for transition risk exposure, in particular since 2015. In contrast, sectoral classifications, in the light of many investors, appears to be sufficient to identify exposures to physical risk.

This paper contributes and relates to a growing strand of literature which focuses on understanding the impact of physical and transition climate risks on asset prices[3]. Pástor et al. (2021a) recently developed an equilibrium model which predicts that, in a crosssectional setting, green assets generate negative alpha (lower expected returns) compared to brown assets, but green assets can outperform brown assets (higher realized returns) when agents are surprised by climate change concerns. While this conjecture appears convincing, empirical evidence on the presence of carbon risk premia is not yet conclusive. Whereas some authors find that investors do require additional compensation for holding brown assets, especially following the Paris

[3] for a more complete review see Hong et al. (2020) and Giglio et al. (2021)

Agreement, others provide no evidence of price differentials (see Bolton & Kacperczyk (2021a); In et al. (2019); Alessi et al. (2019); Hsu et al. (2020); Pastor et al. (2021b)). As such, the literature on the consequences of changes in physical risk is less developed and has so far mainly focused on specific risk events. For example, Addoum et al. (2020) analyse high temperature events, finding only limited impact on companies' sales, productivity, and earnings. Hong et al. (2019) focus on the occurrence of droughts, documenting an impact on food companies' stock returns. Kruttli et al. (2019) explore how the uncertainty resulting from hurricanes impact financial markets.

This paper also relates to the strand of the climate finance literature which uses text analysis to measure climate risks (Batten et al., 2016; Engle et al., 2020; Meinerding et al., 2020; Faccini et al., 2021). While these studies all improve upon risk identification in their own rights, they either consider climate change as a single risk factor (Engle et al., 2020), focus only transition risks (Batten et al., 2016; Meinerding et al., 2020), or focus on specific sub-categories of physical and transition risks (Ardia et al., 2020; Faccini et al., 2021)[4].

This study differs from previous ones as it separates climate change risks into physical and transition risk, capturing the entire multifaceted characteristics and multiple dimensions of the two climate risks without discarding relevant categories. Our vocabularies are able to capture both, extreme and chronical physical hazards directly caused by climate change, including natural disasters attributable to other sources. This sets our physical risk index apart from many other physical risk databases. Another advantage of the proposed methodology is that the phraseology associated is extracted from authoritative texts rather than being defined ex-ante by the authors. Finally, the estimation of physical- and transition specific betas allows us to investigate the information content of specific exposure metrics and to understand how they are used by investors.

The remainder of this paper is organised as follows: Section 2 describes the text analysis methodology and provide a discussion of the resulting physical and transition risk indices. Section 3 provides estimates of transition and physical risk pricing in euro area equity markets. Section 4 describes the data and section 5 lays out the main results. Section 6 concludes.

Measuring climate risk through text analysis

To test whether financial markets are sensitive to shocks in physical and transition climate risks we need proxies to measure these risks. We exploit newspaper content to identify shocks in physical and transition risk. We do so following and expanding upon the text analysis approach used by Engle et al. (2020) - who proxy innovations to climate change news, but without distinguishing between physical and transition risk. More precisely, we first compare authoritative texts on climate risk with a large

[4] Using a textual analysis approach, Ardia et al. (2020) identify eight climate change sub-categories, labelled by the authors as "Financial and Regulation", "Agreement and Summit", "Public Impact", "Research", "Disaster", "Environmental Impact", "Agricultural Impact", and "Other". Faccini et al. (2021) filter news by "climate change" and "global warming" to then employ a Latent Dirichlet Allocation approach to cluster news topics. The authors label the resulting topics into a "Natural Disasters", "Global Warming", "International Summit", and "U.S. Climate Policy" factors

amount of news with a European regional focus from Reuters News[5] based on the assumption that events covered in newspapers can carry relevant and genuinely new information on climate change. We create two separate vocabularies, i.e. lists of words associated with the topic of interest, and use these to construct two risk indices, one containing physical and one containing transition risk shocks. The main innovation here lies in the fact that our indices relate to both risk types *separately* and embody the multifaceted characteristics of each one.

Physical risk and transition risk vocabulary

We create two separate vocabularies for physical risk and transition risk. These are context-scaled, i.e. capture risk-specific characteristics and their interconnections. A key feature of our vocabularies is the ability to rank terms by relevance. This allows for a deeper understanding of each risk nature and to examine which risk aspects turn out to be most important in the overall risk description.

To construct the climate risk vocabularies, we follow three main steps. First, we select a large number of scientific and authoritative texts on the topic of climate change published by governmental authorities and other institutions, starting with the collection already adapted by Engle et al. (2020). We screen these texts' content and retain those whose content can be associated to either physical risk or transition risk topics. We further add financial texts describing both risk types as a genuine attempt to construct risk measures which incorporate multiple perspectives. The complete list of texts is summarised in Table A2 in the Appendix. We aggregate the 13 (10) texts covering physical (transition) risk to create a single document on physical (transition) risk.

Second, we create two lists of unique stemmed unigrams and bigrams, jointly referred to as terms, with the associated term frequency scores (*tf*) from these physical risk and transition risk documents. Then, we create an analogous list of terms and frequencies from Reuters News, where real-time news are aggregated into daily documents. To do so, we retrieve a total of over 2.5 million real time news from the Factiva database over the period Jan 2005-Oct 2021. Thereafter, we apply a one-day novelty filter to the sample to eliminate redundancy among the data. Specifically, only the first news of the day is kept from a series of similar news published on the same day (see Dang et al. (2015), Rognone et al. (2020), and Faccini et al. (2021)) and only news published during days in which European equity markets are open for trading are retained[6]. The final sample contains 1,096,392 news. We then convert the physical transition) risk document and each daily news document into term frequency-inverse document frequency (*tf-idf*). Terms earn high *tf-idf* if they are representative for the individual text. This means that they are frequent within the document (high *tf*) and infrequent among other documents (high *idf*). Low *tf-idf* score terms are common to many documents (low *idf*) or very infrequent within the document (low *tf*) and

[5] Reuters provides business, financial, national and international news to professionals via desktop terminals, the world's media organizations, industry events and directly to consumers. Reuters News also includes the Breakingviews.com content and provides news delivered instantly in multiple languages (Source reuters.com and reutersagency.com, accessed on 16/06/2021). We use English language news.

[6] News which corpus length exceeds 5,000 words are not included in our analysis for both computational reasons and because they can be considered as outliers due to their great length and very marginal occurrence.

therefore have poor ability in representing the content of the individual text (Engle et al., 2020; Gentzkow et al., 2019).

Third, by multiplying the tf scores of the physical risk and transition risk documents by their relative idf scores from the collection of news[7], we are able to obtain vocabularies ranked by term relevance.

The advantage of our methodology, which combines the *tf-idf* with the screening of texts on the topic of physical and transition risks, is that the phraseology associated with the two types of risks is extracted from the authoritative texts rather than being defined ex-ante by the authors. Each vocabulary is also found to capture the multifaceted characteristics of each climate risk type, rather than single aspects. This can be seen in Figure 1, which shows the most relevant terms of the transition risk vocabulary (right panel) and the physical risk vocabulary (left panel) as word clouds, where each term size is proportional to its *tfidf* score. For instance, the physical risk vocabulary includes both extreme and chronical hazards directly caused by climate change, excluding natural disasters attributable to other sources. Accordingly, the transition risk vocabulary includes various aspects of this climate risk such as technological advances and environmental policies. Terms such as "*ecosystems*", "*sea level*", and "*precipitation*" are representative of the physical risk topic, while terms such as "*hydrofluorocarbon*" (HFC), "*bioenergy*", and "*greenhouse gas*" (GHG) are representative of the transition risk topic.

In addition, the estimation technique allows to distinguish between physical and transition risk while acknowledging that these are overlapping concepts to some extent. For instance, the term "*GHG*" appears in both vocabularies, but to a different extent. It plays a primary role in explaining transition risk and a minor one for physical risk. The term "adaptation", on the other hand, represents a common concept for physical and transition risk and therefore appears in both vocabularies. However, its semantic differs depending on it being considered within the context of physical or transition risk and thus depends on the other terms in the vocabulary. These examples suggest that the constructed vocabularies are also likely to capture interconnections between the two complex concepts of physical and transition risks, and to contextualise common terms. Nevertheless, for the exercises to be carried out later on, it has to be assured that dictionaries are sufficiently different in terms of the content they describe. To confirm that this is the case, we apply a test proposed by Dang et al. (2015)[8]. Results show that the transition risk vocabulary is able to explain less than the 5% of the physical risk vocabulary, which in turns carries about 95% of individual information, and vice-versa.

[7] The final collection documents is then composed by T documents, as a total of T-1 daily news documents and 1 physical (transition) risk document, which enables us to calculate the idf scores. At this stage, to lighten the computational load and avoid the so-called machine learning overfitting issue, we consider a subsample of the Reuters News (2015-2019).

[8] We evaluate the actual degree of commonality between the two vocabularies as the R squared from regressing the physical risk vocabulary on the transition risk one, and vice-versa. Despite there not being a clear threshold level (Rognone et al., 2020), the resulting R square of less than 5 percent is considered sufficiently small to support a reliable separation of the two risks.

Word clouds summary for physical and transition risk vocabularies

Figure 1

(a) Physical risk vocabulary

(b) Transition risk vocabulary

Word cloud summaries for the physical risk (a) and transition risk (b) vocabularies. Term sizes depend on the relative importance of the term according to the individual *tf -idf* score. Reported terms are the reconstructed stemmed terms. Major acronyms: Representative Concentration Pathways (RCP), hydrofluorocarbon (HFC), hydrochlorofluorocarbon (HCFC). Table A1 reports the full list of acronyms.

Physical risk and transition risk indices

In order to calculate our two risk indices we first compute two "concern" series. These news media concern series for physical/transition risk, on any given day t, are defined as the cosine similarity between the tf-idf vector of the news document and the physical (transition) risk document. Cosine-similarity is a technique used in text-analysis to evaluate similarity between pairs of texts. It expresses the angular distance between two pairs of text such that the closer these are to each other, the smaller their angular distance, the higher the cosine, and the higher their similarity. In other words, we consider our physical (transition) risk dictionary as a vector, the direction of which depends on the intensity of each element, given by the tf-idf of vocabulary terms. This means that daily news which point in the same direction as the physical (transition) risk vector are assessed to discuss the physical (transition) risk topic.

We then, in order to gauge the unexpected change in physical/transition risk, construct the Physical Risk Index (PRI) and the Transition Risk Index (TRI) as residuals from autoregressive processes of order 1 (AR1), as follows

$$\text{Concern}_{t,PR} = c_{PR} + \phi_{PR}\text{Concern}_{t-1,PR} + PRI_{t,PR} \tag{1a}$$

$$\text{Concern}_{t,TR} = c_{TR} + \phi_{TR}\text{Concern}_{t-1,TR} + TRI_{t,TR} \tag{1b}$$

Table 3 reports the dates with the highest physical and transition risk shocks together with the topic of the most relevant news. For instance, the peak for PRI is registered on 19/09/2018, on account of a large discussion revolving around a natural hazard, which on this occasion was a loss of arctic sea. High shock days might cover a multiplicity of physical risk topics. For example, the PRI peak is related not only to the physical chronic risk of permafrost thawing, but also to a rise of sea levels and changes in the salinity of oceans. As such, the table shows that our PRI shocks capture not only acute risks such as floods, or extreme weather events, but also a plurality of chronic risks such as permafrost thawing, droughts, sea level rise, and the adverse impacts on the ecosystem from e.g. a loss of biodiversity. This sets the PRI apart from many other physical risk databases, which mainly identify extreme weather events only. The largest shock for TRI concurs with news published on 24/08/2011, which covered the worryingly high levels of EU GHG emissions, which would need to be reduced. In addition, the table also lists many news on regulation and measures to curb GHG emissions - all of which generate large spikes in TRI (e.g. news regarding the EU carbon reform deal or the Kyoto Protocol, as well as news concerning the costs associated to the transition and the advances of technological innovation and renewable energies).

AR1 estimates of physical risk and transition risk concern — Table 1

	$\text{Concern}_{t,PR}\ x\ 100$	$\text{Concern}_{t,TR}\ x\ 100$
Drift *c*	7.863	8.462
	(0.047)	(0.061)
ϕ	0.326	0.413
	(0.014)	(0.014)

Note: Estimates of autoregressive process of order 1 (AR1) concern time series on physical risk, as in equation (1a), and transition risk as in equation (1b). Standard error in parenthesis.

Figure 2 shows the scatter plots of daily physical and transition media concerns (panels a and b), together with their monthly average (panels c and d). Table 1 summarises the AR1 estimates from Equations (1a) and (1b). Both physical risk and transition risk concern time series depict positive drifts (c_{TR} = 8.462% and c_{PR} = 7.862%), showing that the news coverage toward these climate risks tends to increase over time. The media concern for transition risk seems to be more persistent than that for physical risk with ϕ_{PR} = 0.326 and ϕ_{TR} = 0.413.

Transition and physical risk pricing in euro are equity markets

In the following, we examine the existence of physical and transition climate risk premia in equity markets using our physical and transition risk indicators. Thereafter, we investigate which metrics may be used by investors to proxy for a firm’s exposure to either physical or transition risk.

A. Transition and physical risk premia

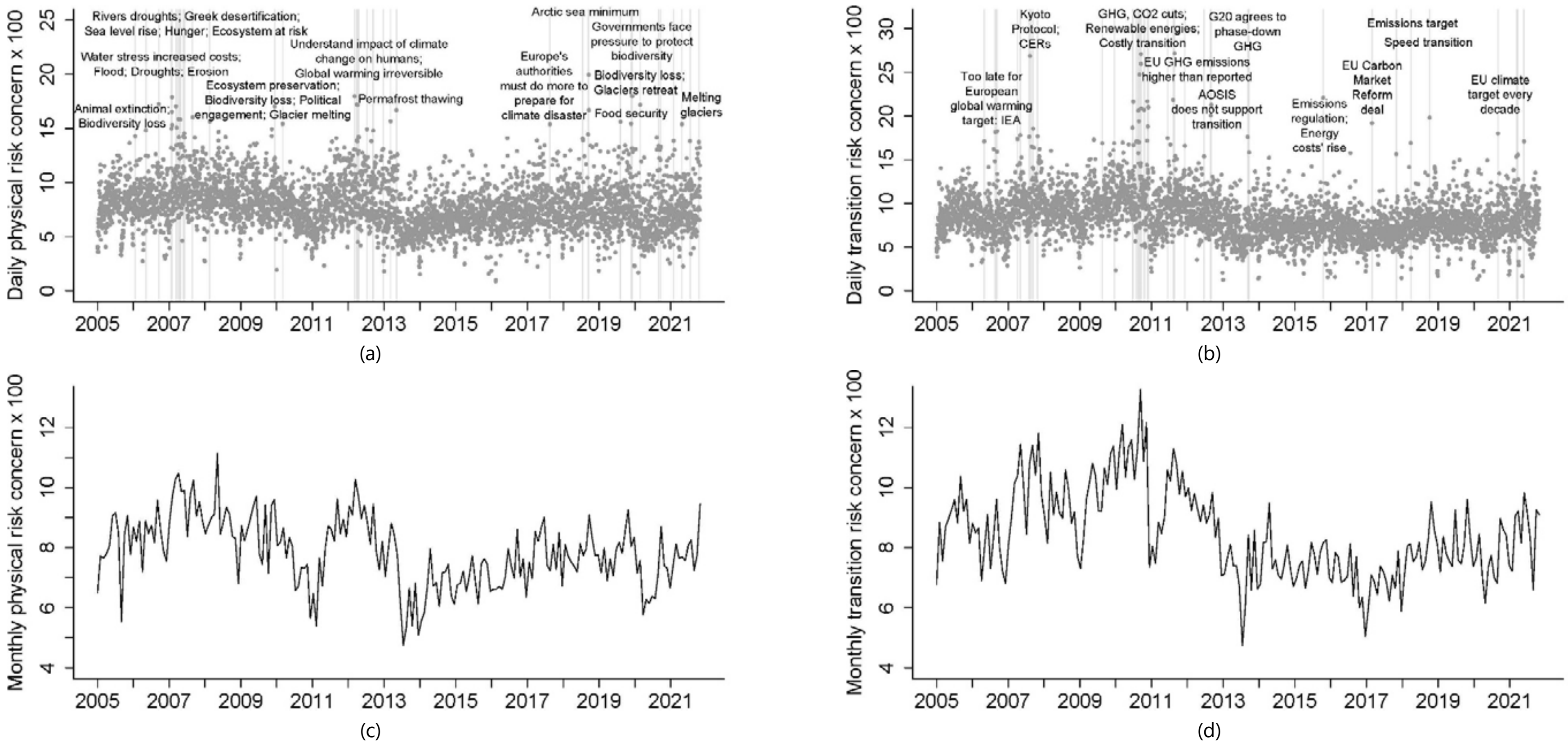
To assess the presence of climate risk premia for physical and transition risk in the cross-section of European stock returns we adopt a standard portfolio sorting approach. We perform time-series regressions of equity returns on our climate risk factors, controlling for Fama French factors which are known to drive returns, to gauge stock return sensitivities to carbon risk. The resulting loading on the risk factors, i.e. the transition and physical risk betas, are our firm-level indicators of climate risk exposure. Stocks which depict a positive climate risk beta tend to appreciate when investors are concerned about climate risk. These stocks can thus be thought of as a hedge against climate risk as they deliver high returns when climate change concerns increase. We sort these companies from low to high according to their climate exposure and group them into portfolios.

Since investors can be expected to want to hedge against climate risk, they should be willing to accept lower expected returns for equities that appreciate when climate risk increases (high beta portfolios). In turn, this means that 'climate risky' stocks should trade at a discount and offer higher expected returns. A low-minus-high transition (physical) climate beta portfolio should therefore earn positive excess returns in case a climate risk premium existed.

Specifically, we recursively estimate the sensitivity of each stock to both transition and physical climate risk, which yields the so-called climate-risk beta. We do so in a three-months rolling window regression with daily observations and control for the standard Fama & French (2015) five factors. We then sort stocks according to their estimated betas and group them into 25 portfolios for which we compute the post-ranking equal-weighted monthly returns. To examine the TRI-return relation (PRI-return relation), we also form a low-minus-high (LMH) portfolio that takes a long position in the negative-beta TRI (PRI) portfolio and a short position in the positive-beta TRI (PRI) portfolio, and we calculate the returns on this portfolio. We evaluate the transition (physical) risk premium, estimating each LMH climate portfolio's alpha while considering the Fama & French (2015) five factors asset pricing model specification.

Physical and transition risk concern timeseries 2005-2021

Figure 2



Note: Daily physical risk concern (a) and daily transition risk concern (b) with the major risk shock topics (vertical bars) for the period Jan 2005-Oct2021. Monthly average physical (c) and transition (d) risk concern.

B. The use of risk exposure metrics by investors

B.a. Indicators for firms' climate risk exposure

In the following we discuss the most relevant metrics to identify exposure to climate risks. We reckon that while most of the metrics have been used to capture exposure to transition, rather than physical risk, this distinction is not always clear and their potential to capture physical exposure has been largely unexplored. For this reason, in this study we decided to test a wide range of exposure metrics in light of their potential use for investors to hedge against physical and/or transition risks.

Academics, practitioners, and supervisors typically use GHG emissions or GHG emissions intensity (GHG emissions scaled by some organization-specific metric) to proxy a firm's exposure to transition risk, motivated by the fact that carbon-intensive activities are likely affected by GHG emissions reduction policies (Ardia et al., 2020; Bolton & Kacperczyk, 2021a; In et al., 2019; NGFS, 2020). However, empirical findings based on these measures are not conclusive. Bolton & Kacperczyk (2021a) provide evidence of the existence of a carbon premium while considering both emissions levels and changes, but no relation with carbon intensity exists. Also Barnett (2019), Bolton & Kacperczyk (2021b) and Ramelli et al. (2021) find that transition risks related to carbon emissions are priced. In contrast, In et al. (2019) find that green firms outperform brown firms when considering carbon intensity and Hsu et al. (2020) show that a long-short portfolio constructed from firms with high versus low emission intensity generates positive excess return.

Other potential measures of climate exposure are E and ESG scores, which aim to measure the environmental, or environmental, social and governance-related performance of a company[9]. A number of academic studies rely on E/ESG scores (possibly in combination with other company-specific metrics) to identify climate sensitive companies. Görgen et al. (2020), for example, build a "grenness" score based on carbon intensity, ESG scores and an adaptability score. Alessi et al. (2019) combines ESG disclosure scores with quantitative measures on emissions, while Engle et al. (2020) focus exclusively on the E score.

Other studies consider sectoral classifications and define climate sensitive companies as those belonging to high GHG emissions sectors. This approach is particularly relevant in contexts where the lack of transparent indicators (e.g. ESG ratings) may limit the ability of investors to understand to steer their investment toward climate-hedged portfolios (Bolton & Kacperczyk, 2021b). As such, Choi et al. (2020) finds that the sectors identified as major emitters by the Intergovernmental Panel on Climate Change (IPCC) earn lower stock returns than other firms. Bolton & Kacperczyk (2021a) argue that relying on a sectoral analysis may facilitate the detection of climate-risky investments, whereas such approach may ignore relevant intra-sectoral differences. Batten et al. (2016) document the impact of transition risk on the energy sector and concludes that only renewable energy companies generate abnormal returns.

Measuring firms' exposure to physical risk is challenging as physical risk arises from the interaction of hazard (occurrence, or probability of occurrence, of a physical

[9] The exact information contained in any ESG score depends on the methodology used to calculate it, which, in turn, differs across credit/rating providers. Existing research documents large differences between ESG ratings (Chatterji et al., 2016; Gibson Brandon et al., 2021) and elaborates on the possible reasons for these Berg et al. (2019).

event), exposure (presence of elements in areas and settings that could be adversely affected), and vulnerability (predisposition of exposed elements to suffer damages due to the hazardous event). Such dimensions typically depend on both local/specific and macro factors. Currently, most of the information on physical risk exposure is provided by some public sources (e.g. EC JRC Risk Data Hub) and private data providers. These databases, however, are not fully comparable as they focus on different risk aspects, types of hazard and types of entities. Due to data limitations, studies that explore the consequences of physical risks on asset prices mainly focus on specific physical events and/or consider only some dimensions of physical risk (see Addoum et al. (2020); Hong et al. (2019); Kruttli et al. (2019)). Alternatively, as is the the case for transition risk, sectors can be used to proxy physical risk exposure. While all sectors can suffer from natural disasters, some sectors, including energy, transportation, and telecommunications, are expected to be more exposed to climate hazards through their infrastructure assets (ECB, 2021). Primary economic activities, including agriculture, forestry, fishing, mining and quarrying, are exposed through the natural and/or food systems on which they depend. Among services, the insurance sector, tourism and health care might be particularly sensitive to physical risk (IPCC, 2014).

While E, ESG, and GHG emissions have mainly been used to capture exposure to transition, rather than physical risk, this distinction is not always clear and these metrics' potential to capture physical exposure has been largely unexplored. In this study we decided to test all of the above-mentioned exposure metrics in light of their potential use for investors to hedge against physical and/or transition risks.

B.b Information content of risk exposure metrics for investors

To test which exposure metrics may be used by investors to proxy firm's exposure to transition and physical risk, we add the Physical Risk Index (PRI) and Transition Risk Index (TRI) to a Fama & French (2015) five factors (FF5) asset pricing model. We consider the E score, ESG score, GHG emissions level, and GHG emissions intensity as exposure metrics to sort firms and create green and brown portfolios, as follows:

- *E score and ESG score metrics.* Firms whose E score is above (below) the 75th (25th) percentile are defined as green (brown). The green (brown) portfolio is then created as an equally weighted portfolio composed of green (brown) firms. The same approach is applied to the ESG score metric. Portfolios are rebalanced annually;
- *GHG emissions level and GHG emissions intensity metrics.* The GHG emissions level ($\mathrm{GHG_E}$) is calculated as the sum of Scope 1 and 2, while the GHG emissions intensity ($\mathrm{GHG_{EI}}$) is calculated as GHG emissions level scaled by firms' net revenue. As before, firms whose emissions level is below (above) the 25th (75th) percentile are defined as green (brown) firms. Portfolios are again rebalanced annually.

We then include our TRI and PRI into a model to gauge equity excess returns

$$r_{p_i,t}^{exc} = c_{p_i} + \beta_{p_i}^{TRI} TRI_t + \gamma_{p_i}^{TRI} X_t + \epsilon_t \qquad (2a)$$

to price transition risk, and

$$r_{p_i,t}^{exc} = c_{p_i} + \beta_{p_i}^{PRI} PRI_t + \gamma_{p_i}^{PRI} X_t + \epsilon_t \tag{2b}$$

to price physical risk. $r_{p_i,t}^{exc}$ denotes the excess return at time t for green or brown portfolios where p = {green portfolio, brown portfolio} and i = $\{\mathrm{GHG_E}, \mathrm{GHG_{EI}}, \mathrm{E}, \mathrm{ESG}\}$. c_{p_i} is the constant term and the vector X_t controls for the market factor, the size factor, the book-to-market factor, as well as the profitability and investment factors[10]. The coefficients β^{PRI} and β^{TRI} measure the contemporaneous relationship between an unexpected change in physical and transition risk, and the excess returns of portfolios constructed according to different exposure metrics. The results from this exercise could inform us about the exposure metric used by investors to proxy firms' exposure to physical or transition risk.

Data

The augmented FF5 model (Equations 2a and 2b) uses the 1-month Overnight Index Swap (OIS) rate as the risk-free rate, and returns of the EuroStoxx 600 Index as the proxy for the market return. All data is used at daily frequency. We collect price time series for the historical constituents of the Eurostoxx 600 Index from Datastream over the period Jan 2005-Oct 2021, resulting in a total of 1,198 companies.

Data on firms' GHG emissions level, GHG emissions intensity, E score, and ESG core are sourced from Refinitiv. The level of GHG emissions indicates (in thousands) the metric tonnes of carbon dioxide equivalent a company produces[11]. We compute the GHG emissions intensity as GHG emissions scaled by the firm's net-revenue. In contrast, the E score reflects the environmental performance of a company in terms of its commitment and effectiveness to tackle issues related to the use of resources, emissions, and innovation, while the ESG score is also argued to be informative about a firm's performance concerning social and governance issues. E and ESG scores are industry-based relative performances and scores range between 0 and 100, with higher values indicating better firm' performances, relative to sector peers[12].

We define sectors using the Statistical Classification of Economic Activities in the European Community (NACE Rev. 2)[13].

[10] The Fama & French (2015) five factors are constructed considering the EuroStoxx 600 Index constituents over the period Jan 2005-Oct 2021 for which we calculate the 6 value-weight portfolios formed on size (market capitalisation) and book-to-market, the 6 value-weight portfolios formed on size and operating profitability, and the 6 value-weight portfolios formed on size and investment (change in total assets). Data are collected from Eikon. More details on the methodology can be found in the Fama-French data library.

[11] The GHG Protocol Accounting and Reporting Standard classifies (WBCSD & WRI, 2004) a company's GHG emissions into three scopes: direct emissions from company-owned and controlled resources, scope 1; indirect emissions from purchased electricity by the owned or controlled equipment or operations of the firm, scope 2; and other supply chain emissions, scope 3. We measure GHG emissions as the sum of scope 1 and 2 because including scope 3 reduces the data coverage. We consider only data reported by the company.

[12] Environmental and Social pillars are constructed according to categories which weights vary with the industry, while the Governance pillar category weights remain fixed across industries. Scores also consider firms' data transparency penalising firms which do not disclose data.

[13] Eurostat (2008). Dafermos et al. (2020) for example identifies high-carbon intensive activities taking NACE 1-digit sectors that mostly contribute to EU emissions.

Descriptive analysis

Table 2 shows the exposure metrics used. The table nicely illustrates a general increase in data coverage over time. In addition, it reports the thresholds used (25th and 75th percentiles) to construct brown and green portfolios.

In order to give a better overview of the composition and characteristics of the EuroStoxx 600 Index at the sectoral level, table 2 reports the number of firms in our sample (No.), the average of the exposure metrics(E, ESG, log-$\mathrm{GHG_{EI}}$,log-$\mathrm{GHG_{E}}$*)* and the yearly average contribution of each sector to EuroStoxx 600 Index GHG emissions. In the last column, we also add the overall sector contribution to EU GHG emissions (EU contribution)[14]. The table is sorted by GHG emissions in descending order, with a light (dark) colour being associated with green (brown) sectors.

As expected, D-Electricity, gas, steam and air conditioning supply (D- Electricity), CManufacturing, and H-Transportation and storage (H-Transportation) are among the most carbon-emitting sectors, contributing around 70% of total EU emissions and 55% of total EuroStoxx 600 Index emissions, respectively.In comparison, the A-Agriculture, forestry and fishing (A-Agriculture) is a high emissions contributor at the European level (16%), but not in our sample (0%), due to low representation of companies from this sector in the EuroStoxx 600 Index (one company). B-Mining and quarrying (B-Mining) and M-Professional, scientific and technical activities (M-Professional)[15] are small contributors at European level but show high level of GHG emissions in our sample.

Table 4 also shows that sectors with good average E (and ESG) ratings also have, on average, high GHG emissions levels (and intensity). This observation suggests that companies with high GHG emissions can receive positive environmental and ESG scores, and vice versa (Boffo et al., 2020). In other words, positive environmental, or ESG, ratings are not necessarily associated with low carbon emissions, aligned with the assumption that E, and ESG, can capture aspects of climate risk further to GHG production (Faccini et al., 2021).

Figure 3 presents the distribution of the four metrics used. E and ESG scores are quite homogeneous across sectors, while GHG emissions differ largely within and across sectors. This is in line with the fact that Refinitiv ESG scoring methodology is aimed at reducing portfolio concentration by sectors and thus recalibrates upwards the rating of high pollution companies if they are in highly polluting sectors, i.e. a company is largely evaluated relative to its sector peers. The distribution of GHG emissions by sectors also shows that the NACE classification does not take into account important emissions-related intra-sectoral differences.

[14] EU27, Data source: Eurostat.

[15] The broad characterisation of this sector makes its interpretation challenging. In our sample 70 percent are activities carried on by head offices.

Exposure data

Table 2

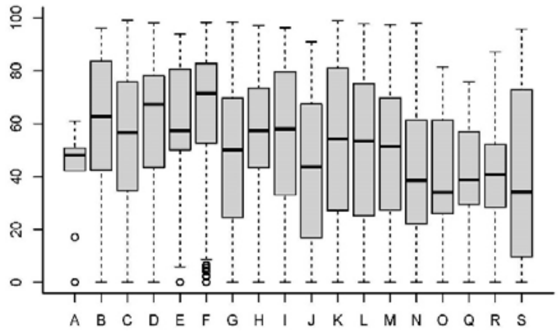
Panel a) % of firms with data

Year	GHG_E	GHG_{EI}	E Score	ESG Score
2005	259	254	537	686
2006	341	336	584	717
2007	423	413	706	777
2008	463	445	756	805
2009	547	518	776	823
2010	587	548	817	852
2011	626	583	833	874
2012	659	608	859	897
2013	689	634	880	913
2014	734	670	900	939
2015	773	707	945	978
2016	811	732	962	994
2017	857	767	1,011	1,044
2018	907	797	1,056	1,089
2019	944	818	1,074	1,105
2020	953	811	1,087	1,115
2021	949	793	1,081	1,116
Panel b) Threshold				
25^{th} Percentile	4.45	0.97	34.55	38.15
75^{th} Percentile	6.00	2.14	76.46	69.56

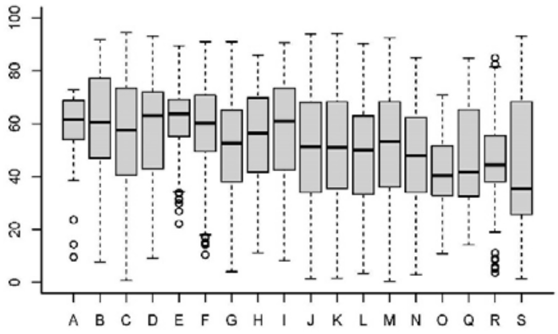
Note: exposure data % coverage over time (from 2015 to 2021) for the EuroStoxx 600 Index constituents (panel a) and the threshold levels to construct green and brown portfolios (panel b) for log-GHG emissions levels (GHG_E), log-GHG emissions intensity (GHG_{EI}), Environmental score (E-Score), and Environmental, Social, and Governance score (ESG-Score).

Finally, Table 5 shows the sectoral composition of brown and green portfolios according to the different exposure metrics used. The composition of brown (green) E and ESG portfolios is very similar, and so is the composition of brown (green) portfolios constructed according to GHG and GHG emission intensity. However, the portfolios constructed according to E or ESG criteria differ significantly from the ones based on GHG emissions. This is in line with the observation that high GHG emitting companies can receive high ESH and E scores.

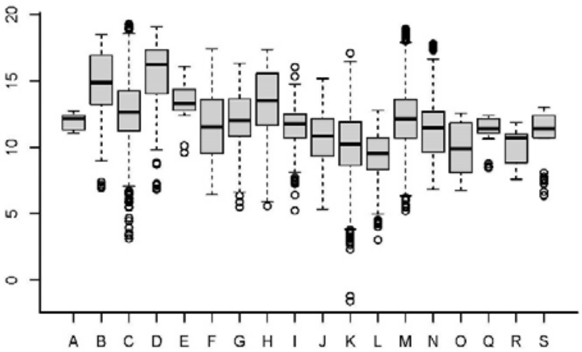
Distribution of exposure metrics Figure 3



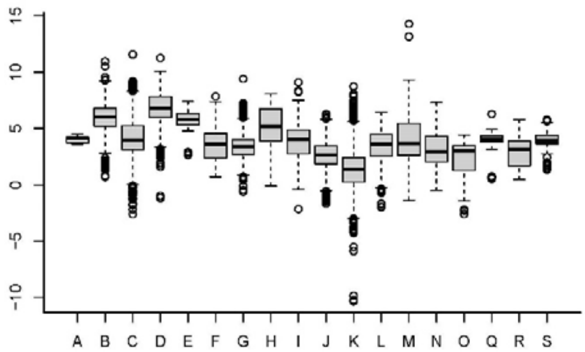
(a) Environmental score



(b) ESG score



(c) GHG emissions level



(d) GHG emission intensity

Note: Environmental score (a), ESG score (b), GHG emissions levels (c), and GHG emissions intensity (d) NACE Rev. 2 sectors boxplots.

Results

A. Transition and Physical Climate Risk Premia

Results indicate the emergence of both, a physical and transition climate risk premium since 2015. First, table 6 presents the annualized average excess stock returns in percent (E[R]-Rf, in excess of the risk free-rate), and Sharpe ratios of the 26 portfolios we form for transition risk (Panel a) and physical risk (Panel b), over the three periods studied (full sample, before 2015 and after 2015). The LMH transition (physical) generates an average annualized return of about -3.08% (-3.75%) in the period before 2015 and 9.61% (6.71%) after 2015. In addition, Figure 4 (a-b) shows a strong increase in the cumulative return of the LMH transition and physical portfolios after 2015 - depicting a decline in the performance of the high beta portfolio (Figure 4 (c-d)).

Second, table 7 shows the estimated physical and transition risk premia (alpha for the LMH portfolio). These estimates document the emergence of a positive risk premium for the low beta portfolio since 2015, i.e. a relatively higher required return for stocks which provide a bad hedge against climate risk. More specifically, the long-short PRI and TRI portfolios generate an average abnormal return of about -4.09% and -3.01% per year before 2015, and of about 6.14% and 7.05% after 2015, respectively.

B. The use of risk exposure metrics by investors

Overall, we find that firm level information appears to be used as a gauge for transition risk, in particular since 2015. In contrast, sectoral classifications appears to be sufficient to be employed to identify exposures to physical risk - but this information may not be granular enough to capture transition risk exposure. More specifically, table 8 reports the results for the estimated factor sensitivities of green and brown portfolios constructed according to E scores, columns (1-4); ESG scores, columns (5-8); $\mathrm{GHG_{EI}}$ columns (9-12); and $\mathrm{GHG_{E}}$, columns (13-16); from the daily augmented FF5 model as presented in Equations (2a) and (2b) over three periods (full sample, before 2015, and after 2015) reported together with t-statistics and considering Newey & West (1987) robust standard errors[16].

The table shows that since 2015 both E/ESG and GHG emissions appear to be a useful gauge for investors to identify companies less effected by climate risk. This is evident from positive and statistically significant TRI coefficients in the bottom panel of the table. In contrast, these measures do not appear to be used by investors to gauge exposures to physical risk. Our findings are in line with with Ardia et al. (2020) and Pastor et al. (2021b) who find that green assets earn positive return when they are surprised by climate risk. Additionally, Ardia et al. (2020) document that unexpected increases in climate change concerns decrease the returns of US brown firms, a finding which we cannot confirm.

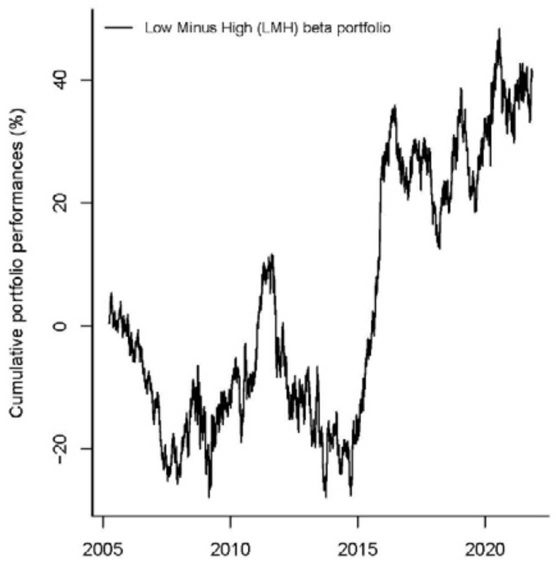
Turning to sector classification as a gauge for climate risk exposures, table 9 shows regression results for the three sample periods (full sample, before 2015, and after 2015), using the NACE sectoral classification to group excess returns of EU companies. Coefficients for TRI are largely insignificant post 2015. This suggests that sectoral information may not or no longer be granular enough to capture transition risk exposure. Rather investors may use more sophisiticated firm-level information, such as ESG or E ratings. This finding also speaks to the discussion raised by Bolton & Kacperczyk (2021a), who question whether investors consider the industry where firms operate as material information on firm' climate exposure, or use firms level information.

Table 10 provides the same information as 9, but for physical risk. We find that, after 2015, coefficients for sectors which are expected to be exposed to physical risk events (mining and quarrying, transportation and storage, and telecommunications) are negative and significant. These sectors are exposed to physical risk through their infrastructure assets or natural system such that these activities suffer losses from, e.g. interruptions of operational activities due physical hazards. This suggests that sectoral classifications may be used by investors to identify exposures to physical risk.

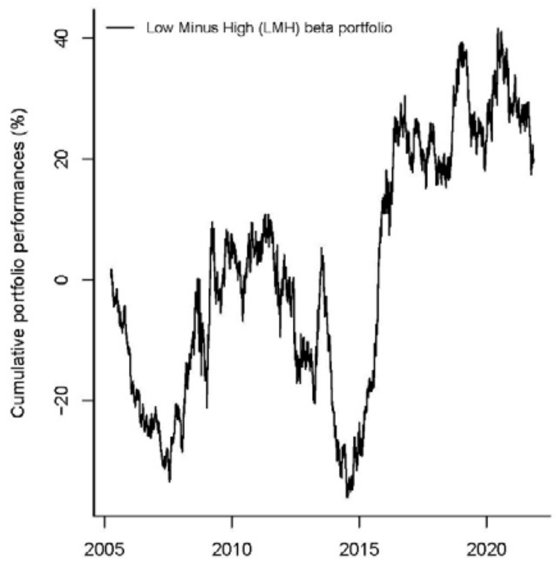
[16] We use Newey-West standard errors throughout.

Cumulative performances of portfolios sorted on TRI and PRI

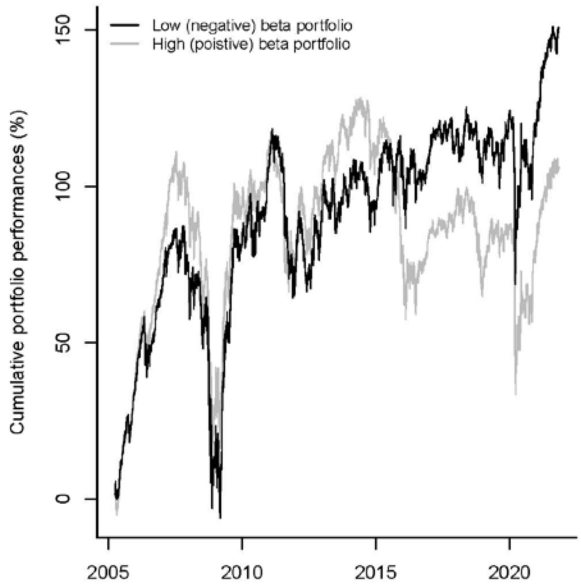
Figure 4



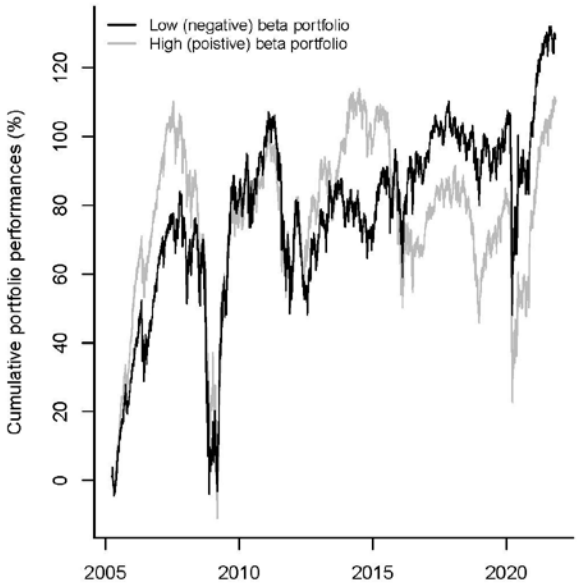
(a) Transition LMH beta portfolio



(b) Physical LMH beta portfolio



(c) Transition low and high beta portfolios



(d) Physical low and high beta portfolios

Note: Cumulative performances of the low-minus-high beta transition (a) and physical (b) beta portfolios; and of the low and high transition and physical beta portfolios separately (c) and (d) considering EuroStoxx 600 Index historical constituents stocks.

Conclusion

This study has examined the existence of physical and transition climate risk premia in euro area equity markets. It laid out two novel physical and transition risk indicators based on text analysis, which were then used to gauge the presence of climate risk premia. Results showed that climate risk premia for both, transition and physical climate risk, have increased since the time of the Paris Agreement. Portfolios, constructed according to the most common firm-specific climate metrics, were used to estimate the sensitivity of these portfolios to our risk indicators. We compared these to sectoral classifications to see if investors may simply pigeonhole firms into the industry they operate in - rather than to use more elaborate firm-level information. Findings showed that firm level information indeed appears to be used as a gauge for transition risk, in particular since 2015, whereas sectoral classifications appear insufficient. However, sectoral classification may be employed to broadly gauge firms' exposures to physical risk.

The findings presented in this study, with the most important contribution being the transition and physical risk indices, can be used to inform investors, policy makers, and financial institutions alike about the extent to which financial markets price climate risks. They can and are already be used by others for applications to other asset classes, risk management and portfolio management issues, or the investigation of climate hedging investment strategies. We deem that future research which more extensively investigates the link between climate risks and granular firm characteristics can yield many interesting results.

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Physical and transition risk top news articles

Table 3

Date	PRI	Physical risk news topics	Physical risk relevant news titles
19/09/2018	12.3%	Artic Sea Minimum; Melting glaciers; Permafrost thawing Ocean acidification	Greenland and the hunt for better climate science; In Greenland a glacier's collapse shows climate impact; Coceral cuts sharply EU cereal rapeseed crop estimates
01/02/2007	9.8%	IPCC draft report by the U.N. climate panel in Paris; Climate Sea Level Rise; change affects fishery	Global warming impacts of temperature rises; Draft findings by U.N. climate panel; Seas rising faster than U.N. predicts study; U.N. panel to link warming to humans project more; Cool water surges could affect fish stocks report; U.N. panel says "very likely" humans cause warming
06/12/2019	9.6%	Biodiversity Loss; Europe must protect rivers and lakes; Fishing, reef, tourism at risk; Increased costs due to climate stress	Europe must do more to protect its rivers and lakes: scientists; Runaway warming could sink fishing and reef tourism researchers warn; Forward prices slip on wetter weather view lower German rates
27/03/2012	9.1%	Global warming irreversible; Spain droughts, water stress; Frost impact on agriculture	Global warming close to becoming irreversible scientists; Spain drought hits hydro, irrigation stocks again; EU wheat too expensive for export – Toepfer Clouds a puzzle for U.N. global warming panel; Millions to go hungry, waterless; Bird ranges move, but is it climate change?; Europe's wheat crop on track, frost fears ease; Compulsory water metering takes step closer
30/01/2007	8.9%	Hunger due to water scarcity; Adaptation measure for companies; Animal migration	
27/02/2020	8.7%	Governments face pressure to protect biodiversity	Governments face pressure to protect nature in biodiversity
18/09/2006	8.7%	Raising temperatures causes floods, droughts, erosion; Hungary risk sand dunes, floods; Rising water costs; Water scarcity	Eco-paradises in crossfire of water scarcity fight; Hungary region battles advancing sand dunes, floods; Water everywhere but not clean enough to drink; Investors bet on rising costs for scarce water; Spanish wetland struggles as water levels drop
05/04/2012	8.6%	People cause climate change, need to understand impact on humans	Climate contrarian case wilts: Gerard Wynn
14/12/2009	8.5%	Forests to climate fight; Coral climate crisis costs; Biodiversity loss; Politic engagement in climate fight	Climate change makes finding Nemo even harder report; Coral climate crisis puts 250 million at risk: U.N.; Forest communities said key to climate fight; Natural disasters at decade low in 2009-UN report; Antarctic researcher commutes across continents for work
08/08/2019	8.4%	Food security	Farming and eating need to change to curb global warming: UN report
Date	**TRI**	**Transition risk news topics**	**Transition risk relevant news titles**
24/08/2011	19.1%	EU GHG emissions higher than reported	EU HFC emissions higher than reported; New research links cosmic rays to cloud formation
13/08/2007	17.5%	Kyoto Protocol; Certified Emission Reduction (CER)	Kyoto projects harm ozone layer: U.N. official; Daily secondary CER market report
01/09/2010	16.3%	Kyoto CO2 scheme probed; CER	HFC cutting plants under Kyoto CO2 scheme probed; EU carbon permit volumes fall in Aug, CERs rise
15/09/2010	15.0%	Review of carbon offsets; Low-carbon heating sources raises industry costs	UN to review CO2 offset request from 9th plant; UK business group warns on new low-carbon support
15/10/2015	13.8%	Emissions regulation; Increase in energy costs	U.S. announces new moves to limit super greenhouse gases; German 2016 green power surcharge at 6.354 cents/kWh - grid firms
09/08/2011	13.8%	Costly transition	Money spinning China carbon scheme may end with loss; Sberbank CO2 role questioned after huge issuance; Kyoto CO2 offset issuances grind to crawl in June; UK needs step change to meet climate target report; India, China seen partly out of carbon mkt post 2012; EU climate policy said costly with tiny benefits; EU carbon hits fresh 3-wk low on weak German power
30/06/2010	12.5%	CER issuances at lowest; Costly transition; International carbon market	
24/08/2012	11.8%	CERs request	Developers seek 4.7 mln CERs, incl. 1.5 mln HFC units
28/02/2017	11.4%	Carbon Reform Deal; Renewable energies; Emissions targets	Nineteen EU nations back common position on carbon market reform; France's EDF hydropower availability down 1.3 GW due to strike; Marshall Islands first to ratify global HFC greenhouse gas pact; Austria's EVN puts Bulgarian hydropower project on hold
16/09/2010	11.4%	Green incentive for coal; Clean energy projects; Carbon Capture and Storage technologies	UN panel to rule on green incentives for coal; Ozone recovering but will take longer over poles; UN gives CO2 auditors time to study liability plan; Carbon capturing technology doomed in Europe - study; Mexico says world should trust U.S. on emissions

Note: This table reports the dates, the Physical Risk Index (PRI) and Transition Risk Index (TRI), the main news topics, and lists of relevant article's title for the ten days with highest physical and transition risk.

EuroStoxx 600 Index historical constituents' sectoral composition

Table 4

	NACE code - sector	No.	log-GHG_E	log-GHG_{EI}	ESG	E	GHG_E contribution Index	GHG_E contribution EU
D	Electricity, gas, steam and air conditioning supply	37	17.09	7.77	56.73	60.4	41%	28%
B	Mining and quarrying	48	16.52	6.95	59.27	59.29	23%	2%
M	Professional, scientific and technical activities	150	15.62	7.64	51.74	48.04	9%	1%
H	Transportation and storage	37	15.36	6.16	55.75	55.93	7%	14%
C	Manufacturing	309	15.36	6.09	56.15	53.57	7%	26%
N	Administrative and support service activities	36	14.87	4.86	47.65	40.75	4%	1%
E	Water supply; sewerage, waste management and remediation activities	9	14.43	6.08	61.2	61.19	3%	5%
F	Construction	35	13.84	4.76	58.88	65.16	2%	2%
G	Wholesale and retail trade; repair of motor vehicles and motorcycles	81	13.66	4.83	51.48	47.81	1%	3%
I	Accommodation and food service activities	16	13.18	5.71	57.7	55.2	1%	1%
K	Financial and insurance activities	252	12.67	3.84	50.67	53.52	0%	0%
J	Information and communication	109	12.53	3.36	50.74	41.76	0%	0%
A	Agriculture, forestry and fishing	1	12.12	4.07	54.92	39.16	0%	16%
S	Other service activities	6	11.81	4.42	45.04	42.05	0%	0%
Q	Human health and social work activities	9	11.67	4.21	47.1	39.97	0%	1%
O	Public administration and defence; compulsory social security	4	11.19	3.08	41.36	41.53	0%	1%
R	Arts, entertainment and recreation	12	10.67	3.55	47.08	39.91	0%	0%
L	Real estate activities	47	10.38	4.3	48.02	49.79	0%	0%

EuroStoxx 600 Index historical constituents sectoral (NACE code - sector) composition over the period Jan 2015-Oct 2021, number of companies per sector (No.), average environmental score (E score), environmental, social, and governance score (ESG score), log-GHG emissions levels (log GHG_E), log-GHG emissions intensity (log GHG_{EI}). Per year average GHG emission contribution of each EuroStoxx 600 Index NACE sector to the total EuroStoxx 600 Index emissions (GHG_E contribution Index), and the per year average GHG emissions of the full NACE sector to the total European Union GHG emission (GHG_E contribution EU) as from EU27 sourced from Eurostat. The table is sorted according to descending greenhouse gas emissions. The lighter the colour the 'greener' the sector, the darker the colour, the 'browner' the sector according to each metric (E score, ESG score, GHG_{EI}, or GHG_E).

Green and brown E, ESG, GHG_{EI}, GHG_E portfolios composition

Table 5

Panel a)	E score		ESG score		log-GHG_{EI}		log-GHG_E	
	Green	Brown	Green	Brown	Green	Brown	Green	Brown
Metric average	85.64	19.89	78.77	25.42	0.92	6.47	8.69	15.67
Number of assets	456	708	524	696	396	285	409	241
Panel b) Sectoral composition (%)								
NACE code - sector								
A Agriculture, forestry and fishing	0.00	0.14	0.19	0.14	0.00	0.00	0.00	0.00
B Mining and quarrying	4.82	3.95	4.58	3.45	1.01	12.63	1.47	11.62
C Manufacturing	28.73	26.55	30.73	27.16	14.65	33.68	16.87	34.44
D Electricity, gas, steam and air conditioning supply	4.17	2.97	3.82	2.59	0.51	9.82	0.98	11.62
E Water supply; sewerage; waste management and remediation activities	0.88	0.56	0.95	0.29	0.00	2.11	0.24	2.07
F Construction	5.48	2.97	3.82	2.73	3.28	3.51	3.42	4.15
G Wholesale and retail trade; repair of motor vehicles and motorcycles	5.26	7.91	5.53	6.61	5.05	2.81	5.87	6.64
H Transporting and storage	3.51	2.40	3.44	2.87	1.26	7.02	1.71	7.05
I Accommodation and food service activities	1.75	1.69	1.53	1.29	1.26	1.40	0.98	0.83
J Information and communication	5.48	9.75	7.82	8.91	13.89	2.11	12.71	2.90
K Financial and insurance activities	24.12	19.63	18.32	20.98	39.65	4.56	33.50	5.39
L Real estate activities	3.29	3.25	3.24	4.17	3.79	3.51	7.33	0.00
M Professional, scientific and technical activities	9.87	12.15	12.98	11.78	10.10	13.68	9.54	11.62
N Administrative and support service activities	1.75	2.82	1.53	3.30	3.28	1.75	2.93	1.66
O Public administration and defence; compulsory social security	0.22	0.56	0.19	0.57	0.51	0.00	0.49	0.00
Q Human health and social work activities	0.00	0.56	0.38	0.72	0.25	0.35	0.24	0.00
R Arts, entertainment and recreation	0.22	1.41	0.57	1.58	1.26	0.35	1.47	0.00
S Other services activities	0.44	0.71	0.38	0.86	0.25	0.70	0.24	0.00

Note: We sort the EuroStoxx 600 Index historical constituents on environmental score (E score), environmental, social and governance score (ESG score), greenhouse gas emissions intensity (GHG_{EI}), greenhouse gas emissions (GHG_E) and we create individual green and brown portfolios. This table reports each portfolio metric average (E, ESG, GHG_{EI}, or GHG_E), the number of assets, and the relative NACE sectoral (%) composition over the period Jan 2005-Oct 2021. Environmental, ESG, and GHG emissions data are sourced from Refinitiv.

Portfolios sorted on transition and physical climate betas			Table 6
Panel a) Transition risk beta portfolios			
Full sample TRI	L	H	LMH
E(R)-Rf (%)	8.46	5.71	1.96
σ (%)	22.35	22.47	13.05
SR	0.38	0.25	0.15
Before 2015 TRI	L	H	LMH
E(R)-Rf (%)	8.32	10.21	-3.08
σ (%)	23.53	23.16	12.76
SR	0.35	0.44	-0.24
After 2015 TRI	L	H	LMH
E(R)-Rf (%)	8.68	-0.41	9.61
σ (%)	20.57	21.46	13.44
SR	0.42	-0.02	0.71
Panel b) Physical risk beta portfolios			
Full sample PRI	L	H	LMH
E(R)-Rf (%)	7.08	5.94	0.43
σ (%)	22.83	23.07	13.29
SR	0.31	0.26	0.03
Before 2015 PRI	L	H	LMH
E(R)-Rf (%)	6.11	8.71	-3.75
σ (%)	23.71	23.62	12.91
SR	0.26	0.37	-0.29
After 2015 PRI	L	H	LMH
E(R)-Rf (%)	8.47	2.1	6.71
σ (%)	21.51	22.26	13.8
SR	0.39	0.09	0.49

Note: This table shows the performances of the low (L), high (H), and low-minus-high (LMH) 25 portfolios sorted according to their sensitivity to the Transition Risk Index (TRI) and to the Physical Risk Index (PRI), alongside the low-minus-high (LMH) transition and physical risk spread returns portfolios. The table reports the portfolios percentage annualised excess returns(E(R)-Rf) and standard deviations (σ), as well as the Sharpe ratios (SR), for three periods (full sample, Jan 2005-Oct 2021; before 2015, Jan 2005-Dec 2014; and after 2015, Jan 2015-Oct 2021). The EU stocks return universe is composed by the EuroStoxx 600 Index constituents.

Transition and physical risk premium — Table 7

Physical risk premium				Transition risk premium			
Full sample	25 Percentiles			Full sample	25 Percentiles		
	L	H	LMH		L	H	LMH
αFF5	5.14	4.54	-0.07	αFF5	6.1	3.94	1.42
[t]	1.69	1.65	-0.02	[t]	2.19	1.51	0.46
MKT_t	1.08	1.09	0	MKT_t	1.06	1.07	-0.02
[t]	48.6	62.6	-0.18	[t]	63.7	44.2	-0.73
SMB_t	0.63	0.66	-0.03	SMB_t	0.54	0.58	-0.04
[t]	12.7	16.9	-0.68	[t]	13.9	12	-0.71
HML_t	0.23	0.25	-0.02	HML_t	0.21	0.21	0
[t]	5.5	5.5	-0.49	[t]	6.91	5.54	-0.06
CMA_t	0.11	0.09	0.02	CMA_t	0.12	0.08	0.04
[t]	2.4	2.32	0.39	[t]	3.05	1.99	0.72
RMW_t	-0.19	-0.23	0.04	RMW_t	-0.2	-0.2	0
[t]	-6.33	-7.01	1.16	[t]	-7.5	-6.03	-0.08
Before 2015	25 Percentiles			Full sample	25 Percentiles		
	L	H	LMH		L	H	LMH
αFF5	3.15	6.06	-4.09	αFF5	5.22	6.98	-3.01
[t]	0.85	1.64	-0.98	[t]	1.36	2.06	0.77
MKT_t	1.11	1.09	0.01	MKT_t	1.1	1.09	0
[t]	47.6	57	0.51	[t]	49.7	52.1	0.06
SMB_t	0.57	0.57	0	SMB_t	0.51	0.51	0
[t]	10.9	12	0.02	[t]	7.19	11.8	0.02
HML_t	0.19	0.25	-0.06	HML_t	0.16	0.17	-0.01
[t]	3.57	3.9	-0.88	[t]	3.24	3.81	-0.12
CMA_t	0.13	0.13	0.01	CMA_t	0.12	0.15	-0.04
[t]	2.54	2.74	0.11	[t]	2.13	3.42	-0.51
RMW_t	-0.25	-0.25	0	RMW_t	-0.23	-0.24	-0.24
[t]	-6.95	-5.55	-0.07	[t]	-6.37	-6.38	0.04
After 2015	25 Percentiles			Full sample	25 Percentiles		
	L	H	LMH		L	H	LMH
αFF5	9.85	3.95	6.14	αFF5	8.63	1.92	7.05
[t]	2.15	0.97	1.15	[t]	2.1	0.49	1.41
MKT_t	1.02	1.05	-0.03	MKT_t	0.98	1.01	-0.04
[t]	35.9	41	-1.19	[t]	47.8	27.2	-1.15
SMB_t	0.76	0.82	-0.06	SMB_t	0.64	0.7	-0.06
[t]	14.9	21.8	-1.08	[t]	17.6	11.2	-0.85
HML_t	0.24	0.21	0.03	HML_t	0.25	0.22	0.03
[t]	5.89	5.27	0.59	[t]	5.69	5.08	0.5
CMA_t	0.11	0.06	0.05	CMA_t	0.16	0.02	0.14
[t]	2	0.99	0.64	[t]	2.66	0.27	1.99
RMW_t	-0.09	-0.22	0.13	RMW_t	-0.14	-0.15	0.01
[t]	-2.45	-4.99	2.53	[t]	-3.66	-3.2	0.15

Note: This table shows the estimated abnormal returns (αFF5) and coefficients to the market factor (MKT), size factor (SMB), value factor (HML), the investment factor (CMA) and the profitability factor (RMW) of the 25 portfolios sorted according to their sensitivity to the Transition Risk Index (TRI), alongside the low-minus-high (LMH) transition and physical risk spread returns portfolios, considering a Fama & French (2015) five factor (FF5) asset pricing model specification. Eurostoxx 600 Index historical constituents are used and results are reported for three periods (full sample, Jan 2005-Oct 2021; before 2015, Jan 2005-Dec 2014; and after 2015, Jan 2015-Oct 2021).

Sensitivity of green and brown E, ESG, GHG_EI, GHG_E portfolios to PRI and TRI

Table 8

Full sample	E score				ESG score				GHG_{EI}				GHG_{E}			
	Brown		Green		Brown		Green		Brown		Green		Brown		Green	
Intercept	0.038***	0.038***	0.022***	0.022***	0.040***	0.040***	0.021***	0.021***	0.029***	0.029***	0.044***	0.044***	0.029***	0.029***	0.046***	0.046***
[t]	7.285	7.349	6.789	6.838	6.357	6.431	7.381	7.329	4.994	4.991	7.211	7.212	5.915	5.920	8.244	8.204
MKT	0.960***	0.960***	1.029***	1.029***	0.922***	0.922***	1.016***	1.016***	1.024***	1.024***	1.047***	1.047***	1.018***	1.017***	1.008***	1.008***
[t]	104.020	103.918	125.059	125.438	89.915	90.097	145.915	148.181	95.980	96.076	74.323	74.183	119.278	119.423	80.639	80.872
SMB	0.451***	0.451***	0.101***	0.101***	0.398***	0.398***	0.082***	0.082***	0.230***	0.229***	0.264***	0.264***	0.151***	0.150***	0.467***	0.467***
[t]	22.770	22.987	5.242	5.330	18.266	18.441	5.161	5.431	8.227	8.237	8.921	8.935	6.295	6.303	20.994	20.907
HML	-0.010	-0.010	0.253***	0.253***	-0.001	-0.001	0.161***	0.161***	0.105***	0.105***	0.372***	0.372***	0.127***	0.128***	0.173***	0.173***
[t]	-0.568	-0.567	17.833	18.073	-0.048	-0.043	16.861	17.002	3.459	3.465	10.436	10.447	5.306	5.317	5.839	5.790
RMW	-0.059***	-0.059***	-0.067***	-0.067***	-0.111***	-0.111***	-0.043***	-0.043***	-0.139***	-0.139***	-0.041*	-0.041*	-0.085***	-0.085***	-0.001	-0.001
[t]	-4.208	-4.225	-5.486	-5.535	-7.209	-7.268	-4.562	-4.604	-7.103	-7.100	-1.649	-1.647	-4.999	-4.991	-0.047	-0.043
CMA	0.183***	0.183***	-0.008	-0.009	0.192***	0.192***	-0.025**	-0.025**	0.049	0.049	0.092***	0.092***	-0.033	-0.033	0.199***	0.199***
[t]	9.498	9.543	-0.629	-0.644	9.227	9.305	-1.969	-1.997	1.607	1.610	3.442	3.446	-1.323	-1.326	9.005	8.970
TRI	0.095		0.145		0.170		0.276**		-0.031		0.005		0.040		0.055	
[t]	0.529		1.202		0.866		2.488		-0.145		0.023		0.215		0.268	
PRI		-0.269		0.010		-0.087		-0.072		-0.249		-0.019		-0.312		-0.123
[t]		-1.353		0.068		-0.381		-0.548		-0.985		-0.075		-1.468		-0.535
Before 2015	E score				ESG score				GHG_{EI}				GHG_{E}			
	Brown		Green		Brown		Green		Brown		Green		Brown		Green	
Intercept	0.028***	0.029***	0.021***	0.021***	0.029***	0.030***	0.017***	0.018***	0.033***	0.033***	0.036***	0.035***	0.030***	0.030***	0.038***	0.038***
[t]	4.594	4.744	4.711	4.832	4.430	4.617	4.584	4.916	4.486	4.519	4.872	4.873	5.090	5.259	5.469	5.570
MKT	0.978***	0.978***	1.038***	1.038***	0.958***	0.958***	1.015***	1.015***	1.039***	1.039***	1.056***	1.056***	1.007***	1.007***	1.029***	1.030***
[t]	93.189	93.319	111.193	111.521	100.705	100.708	113.891	113.882	78.573	78.984	62.179	62.370	94.196	93.987	59.989	59.455
SMB	0.453***	0.453***	0.045**	0.045**	0.450***	0.450***	0.009	0.009	0.137***	0.137***	0.252***	0.252***	0.046**	0.046**	0.511***	0.511***
[t]	18.773	18.789	2.415	2.418	17.683	17.686	0.550	0.564	4.341	4.373	8.436	8.444	2.039	2.041	20.194	20.274
HML	0.051**	0.051**	0.266***	0.266***	0.063***	0.062***	0.160***	0.160***	0.005	0.005	0.533***	0.534***	0.011	0.011	0.293***	0.293***
[t]	2.376	2.376	15.096	15.110	2.762	2.761	13.576	13.567	0.144	0.148	16.091	16.141	0.480	0.477	9.501	9.575
RMW	-0.052***	-0.052***	-0.087***	-0.087***	-0.085***	-0.085***	-0.053***	-0.054***	-0.164***	-0.164***	-0.028	-0.027	-0.124***	-0.125***	0.042	0.042
[t]	-3.006	-3.018	-5.943	-5.944	-4.825	-4.847	-4.257	-4.284	-6.820	-6.886	-0.899	-0.892	-7.358	-7.373	1.613	1.621
CMA	0.151***	0.151***	0.003	0.003	0.155***	0.155***	-0.023	-0.023	0.114***	0.114***	0.043	0.044	0.028	0.028	0.154***	0.154***
[t]	6.335	6.322	0.155	0.156	6.399	6.381	-1.490	-1.496	3.216	3.253	1.359	1.373	1.135	1.131	5.768	5.823
TRI	0.148		0.047		0.307		0.308**		-0.050		-0.138		0.108		0.040	
[t]	0.657		0.302		1.375		2.245		-0.196		-0.517		0.518		0.143	
PRI		-0.022		0.171		0.178		0.137		0.112		0.376		-0.076		0.172
[t]		-0.087		0.863		0.680		0.815		0.387		1.130		-0.334		0.568
After 2015	E score				ESG score				GHG_{EI}				GHG_{E}			
	Brown		Green		Brown		Green		Brown		Green		Brown		Green	
Intercept	0.049***	0.047***	0.029***	0.027***	0.052***	0.051***	0.031***	0.029***	0.033***	0.032***	0.056***	0.053***	0.038***	0.036***	0.053***	0.051***
[t]	6.237	6.514	5.863	5.623	5.420	5.413	6.576	6.258	3.784	3.821	7.895	8.051	4.735	4.742	7.861	8.141
MKT	0.926***	0.926***	0.996***	0.996***	0.873***	0.873***	0.995***	0.995***	0.975***	0.975***	1.020***	1.020***	1.010***	1.009***	0.981***	0.980***
[t]	70.400	71.267	100.968	102.227	67.682	67.457	103.725	110.242	86.887	85.273	64.946	65.476	86.060	85.419	82.930	83.117
SMB	0.528***	0.527***	0.231***	0.230***	0.411***	0.410***	0.219***	0.218***	0.352***	0.351***	0.417***	0.416***	0.244***	0.243***	0.504***	0.503***
[t]	23.411	23.372	13.456	13.554	15.574	15.649	13.882	14.417	14.119	14.212	15.100	15.135	9.711	9.727	19.735	19.479
HML	-0.113***	-0.112***	0.205***	0.206***	-0.099***	-0.099***	0.144***	0.145***	0.222***	0.224***	0.105***	0.106***	0.283***	0.285***	-0.013	-0.012
[t]	-6.452	-6.441	15.675	15.814	-4.894	-4.897	11.520	12.126	11.838	11.932	5.869	5.979	15.624	16.018	-0.830	-0.760
RMW	-0.047**	-0.046**	-0.035***	-0.034**	-0.122***	-0.121***	-0.031***	-0.029***	-0.132***	-0.131***	-0.016	-0.014	-0.064***	-0.063***	-0.031	-0.029
[t]	-2.471	-2.427	-2.605	-2.531	-5.899	-5.822	-2.744	-2.660	-6.576	-6.641	-0.916	-0.805	-3.314	-3.322	-1.574	-1.500
CMA	0.191***	0.192***	-0.017	-0.017	0.187***	0.187***	-0.002***	-0.002	0.039	0.040*	0.069***	0.069***	-0.022	-0.021	0.176***	0.177***
[t]	7.532	7.631	-1.121	-1.104	6.502	6.405	-0.149	-0.118	1.567	1.649	3.515	3.541	-0.927	-0.876	7.744	7.745
TRI	0.156		0.330*		0.059		0.345*		-0.166		0.521*		-0.095		0.284	
[t]	0.484		1.716		0.150		1.931		-0.456		1.902		-0.283		1.014	
PRI		-0.463		-0.160		-0.313		-0.298		-0.921***		-0.260		-0.765**		-0.330
[t]		-1.475		-0.789		-0.791		-1.595		-2.642		-1.010		-2.376		-1.109

Note: We group the EuroStoxx 600 Index historical constituents into brown and green portfolios according to firms' environmental score (E), environmental, social and governance score (ESG), greenhouse gas emissions intensity (GHGEI) calculated as the sum of scope 1 and 2 divided by net revenue, and greenhouse gas emissions (GHGE) calculated as the sum of scope 1 and 2. We perform time-series regressions of the brown and green portfolios excess returns on the Fama-French five factors (the market factor, MKT; the size factor, SMB; the value factor, HML; the profitability factor, RMW; and the investment factor, CMA) plus Physical Risk Index (PRI) or Transition Risk Index (TRI) over the period Jan 2005-Oct 2021 (Full sample), Jan 2005-Dec 2014 (Before 2015), and Jan 2015-Oct 2021 (After 2015). t-statistics ([t]), and Newey-West standard are adopted. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Sensitivity of NACE to TRI

Table 9

Full sample	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Q	R	S
Intercept	0.061	0.034**	0.033***	0.044***	0.037***	0.013	0.040***	0.032***	0.018*	0.037***	0.041***	0.022**	0.041***	0.041***	0.022*	0.068***	0.023*	-0.006
[t]	1.465	1.994	6.606	4.778	3.008	1.552	5.951	4.238	1.745	7.120	8.271	2.264	7.284	5.356	1.946	4.856	1.731	-0.450
MKT	0.919***	1.156***	0.933***	0.780***	0.696***	1.084***	0.908***	0.951***	1.068***	0.866***	0.950***	0.747***	0.915***	1.055***	0.986***	0.663***	0.824***	0.827***
[t]	15.604	39.596	60.647	35.638	35.224	47.997	78.261	55.310	45.394	124.048	74.829	33.050	76.782	55.300	26.580	40.358	43.674	32.875
SMB	-0.070	0.523***	0.403***	0.015	0.235***	1.055***	0.813***	0.998***	1.365***	0.514***	0.393***	0.646***	0.383***	0.919***	1.141***	0.408***	1.115***	0.893***
[t]	-0.423	5.990	17.580	0.379	4.859	23.723	28.388	22.929	15.660	22.307	13.224	11.394	13.044	21.943	20.960	7.667	17.154	14.510
HML	-0.051	0.359***	-0.043	-0.125***	-0.194***	0.444***	-0.046	0.195***	0.349***	-0.101***	0.462***	0.171***	-0.027	-0.021	-0.038	-0.239***	-0.086**	0.321***
[t]	-0.396	4.915	-1.643	-3.296	-5.691	10.271	-1.462	5.758	6.058	-5.764	18.719	4.762	-0.989	-0.457	-0.625	-6.789	-2.266	5.779
RMW	-0.658***	-0.170**	-0.111***	-0.226***	0.166***	0.174***	0.106***	0.070**	0.431***	-0.080***	-0.105***	-0.126***	-0.184***	0.141***	0.399***	-0.221***	0.117***	0.205***
[t]	-4.802	-2.456	-6.958	-7.617	3.746	5.256	4.574	2.237	8.379	-4.373	-5.358	-3.781	-10.523	4.148	8.556	-5.352	2.711	4.144
CMA	0.493***	0.367***	0.138***	-0.067*	-0.094*	0.290***	0.113***	0.013	0.101*	0.047**	0.006	0.289***	0.177***	0.147***	0.016	0.238***	0.197***	0.115*
[t]	3.097	3.870	6.493	-1.740	-1.860	8.617	4.459	0.341	1.719	2.055	0.211	6.836	6.035	4.686	0.282	5.434	4.568	1.792
TRI	-3.045*	0.004	0.474**	-0.589	-0.121	0.424	0.207	0.561*	0.127	0.024	0.063	0.624	0.268	0.391	0.422	0.665	-0.369	0.119
[t]	-1.847	0.008	2.380	-1.532	-0.233	1.262	0.853	1.734	0.292	0.111	0.338	1.482	1.252	1.252	0.712	1.113	-0.643	0.207
Before 2015	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**Q**	**R**	**S**
Intercept	0.108*	0.060***	0.033***	0.056***	0.045***	0.015	0.019**	0.025***	0.008	0.037***	0.039***	0.015	0.045***	0.037***	0.029**	0.072***	0.002	0.006
[t]	1.728	3.153	4.823	5.081	2.915	1.324	2.304	2.625	0.536	5.628	6.767	1.299	5.598	3.857	2.007	3.807	0.122	0.326
MKT	1.030***	1.156***	0.915***	0.732***	0.673***	1.090***	0.887***	0.899***	1.036***	0.863***	0.912***	0.724***	0.909***	1.040***	0.920***	0.670***	0.760***	0.814***
[t]	12.510	36.493	45.507	29.713	27.602	30.652	74.889	55.238	39.407	104.128	63.404	42.851	54.799	60.177	18.917	31.210	34.319	22.558
SMB	-0.058	0.117	0.443***	-0.009	0.338***	1.035***	0.852***	0.835***	1.179***	0.596***	0.360***	0.677***	0.389***	0.970***	1.127***	0.440***	0.930***	0.814***
[t]	-0.234	1.325	15.736	-0.196	6.523	21.279	27.204	20.551	16.535	19.150	12.881	15.178	10.298	23.818	14.585	6.103	12.829	11.308
HML	-0.219	0.014	0.022	-0.093*	-0.154***	0.557***	0.082***	0.220***	0.445***	-0.039*	0.517***	0.252***	0.023	0.090*	-0.052	-0.175***	-0.025	0.372***
[t]	-1.142	0.166	0.606	-1.781	-3.176	8.783	2.578	6.245	6.452	-1.822	17.021	6.618	0.645	1.867	-0.558	-3.514	-0.523	4.492
RMW	-1.037***	-0.161**	-0.107***	-0.203***	0.131**	0.170***	0.146***	0.074**	0.473***	-0.122***	-0.158***	-0.197***	-0.186***	0.173***	0.397***	-0.218***	0.08	0.218***
[t]	-5.256	-2.443	-4.702	-5.752	2.196	3.526	4.912	2.054	8.670	-5.003	-6.321	-4.710	-7.786	4.227	6.243	-3.917	1.429	2.994
CMA	0.563***	0.727***	0.132***	-0.092*	-0.144**	0.259***	0.073**	0.057	0.110*	-0.022	0.043	0.226***	0.181***	0.164***	0.174***	0.173***	0.248***	0.175**
[t]	2.615	8.265	4.663	-1.942	-2.156	6.303	2.237	1.509	1.766	-0.738	1.326	4.922	4.608	5.397	2.842	3.047	4.821	2.111
TRI	-4.337*	-0.056	0.841***	-0.900*	-0.405	0.341	0.468	0.827**	0.484	0.029	-0.099	0.760	0.298	0.498	0.993	1.017	-0.223	-0.129
[t]	-1.951	-0.091	3.121	-2.032	-0.657	0.793	1.567	2.256	0.883	0.116	-0.427	1.516	0.990	1.281	1.260	1.288	-0.312	-0.172
After 2015	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**Q**	**R**	**S**
Intercept	0.018	0.017	0.023***	0.027*	0.024	0.007	0.064***	0.041***	0.028	0.032***	0.039***	0.027*	0.032***	0.042***	0.004	0.051***	0.055**	-0.020
[t]	0.510	0.662	3.691	1.659	1.319	0.547	6.961	2.866	1.603	4.026	6.767	1.831	4.543	3.260	0.205	2.750	2.562	-0.992
MKT	0.754***	1.136***	0.958***	0.853***	0.739***	1.063***	0.934***	1.016***	1.094***	0.873***	0.912***	0.779***	0.920***	1.069***	1.079***	0.652***	0.899***	0.833***
[t]	13.133	33.200	73.758	29.179	21.313	49.199	64.873	42.316	28.970	69.284	63.404	19.525	66.340	31.827	35.161	28.689	33.336	29.325
SMB	0.044	0.753***	0.379***	-0.001	0.080	1.246***	0.858***	1.211***	1.737***	0.469***	0.360***	0.687***	0.423***	0.926***	1.004***	0.451***	1.408***	1.055***
[t]	0.278	7.908	12.589	-0.013	0.780	19.967	22.017	20.215	12.750	15.722	12.881	6.550	11.930	11.638	14.552	5.597	14.069	13.782
HML	-0.049	0.714***	-0.134***	-0.085*	-0.160***	0.171***	-0.245***	0.143***	0.101	-0.163***	0.517***	0.075	-0.135***	-0.236***	0.018	-0.344***	-0.222***	0.143**
[t]	-0.308	10.171	-5.915	-1.689	-3.031	3.719	-10.107	2.885	1.538	-6.900	17.021	1.579	-5.071	-5.315	0.296	-6.672	-3.492	2.451
RMW	-0.200	-0.336***	-0.103***	-0.232***	0.260***	0.164***	0.071**	0.053	0.344***	0.012	-0.158	0.010	-0.185***	0.093*	0.396***	-0.213***	0.159**	0.150***
[t]	-1.494	-4.639	-4.540	-4.845	4.359	4.183	2.527	1.084	4.087	0.449	-6.321	0.190	-7.080	1.941	6.529	-3.557	2.502	2.610
CMA	0.223	0.129	0.097***	0.064	0.005	0.156***	0.058*	0.004	0.006	0.096***	0.043***	0.335***	0.104***	-0.021	-0.129	0.258***	0.130*	-0.062
[t]	1.478	1.489	3.633	0.967	0.070	3.139	1.799	0.070	0.064	2.946	1.326	4.903	3.937	-0.432	-1.528	3.760	1.742	-0.777
TRI	-2.601	-0.553	-0.308	0.006	0.384	0.284	0.236	0.292	-0.449	-0.038	-0.099	0.464	0.014	0.227	-0.753	-0.311	-0.084	0.210
[t]	-1.503	-0.499	-1.110	0.008	0.422	0.530	0.577	0.421	-0.575	-0.101	-0.427	0.672	0.050	0.422	-0.915	-0.396	-0.086	0.242

Note: We group the EuroStoxx 600 Index historical constituents into NACE sectors: Agriculture, forestry and fishing (A), Mining and quarrying (B), Manufacturing (C), Electricity, gas, steam and air conditioning supply (D), Water supply; sewerage, waste management and remediation activities (E), Construction (F), Wholesale and retail trade; repair of motor vehicles and motorcycles (G), Transportation and storage (H), Accommodation and food service activities (I), Information and communication (J), Financial and insurance activities (K), Real estate activities (L), Professional, scientific and technical activities (M), Administrative and support service activities (N), Public administration and defence; compulsory social security (O), Human health and social work activities (Q), Arts, entertainment and recreation (R), Other service activities (S). We perform time-series regressions of the NACE sectors excess returns on the Fama-French five factors (the market factor, MKT; the size factor, SMB; the value factor,HML; the profitability factor, RMW; and the investment factor, CMA) plus Transition Risk Index (TRI) over the period Jan 2005-Oct 2021 (Full sample), Jan 2005-Dec 2014 (Before 2015), and Jan 2015-Oct 2021 (After 2015). t-statistics ([t]), and Newey-West standard are adopted. * p < 0.1; ** p < 0.05; *** p < 0.01.

Sensitivity of NACE to PRI

Table 10

Full sample	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Q	R	S
Intercept	0.061	0.034**	0.033***	0.044***	0.037***	0.013	0.040***	0.032***	0.018*	0.037***	0.041***	0.022**	0.041***	0.041***	0.022*	0.068***	0.023*	-0.006
[t]	1.466	1.992	6.581	4.750	3.037	1.554	5.976	4.242	1.746	7.132	8.319	2.270	7.289	5.369	1.947	4.876	1.728	-0.450
MKT	0.920***	1.155***	0.933***	0.780***	0.697***	1.083***	0.908***	0.951***	1.068***	0.865***	0.950***	0.746***	0.915***	1.054***	0.987***	0.663***	0.824***	0.826***
[t]	15.741	39.588	60.500	35.631	34.818	47.971	77.954	55.223	45.335	123.484	75.016	33.020	76.784	55.286	26.585	40.543	43.658	32.995
SMB	-0.068	0.522***	0.402***	0.014	0.235***	1.054***	0.813***	0.997***	1.365***	0.513***	0.394***	0.645***	0.383***	0.918***	1.142***	0.407***	1.116***	0.891***
[t]	-0.410	5.994	17.480	0.353	4.825	23.717	28.412	22.885	15.640	22.288	13.346	11.357	13.034	21.867	20.967	7.588	17.115	14.580
HML	-0.051	0.359***	-0.043	-0.125***	-0.194***	0.444***	-0.046	0.195***	0.349***	-0.101***	0.462***	0.171***	-0.027	-0.021	-0.038	-0.239***	-0.086**	0.321***
[t]	-0.392	4.918	-1.640	-3.285	-5.621	10.263	-1.459	5.749	6.059	-5.748	18.915	4.755	-0.991	-0.457	-0.628	-6.837	-2.267	5.815
RMW	-0.659***	-0.170**	-0.111***	-0.226***	0.166***	0.174***	0.106***	0.070**	0.431***	-0.079***	-0.105***	-0.126***	-0.184***	0.141***	0.399***	-0.221***	0.117***	0.206***
[t]	-4.825	-2.454	-6.973	-7.621	3.721	5.254	4.580	2.245	8.373	-4.372	-5.390	-3.769	-10.512	4.153	8.548	-5.399	2.698	4.149
CMA	0.497***	0.367***	0.137***	-0.066*	-0.094*	0.290***	0.113***	0.012	0.100*	0.047**	0.005	0.288***	0.177***	0.146***	0.016	0.237***	0.198***	0.115*
[t]	3.148	3.871	6.443	-1.708	-1.859	8.584	4.445	0.321	1.717	2.063	0.208	6.798	6.032	4.671	0.270	5.399	4.586	1.802
PRI	-0.981	-0.248	-0.107	-0.935**	0.217	0.181	-0.164	-0.184	0.081	-0.559**	0.326*	0.102	0.145	0.071	0.483	0.173	0.1	-0.633
[t]	-0.564	-0.366	-0.506	-2.260	0.400	0.482	-0.585	-0.525	0.152	-2.421	1.708	0.244	0.596	0.198	0.846	0.280	0.165	-0.954
Before 2015	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Q	R	S
Intercept	0.094	0.059***	0.036***	0.055***	0.044***	0.016	0.021**	0.027***	0.010	0.038***	0.038***	0.017	0.045***	0.038***	0.031**	0.074***	0.001	0.006
[t]	1.525	3.109	5.297	4.848	2.791	1.399	2.509	2.895	0.695	5.766	6.681	1.421	5.712	3.999	2.185	3.899	0.057	0.363
MKT	1.030***	1.157***	0.915***	0.732***	0.673***	1.090***	0.887***	0.900***	1.036***	0.863***	0.912***	0.725***	0.909***	1.041***	0.920***	0.671***	0.760***	0.813***
[t]	12.599	36.547	45.192	29.763	27.119	30.676	74.532	54.994	39.334	104.057	63.883	42.482	54.786	60.116	18.928	30.981	34.362	22.520
SMB	-0.051	0.119	0.441***	-0.010	0.339***	1.035***	0.851***	0.835***	1.177***	0.595***	0.362***	0.678***	0.389***	0.970***	1.128***	0.441***	0.930***	0.813***
[t]	-0.208	1.336	15.511	-0.208	6.469	21.259	27.032	20.246	16.577	19.123	12.892	14.957	10.301	24.065	14.610	6.139	12.808	11.268
HML	-0.215	0.014	0.021	-0.092*	-0.153***	0.556***	0.082**	0.219***	0.445***	-0.039*	0.517***	0.252***	0.022	0.089*	-0.053	-0.177***	-0.025	0.373***
[t]	-1.134	0.165	0.582	-1.762	-3.115	8.784	2.523	6.138	6.438	-1.821	17.163	6.547	0.635	1.822	-0.572	-3.508	-0.521	4.493
RMW	-1.032***	-0.161**	-0.108***	-0.201***	0.131**	0.169***	0.145***	0.073**	0.472***	-0.121***	-0.158***	-0.198***	-0.187***	0.172***	0.396***	-0.219***	0.08	0.218***
[t]	-5.231	-2.449	-4.758	-5.712	2.177	3.521	4.890	2.021	8.668	-5.029	-6.336	-4.754	-7.807	4.196	6.224	-3.914	1.436	2.999
CMA	0.567***	0.727***	0.131***	-0.090*	-0.143**	0.259***	0.073**	0.055	0.109*	-0.022	0.043	0.224***	0.181***	0.164***	0.173***	0.171***	0.248***	0.176**
[t]	2.665	8.283	4.601	-1.891	-2.129	6.276	2.208	1.455	1.764	-0.733	1.330	4.847	4.616	5.347	2.812	3.040	4.824	2.121
PRI	-0.452	0.711	0.010	-0.946*	0.064	0.241	0.010	0.442	-0.345	-0.408	0.475**	0.686	0.441	0.511	1.094	0.994	0.161	-0.623
[t]	-0.176	0.968	0.036	-1.882	0.096	0.489	0.028	0.981	-0.500	-1.453	2.071	1.355	1.343	1.124	1.416	1.163	0.223	-0.735
After 2015	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Q	R	S
Intercept	0.026	0.014	0.024***	0.024	0.023	0.006	0.062***	0.037***	0.032*	0.031***	0.046***	0.024	0.031***	0.039***	0.006	0.050***	0.057***	-0.024
[t]	0.722	0.571	4.023	1.539	1.309	0.479	7.075	2.709	1.954	4.021	5.724	1.625	4.620	3.288	0.334	2.704	2.783	-1.187
MKT	0.755***	1.136***	0.958***	0.852***	0.739***	1.063***	0.933***	1.015***	1.095***	0.873***	0.999***	0.778***	0.920***	1.068***	1.080***	0.651***	0.899***	0.833***
[t]	13.344	33.262	74.030	28.942	21.414	49.206	64.928	42.411	28.881	68.577	79.506	19.546	66.847	31.856	35.489	28.781	33.132	29.225
SMB	0.042	0.749***	0.379***	-0.002	0.081	1.246***	0.857***	1.209***	1.738***	0.468***	0.464***	0.686***	0.422***	0.925***	1.003***	0.449***	1.408***	1.053***
[t]	0.262	7.902	12.527	-0.039	0.782	19.910	22.024	20.210	12.794	15.726	12.040	6.474	11.840	11.528	14.835	5.550	14.059	13.529
HML	-0.047	0.714***	-0.133***	-0.085*	-0.160***	0.171***	-0.245***	0.142***	0.101	-0.163***	0.360***	0.075	-0.135***	-0.236***	0.018	-0.344***	-0.222***	0.143**
[t]	-0.305	10.233	-5.927	-1.681	-3.033	3.716	-10.127	2.886	1.547	-6.903	13.536	1.565	-5.089	-5.341	0.303	-6.732	-3.494	2.409
RMW	-0.205	-0.338***	-0.104***	-0.233***	0.261***	0.164***	0.072**	0.053	0.344***	0.012	-0.028	0.010	-0.185***	0.093*=	0.394***	-0.214***	0.159**	0.150***
[t]	-1.540	-4.669	-4.566	-4.857	4.367	4.185	2.529	1.083	4.079	0.428	-1.126	0.195	-7.105	1.945	6.454	-3.572	2.497	2.598
CMA	0.228	0.130	0.098***	0.064	0.005	0.155***	0.057*	0.003	0.007	0.096***	-0.081***	0.334***	0.104***	-0.022	-0.128	0.259***	0.130*	-0.063
[t]	1.497	1.495	3.657	0.958	0.061	3.120	1.786	0.057	0.076	2.928	-2.597	4.861	3.929	-0.446	-1.499	3.769	1.743	-0.766
PRI	-2.184	-2.420**	-0.299	-1.006	0.464	0.065	-0.122	-1.058*	0.826	-0.697**	0.452	-0.574	-0.364	-0.564	-0.615	-1.124	0.361	-0.868
[t]	-1.151	-2.392	-0.963	-1.438	0.574	0.123	-0.289	-1.828	0.990	-2.012	1.345	-0.841	-1.090	-1.008	-0.698	-1.308	0.358	-0.840

Note: We group the EuroStoxx 600 Index historical constituents into NACE sectors: Agriculture, forestry and fishing (A), Mining and quarrying (B), Manufacturing (C), Electricity, gas, steam and air conditioning supply (D), Water supply; sewerage, waste management and remediation activities (E), Construction (F), Wholesale and retail trade; repair of motor vehicles and motorcycles (G), Transportation and storage (H), Accommodation and food service activities (I), Information and communication (J), Financial and insurance activities (K), Real estate activities (L), Professional, scientific and technical activities (M), Administrative and support service activities (N), Public administration and defence; compulsory social security (O), Human health and social work activities (Q), Arts, entertainment and recreation (R), Other service activities (S). We perform time-series regressions of the NACE sectors excess returns on the Fama-French five factors (the market factor, MKT; the size factor, SMB; the value factor,HML; the profitability factor, RMW; and the investment factor, CMA) plus Physical Risk Index (PRI) over the period Jan 2005-Oct 2021 (Full sample), Jan 2005-Dec 2014 (Before 2015), and Jan 2015-Oct 2021 (After 2015). t-statistics ([t]), and Newey-West standard are adopted. * p < 0.1; ** p < 0.05; *** p < 0.01.

Appendix 1

Physical risk and transition risk vocabularies list of acronyms

Table A1

Physical risk vocabulary acronyms			
GHG	Greenhouse gas	RCP	Representative Concentration
IPCC	Intergovernmental Panel on Climate change		
Transition risk vocabulary acronyms			
EJ/yr	Exajoules per year	MtCO2	Megatonne of carbon
eq/yr	Equivalent per year	MtCO2 eq	Megatonne of carbon equivalent
GHG	Greenhouse gas	TCO2	Tonne of carbon
GtCO2	Gigatonne of carbon	TEAP	Technology and Economic Assessment Panel
HCF	Hydrofluorocarbon	TWh/yr	Terawatt hours/year
HCFC	Hydrochlorofluorocarbon	UNEP	United Nations Environment Programme
IPCC	Intergovernmental Panel on Climate change	UNFCCC	United Nations Framework Convention on Climate Change
IEA	International Energy Agency	USD/kWh	United States Dollar/Kilowatt hour

Note: Physical risk and transition risk summary vocabularies as in figure 1 list of acronyms.

List of climate change white papers for transition and physical risk

Table A2

Year	Source	Title	Transition	Physical
1990	IPCC	IPCC Synthesis Report 1990	115-148p	
1990	IPCC	Climate change: The IPCC Impacts Assessment		Entire
1992	IPCC	Climate change: The IPCC 1990 and 1992 Assessments		87-113p
1999	IPCC	IPCC Special Report: Aviation and the global atmosphere	Entire	
2000	IPCC	IPCC Special Report: Methodological and technological issues in technology transfer	Entire	
2001	IPCC	IPCC Synthesis Report 2001	302-354p	
2001	IPCC	Climate change 2001: Impacts, adaptation and vulnerability		Entire
2005	IPCC	IPCC Special Report: Carbon dioxide capture and storage	Entire	
2005	IPCC	IPCC Special Report: Safeguarding the ozone layer and the global climate system: Issues related to hydrofluorocarbons and perfluorocarbons	Entire	
2007	IPCC	IPCC Synthesis Report 2007	55-70p	
2007	IPCC	Climate change 2007: Impacts, Adaptation and Vulnerability		Entire
2011	IPCC	IPCC Special Report: Renewable energy sources and climate change mitigation	Entire	
2012	IPCC	IPCC Special Report: Managing the risks of extreme events and disasters to advance climate change adaptation		Ch. 2 & 4
2014	IPCC	IPCC Synthesis Report 2014	75-112p	
2014	IPCC	Climate change 2014: Impacts, adaptation and vulnerability		Part A & B
2018	UNEP FI - Acclimatise	Navigating a new climate. Part 2: Physical risks and opportunities		Entire
2019	IPCC	IPCC Special Report: Global warming of 1.5C	Ch. 2 & 4	Ch. 3
2019	IPCC	IPCC Special Report: Climate change and land		Ch. 1-5
2019	IPCC	IPCC Special Report: The ocean and cryosphere in a changing climate		Entire
2020	IMF – Journal of Macroeconomics	The effects of weather shocks on economic activity: What are the channels of impact?		Entire
2020	McKinsey Global Institute	Climate risk and response: Physical hazards and socioeconomic impacts		Entire
2020	Swiss Re Institute	Natural catastrophes in times of economic accumulation and climate change		Entire

Note: This table reports the year of publication, source, title of the list of texts used to construct the physical and transition risk vocabularies.
List of acronyms: IPCC, Intergovernmental Panel on Climate Change; IMF, International Monetary Fund; UNEP FI, United Nations Environment Programme Finance Initiative.

International Conference on "Statistics for Sustainable Finance", co-organised with the Banque de France and the Deutsche Bundesbank

14-15 September 2021, Paris, France, hybrid format

How proxies and publicly available data can be used to construct indicators on transition risk, physical risks and green taxonomies[1]

Justin Dijk, Derek Dirks, Willemijn Ouwersloot and Juan Pablo Trespalacios Miranda,
Netherlands Bank

[1] This presentation was prepared for the conference. The views expressed are those of the authors and do not necessarily reflect the views of the BIS, the IFC or the central banks and other institutions represented at the event.

How proxies and publicly available data can be used to construct indicators on transition risk, physical risks and green taxonomies

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De Nederlandsche Bank (DNB)[1]

Abstract

In this paper, we introduce new experimental indicators for transition risk, physical risks and green taxonomies based on the preliminary results of three MSc research projects performed at de Nederlandsche Bank (DNB). For transition risk, the publicly available OECD Trade in Value-Added (TiVA) and the accompanying Trade in Embodied CO_2 ($TECO_2$) database are employed to determine an optimal environmental (Pigouvian) tax on carbon emissions. This tax is used to determine an 'expected impact ratio', e.g. a carbon tax that is expected to absorb X% of the profits of a particular asset position. For physical risks, open-access historical macro-economic damage data on storms and floods are used to calibrate micro-economic damage functions. The micro-scale damage functions are subsequently used to estimate risks for real estate portfolios due to future storms and floods, e.g. to calculate the 99% Value-at-Risk of a real estate portfolio based on historically calibrated model predictions. Finally, we explore the distribution and demand of climate-aligned financial investments through green taxonomic criteria and remote sensing data. The results show that overall, there is substantial scope for financial institutions and central banks to better leverage publicly available data sources and models to develop climate risk proxies. In particular, there are promising results for transition risk and green taxonomy applications, while for physical risk the performance of the models could be improved if more granular data (e.g. historical damage data on ZIP-code level) were to be made publicly available.

Keywords: transition risk, physical risk, green taxonomies, open access data, proxies

JEL classification: G11, G17, H21, H23, Q54

[1] Views expressed in this paper are those of the authors, and do not necessarily reflect the official positions of de Nederlandsche Bank or the Eurosystem.

Contents

1. Introduction

There is substantial scope for financial institutions and central banks to better leverage publicly available data sources and models to develop climate risk proxies. Giving the urgency of climate change, the financial sector does not have the luxury to wait until 'perfect' or better data becomes available, and should consider using the alternatives that are currently available. This paper is inspired by the call for research of the ECB STC Expert Group on Climate Change and Statistics (EG CCS) on three priority sets of indicators, namely indicator related to transition risk (and carbon footprint), physical risks and green taxonomies. The EG CCS recommends to develop pilot statistics for these three sets of priority indicators and pair them with transparent methodologies. Considering the combination of the urgency with which these indicators are needed, and the practical barriers that will need to be overcome, the EG CCS stresses that feasibility is a key variable in the prioritisation.[2]

At the same time, international organizations such as the G20 Sustainable Finance Working Group, the NGFS, and the FSB are studying the different ways to bridge the data gaps that are currently limiting practitioners in their ability to assess the current state of sustainable finance. At present, incompleteness and inconsistency in sustainability-related disclosures pose challenges to practitioners due to the proliferation of different disclosure frameworks. In addition, sustainability data is held and defined mostly by private sector data providers in an uncoordinated manner, which hinders its accessibility and transparency. Improving sustainability reporting standards and data governance and architecture will allow for a better identification of sustainability risks, impacts and opportunities.[3]

Until significant progress is made in this area, one of the often repeated recommendations is to make better use of proxies, modelled data, aggregates and estimates when (more) granular or reported data is currently unavailable. For example, industry averages can be used to estimate financed emissions when data is not (yet) available for a specific firm. The obvious downside being the lower accuracy of modelled (or aggregated) data when compared with reported data. As such, it is best to consider the use of modelled data as an intermediate step, which will help bridge some of the data gaps in the short term. In any case, postponing the identification of climate risks is not an option as market players acknowledge: data will never be perfect thus action should be taken with what is available currently.[4]

In this paper, new experimental indicators for transition risk, physical risk and green taxonomies based on the preliminary results of three MSc research projects performed at de Nederlandsche Bank (DNB). For transition risk, the publicly available OECD Trade in Value-Added (TiVA) and the accompanying Trade in Embodied CO_2 ($TECO_2$) database are employed to determine an optimal environmental (Pigouvian) tax on carbon emissions. This tax is used to determine an 'expected impact ratio', e.g. a carbon tax that is expected to absorb X% of the profits of a particular asset position. For physical risk, open-access historical macro-economic damage data on storms and floods are used to calibrate micro-economic damage functions. The micro-scale

2 ECB "Towards statistics on climate change relevant for Central Bank activities", Final Report by the STC Expert Group on Climate Change and Statistics (STC-SSM/2020/143), 15 October 2020.

3 G20, "Sustainable Finance Roadmap Draft", 24 August 2021.

4 Network for Greening the Financial System "Progress report on bridging data gaps", May 2021

damage functions are subsequently used to estimate risks for real estate portfolios due to future storms and floods, e.g. to calculate the 99% Value-at-Risk of a real estate portfolio based on historically calibrated model predictions. Finally, we explore the distribution and demand of climate-aligned financial investments through green taxonomic criteria and remote sensing data.

Our results show that overall, there is substantial scope for financial institutions and central banks to better leverage publicly available data sources and models to develop climate risk proxies. In particular, the results are promising for the transition risk and green taxonomy applications, while for physical risk the performance of the models could be improved if more granular data (e.g. historical damage data on ZIP-code level) were to be made publicly available.

The remainder of this paper organized as follows. The transition risk, physical risks and green taxonomies sections (in that order) each offer subsections that contain i) a short summary of the methodology, ii) the public datasets that are used, and iii) the results of the application on Dutch portfolio data that is provided by the Nederlandsche Bank. The three MSc research projects that allowed us to write this paper are available upon request.

2. Transition risk

In 2020, 84% of the world's total consumption of energy originated from fossil fuels (BP,2020). Stern (2007) argues that radical changes to the global economy and energy systems are needed to achieve the required reduction in GHG emissions. In his 2015 speech to the UK insurance sector, Mark Carney, then Governor of the Bank of England, warned that financial risks could arise due to this energy transition (Carney, 2015). He also introduced a distinction between physical and transition risks that has since then been adopted as the standard way of classifying financial risks related to climate change.

The literature shows that the impact of transition risk might be severe and that financial institutions need to adopt a forward-looking and comprehensive risk management approach to increase their resilience (NGFS, 2020). In this section, a new risk management tool is constructed that can assess the impact of the introduction of (new) carbon tax scenarios on any investment portfolio. Inspired by Smeets et al. (2021), an impact ratio is constructed that quantifies the risk a financial institution faces in terms of potential reductions in portfolio value and returns when a particular carbon tax is introduced.

2.1 Methodology

Taxes on environmental externalities are often referred to as Pigouvian taxes, acknowledging the pioneering work on pricing environmental externalities by Pigou (1929). In the literature, two carbon pricing instruments are often viewed as the main solutions for reducing GHG emissions, namely a carbon tax and an emission trading scheme (ETS) (Baranzini et al., 2017; Jenkins, 2014). A carbon tax fixes the price of GHGs emitted by taxing the quantity emitted by corporations but lets the quantity of GHGs emitted fluctuate. An ETS sets a cap on the total amount of GHGs emitted and emission allowances are allocated between corporations (Baranzini et al., 2017). In this case, the amount of emissions is fixed, while the price of GHGs fluctuates. Thus in a very simple world, a carbon price can be established either through a tax or an ETS. Here, we evaluate the impact of a carbon tax that is based on the Pigouvian, optimal environmental tax principle; the tax rate is set equal to (marginal) environmental damage caused by the negative externality. Based on the available literature on the social costs of carbon, three tax scenarios are considered: a global carbon tax rate of €38 (based on current politics; low scenario), €119 (policy-science estimate; medium scenario), and €175 per tonne CO_2 (based on the recent scientific literature; high scenario).

Equation (1) offers a simplified version of how the environmental footprint, based on the ownership perspective or 'financed emissions', is determined for the investments in stocks and bonds. Consider a pension fund *p* that holds α_A EUR (€) in stocks and bonds of company A and α_B EUR (€) in stock and bonds of company B. Firm A operates in sector 1 and firm B produces its goods and services in sector 2, both active in country *x*. The environmental footprint (*ef*) of pension fund *p* can then be calculated as:

$$ef_p = \frac{\alpha_A}{Enterprise\ Value_A} * \mathrm{r}_A * ci_{1,x} + \frac{\alpha_B}{Enterprise\ Value_B} * \mathrm{r}_B * ci_{2,x} \qquad (1)$$

with ef_p the environmental footprint of pension fund *p* in tonnes of CO_2, $Enterprise\ Value_i$ the Enterprise Value (EV) of company *i*, r_i the revenue of company *i* and $ci_{k,x}$ the carbon intensity (in tonnes of CO_2/revenue) of sector *k* and country *x* that the firms operate in. Given that revenue drops out as it is the numerator and in the denominator, and the term α_i/Enterprise Value_i is a simple weight factor in this equation, ef_p has tonnes of CO_2 (i.e. absolute emissions) as its unit. The formula is somewhat intricate due to the use of a combination of different data sources to calculate it. Revenue (r_i) and EV are typically available at third-party data providers whereas data carbon emissions is often not available or complete. That is why here carbon intensities at the country-sector level ($ci_{k,x}$) are employed and taken from an input-output model (see section 2.2 for more details). Equivalently, 'financed profits', the profits that can be assigned to a pension fund based on its ownership share, are given by:

$$\pi_p = \frac{\alpha_A}{Enterprise\ Value_A} * \pi_A + \frac{\alpha_B}{Enterprise\ Value_B} * \pi_B \qquad (2)$$

with π_p the financed profits of pension fund *p*, and as before, company level data for EV and profits, and α_A, α_B representing the EUR (€) amount in stock and bonds invested in companies A and B. Combining general version of equations (1) and (2), we end up with the following formula for the impact ratio of the portfolio of a pension fund (which can easily be applied to specific sectors separately by splitting up the portfolio dataset for each sector *k* of the input-output model):

$$\text{Impact factor}_p = \frac{ef_p}{\pi_p} * \tau_c \qquad (3a)$$

With ef_p and π_p representing financed absolute emission and financed profits, respectively, and τ_c the tax rate in scenario *c*. Given that ef_p is depicted in tonnes of CO_2, τ_c has € per tonne CO_2 as a unit, and π_p is in EUR (€) the resulting unit of the impact factor is simply a percentage (%).

2.2 Data

To determine the environmental footprint of the investment portfolios of the pension funds, we employ portfolio data provided by DNB for pension funds' direct and indirect investments in equity and corporate bonds. For 2020, these direct and indirect investments have a total value of EUR 851,6 billion based on the security holding statistics by sector (SHSS) dataset. Comparing this to the total balance sheet of the entire Dutch pension fund sector, the data in this study covers approximately 44% of the total assets of Dutch pension funds.

The portfolio data is provided by DNB for the end of the fourth quarter of 2020. Stocks and bonds are issued by (inter)national companies that operate in various sectors. In the portfolio data, these sectors are indicated by NACE codes. A stock can get issued by a head office, which results in the stock being assigned the NACE code M.70.1(0) corresponding to head office activities. Given that sector carbon intensities are used from the input-output model and assigned to the company level data based on the NACE codes it is important to "correct" sector codes for headquarters to the actual industry. As an example, if the stock of Heineken has NACE code M.70, it needs to be assigned to C.11.05, which is the NACE code for the manufacture of beer sector. As the correct NACE codes need to be determined manually based on expert judgement, the choice is made to correct only the largest equity and bond positions. This yields a list of stocks and bond for which the correct NACE sector is attributed of >80% for direct and indirect investment in equity and corporate bonds.

The Organisation for Economic Cooperation and Development (OECD) developed the Trade in Value-Added (TiVA) database to address the problem that the flows of goods and services are occasionally not reflected in measures of trade within global production chains. The TiVA database solves this by considering the value-added by each country-specific industry in the global production of goods and services. In this study, the 2015 data from the 2018 edition is taken. It comprises 69 countries (including 1 rest of the world (ROW)) and 36 industries, which use International Standard Industrial Classification Revision 4 (ISIC Rev. 4). From the 2015 TiVA data, the output vector is taken from the underlying Inter-Country Input-Output (ICIO) table to determine the carbon intensity of the country-specific industries. However, the data for Mexico and China is split into two categories: MX1 and MX2 for Mexico and CN1 and CN2 for China. These are placed at the end of the output vector, while within the vector there are zero values for Mexico and China (MEX and CHN respectively). Hence, MX1 and MX2 are aggregated and substituted for MEX and the same is done for China. Wiebe and Yamano (2016) combined the ICIO table with the CO_2 emissions from fuel combustion statistics from the International Energy Agency (IEA) and other industry statistics to create the Trade in embodied CO2 ($TECO_2$) database. This database embodies scope 1, 2 and 3 emissions, which are all direct emissions, all indirect emissions from energy purchase and use, and all other indirect emissions, respectively (Huang et al., 2009). The consumption-based emission data is then converted to production-based data, as a carbon tax is assumed to be levied on emissions emitted during the production process of companies.

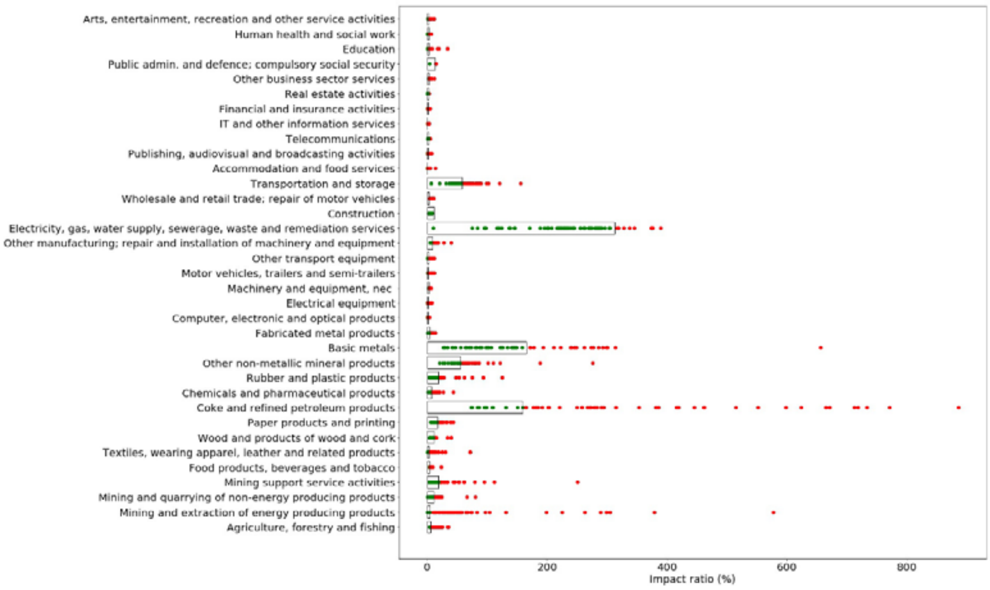
Finally, company level data are retrieved using Refinitiv Thompson Reuters EIKON (for profits, revenue and Enterprise Value) to determine financed emissions and financed profits based on the ownership approach. Details on how the social cost of carbon literature is used to determine optimal Pigouvian tax rates for the different scenarios is available upon request (i.e. the final thesis on which this section is based).

2.3 Results

For a global carbon tax rate of €38, €119, and €175 per tonne CO2, an impact ratio of 4,4%, 13,9% and 20,4% is estimated for the fourth quarter of 2020, respectively. Thus, the profits that the portfolios of the Dutch pension funds are exposed to through their investments would, ceteris paribus, be sufficient to bear the costs associated with a global carbon tax in all scenarios.

Comparing, at the sector level, the benchmark impact ratio to the impact ratios of investments by individual Dutch pension funds shows that there is room for improvement across nearly every sector (see Figure 1). Note that for the benchmark, it holds that investments are 'sector neutral'; a hypothetical portfolio with investment weights equal to EV_i divided by the sum of sector k's EV_i over all companies (*i*) is determined within the dataset. Figure 1 shows results for the (medium) €119 per tonne CO2 scenario. It shows that for nearly every sector, individual pension funds can improve on their impact ratio compared to the benchmark (in red). Also, there are large differences among pension funds. Many of them have sector positions where profits are insufficient to bear the env. damage cost (i.e. the impact ratio is >100%). The benchmark impact ratio also exceeds 100% for three sectors, namely refined petroleum products sector (159%), the basic metals sector (165%) and the electricity, gas, water supply, sewerage, waste, and remediation services sector (313%).

Figure 1: Benchmark impact ratio vs. the impact ratios of the portfolio positions of individual pension funds.



Note: The benchmark impact ratio of the sector is depicted by the bar. The green dots represent impact ratios of investments of pension funds that are below the benchmark, and the red dots represent impact ratios of pension funds above the benchmark.

3. Physical risks

Estimating physical risk for assets is important, especially in light of climate change. Physical risk is the risk that extreme weather events, or hazards, lead to large losses in assets. ECB/ESRB Project Team on climate risk monitoring estimates that between 1980 and 2017, about 453 billion Euros of economic losses in the European Economic Area and the United Kingdom were suffered due to climate-related events. Furthermore, they state that if no risk mitigation measures are taken, the economic losses due to these events will have grown to nearly 50 billion Euros per year by the end of this century because of climate change. Therefore, estimating the physical risk for assets is important. In this research, physical risk models are constructed based on historical damage data due to storms and floods in Germany.

3.1 Methodology

To model physical risk, damage due to hazards is often modelled as a function of hazard, exposure and vulnerability (Koks & Haer, 2020). A damage function maps hazard characteristics to expected damages to the exposure. Hazard characteristics concern variables that can be used as a proxy for the severity of the hazard. We focus on two specific hazards: storms and floods. For storms, the hazard characteristic is the maximum wind gust speed during the storm. For floods, the hazard characteristic is either the cumulative sum of precipitation in the three days prior to the flood or the weighted sum of precipitation in the seven days before the flood, which is the so-called antecedent precipitation index or API.

First, we ensure that all monetary values in the research are converted to the same reference year and currency. Moreover, we ensure that exposure data and hazard characteristics data are given on the same level of granularity. Then we model the damage to physical assets as follows. For each grid cell in the entire country grid, we model the expected damage ratio using some micro-scale damage function and the hazard characteristics for that cell. The damage ratio denotes the percentage of damage to the physical assets located on that grid cell. Physical assets are assets which are susceptible to damage due to extreme weather events. Multiplying the damage ratio with the physical asset exposure in that cell gives an estimate of damage to assets in that cell. Aggregating the damages of all cells results in an estimate for national damage due to a specific hazard. We subsequently explore which damage function best approximates the true damage on national level. We do this for both storms and floods.

We consider various storm damage functions: a benchmark function, the exponential function, logistic function, power law function, and several threshold functions, which are the ones based on Klawa & Ulbrich (2003), Emanuel (2011) and Heneka & Ruck (2008). For floods, the investigated damage functions are a benchmark function and the logistic damage function. For all functions except for the one based on Heneka & Ruck (2008) we estimate a univariate variant, including only the hazard characteristic as variable, and a bivariate variant, which also includes hazard duration.

As the samples for storms and floods are both small, we evaluate the accuracy of the estimated parameters by applying bootstrap. Moreover, we evaluate the models by investigating the mean absolute percentage error (MAPE) and the root mean squared error (RMSE). Furthermore, we test for significant differences in damage function accuracy in a pairwise manner by applying the Friedman test. We combine this sequential pairwise testing with the Holm step-down procedure to control the family-wise error rate (Derrac et al., 2011).

The models as investigated in this research are not yet able to approximate storm and flood damage enough to make reliable decisions on risk management. The mediocre performance of the models is due to a lack of sufficient(ly granular) data. The models in this research are estimated on 35 and 36 historical records for storms and floods, respectively. Moreover, for storms, the damage is reported on a national level, making it impossible to distinguish regions that may be less hard hit by the storm. For floods, it is known which regions are affected by the flood, but these regions still cover relatively large NUTS areas (See 3.2 Data).

The main difficulty in quantifying and modelling physical risk thus lies in a so-called data gap. In order to properly fit the models on historical data, that data should be available. The models in this research are fit solely based on open-access data. If, for instance, damage data on a more granular level, for example on ZIP-code level, were available publicly, this could improve the fit of the models. We therefore strongly suggest that such data, after being anonymised, should be made publicly available.

3.2 Data

We construct our models on exposure, hazard, and damage data for Germany. Note that, on average, a significant amount of the invested real estate of Dutch pension funds and insurers that is not situated in the Netherlands is located in Germany (7%). Data on the actual damage for real estate due to storms are either not available or only known at (re)insurance companies. This complicates modelling climate related risks, as endorsed by the Network for Greening the Financial System (2021). In order to model physical risk, we use several open-access data sources.

Exposure data

Exposure data are obtained from Eberenz et al. (2020). This data set contains, per country, the estimated total physical asset value per square kilometre. Physical assets are assets susceptible to physical risk. The estimated total physical asset exposure in 2014 U.S. Dollars (USD) is given for each grid cell with a spatial resolution of 30 arc-seconds. This corresponds to grid cells of a square kilometre, approximately. For Germany, there are in total 661,392 grid cells for which the value of the physical exposure is given. There are no missing values. Furthermore, for the simulation application, we about survey data of a German real-estate portfolio of 1 Dutch financial institution (incl. detailed location information of the real estate assets).

Total hazard damages

We use historical macro-economic damage data to calibrate micro-economic damage functions. Two data sets on historical damages are used to this end. First, macro-economic damage data due to storms are obtained from CRED / UCLouvain (2021). This data set contains data on damaging storms in the period 1979 through 2019. In this research, we include storms in Germany for which the total economic damage is known. This value is given in thousands USD in the value of the year of the storm occurrence. Moreover, for each storm it is known what the start and end date was of the storm. There are 35 storms in the data set.

Macro-economic damage data due to floods are obtained from Paprotny et al. (2018). We use data on 36 damaging floods in Germany in the period 1979 through 2016. For each flood, the total damage in millions of Euros, 2011 value, is known, as well as the start and end date of the flood. Moreover, it is known which regions were affected by the flood. The regions follow the Nomenclature of Territorial Units for Statistics (NUTS) classification from 2010, as given by Eurostat (2010).

Hazard characteristics

As described under 3.1 Methods, the storm and flood damage functions model damage as a function of wind gust speed and precipitation, respectively. These data can be obtained from Climate Data Store (2021). This reanalysis data set contains hourly estimates of wind gust speed and total precipitation at a 900 arcseconds spatial resolution. This corresponds to about 30 kilometres.

The wind gust speed is measured ten metres above the surface of the Earth. The maximum wind gust speed is taken as the maximum of the wind speed averaged over three second intervals (World Meteorological Organization, 2021) and is given in metres per second. The total precipitation is given in metres. In total, there are 1184 locations in Germany for which hourly wind gust speed and total precipitation are known. These values are known for the entire period 1979 through 2019 and there are no missing values.

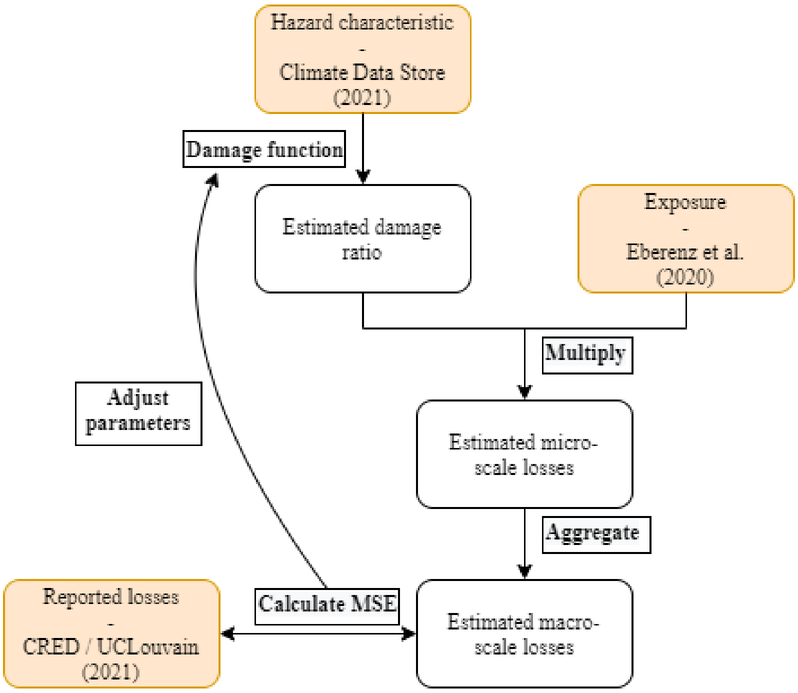
As mentioned under 3.1 Methods, we also incorporate a hazard duration variable in our damage functions. For floods, we simply take the reported start and end date of the flood and calculate the number of hours in that period. We define that to be the flood duration. For storms, we determine the 98th percentile wind gust speed for each location in the exposure data set. We take this value as a threshold above which we speak of gusts with potentially damaging speeds. For the reported duration of the storm, we determine for each location how many hours the maximum wind gust speed was above the threshold. This amount of hours is the value for the storm duration variable.

3.3 Results

Storm simulation

Figure 2 represents the model optimisation process, and shows how the input data sets are used in model calibration. We apply the best performing storm and flood damage functions to show, through two applications, how these functions could be used to estimate and quantify the physical risk for financial institutions.

Figure 2: Physical risk model optimization/calibration process and the use of the different data sources (orange).



In the first application we simulate storms. We then calculate the damage to the real estate portfolio for each storm on the portfolio of 1 Dutch financial institution. Using these values, we calculate the values for several risk metrics such as the expected annual loss, the Value-at-Risk (99%), and the expected shortfall at 98% level (Table 1).

Table 1: Risk metrics and their values in percentages of the total portfolio worth based on a simulation of damages due to 1000 years of storms.

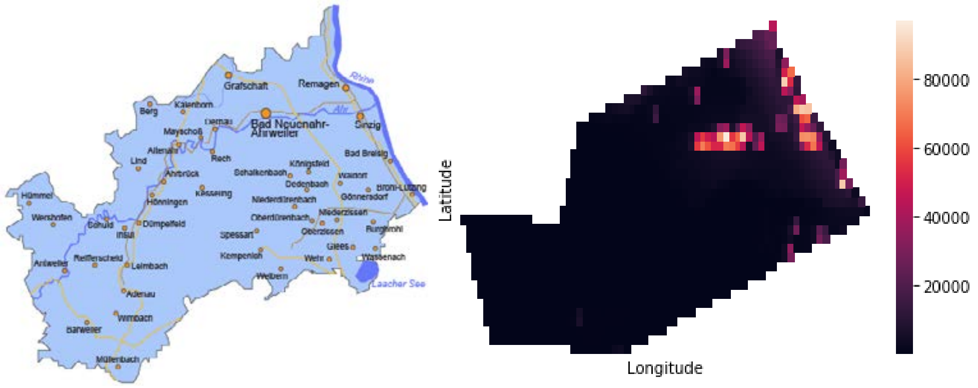
Risk metric	Value
$\widehat{\mathrm{EAL}}$	1.340%
$\widehat{\mathrm{VaR}}_{0.99}$	40.583%
$\widehat{\mathrm{ES}}_{0.98}$	41.445%

On average, about one percent of the total portfolio worth is estimated to be lost each year due to storm damage. The $\mathrm{VaR}_{0.99}$ and $\mathrm{ES}_{0.98}$ are about 40% of the portfolio's worth. As the real estate portfolio can represent a substantial amount of the total asset portfolio of an FI, such values for the risk metrics indicate that financial institutions would do well to take the physical risk due to storms into account on their balance sheet. However, given the lack of sufficient granular data on historical damages, the values that arise from this analysis are not reliable. The simulation does shows that very interpretable risk metrics can be calculated and risk mitigation matters could be taken based on these results. Furthermore, the distributional assumptions that are made in this simulation are not rejected. Therefore, with a suitable damage function, the estimates for the risk metrics for storms that result from this simulation would be quite interpretable and reliable. FIs could use this risk analysis to estimate their exposure to physical risk and take risk mitigating measures.

Flood stress test

One of the regions that incurred the most damage due to the July 2021 floods is Ahrweiler, Germany (Figure 3). For this region, we estimate the damage ratio as well as the losses for each exposure location in our exposure data set. We do this using the best performing flood damage function. The necessary precipitation data is obtained from Climate Data Store (2021). Aggregating all expected losses for the region, we obtain a total expected loss of 5.8 million Euros for Ahrweiler (very low; unreliable). The application shows the possibility to forecast total damages when an extreme weather event hits. With a better calibrated damage function, those forecasts will be more reliable (and likely much higher).

Figure 3: Map of Ahrweiler (left) and heat map of estimated damage in Ahrweiler due to the July 2021 floods (right).



If more granular data (e.g. historical damage data on ZIP-code level) would become available, we encourage that further research be done with these more granular damage data to determine whether other damage functions can better approximate storm and flood damage. Moreover, instead of constructing a model to approximate macro-economic damage, a model to approximate micro-economic damage could be estimated. This would lead to a more local model, but perhaps such a model would result in more accurate predictions of hazard damage. Another advantage of more granular damage data would be that other methods would become possible to implement, such as a fixed effect model. Such a model incorporates a location effect.

Furthermore, using more granular data, it could be researched whether other hazard characteristics, for instance flow velocity for floods, improve the damage models. A final suggestion for future research would be to examine whether a proxy for climate change should be included in the damage models. These directions of research could lead to physical risk models becoming more reliable and eventually becoming a tool to adequately predict and mitigate the risk for damage due to extreme weather events. The results show that, at least for the German case, the current open access data on historical damages are insufficient to produce reliable results for these such applications.

4. Green taxonomies

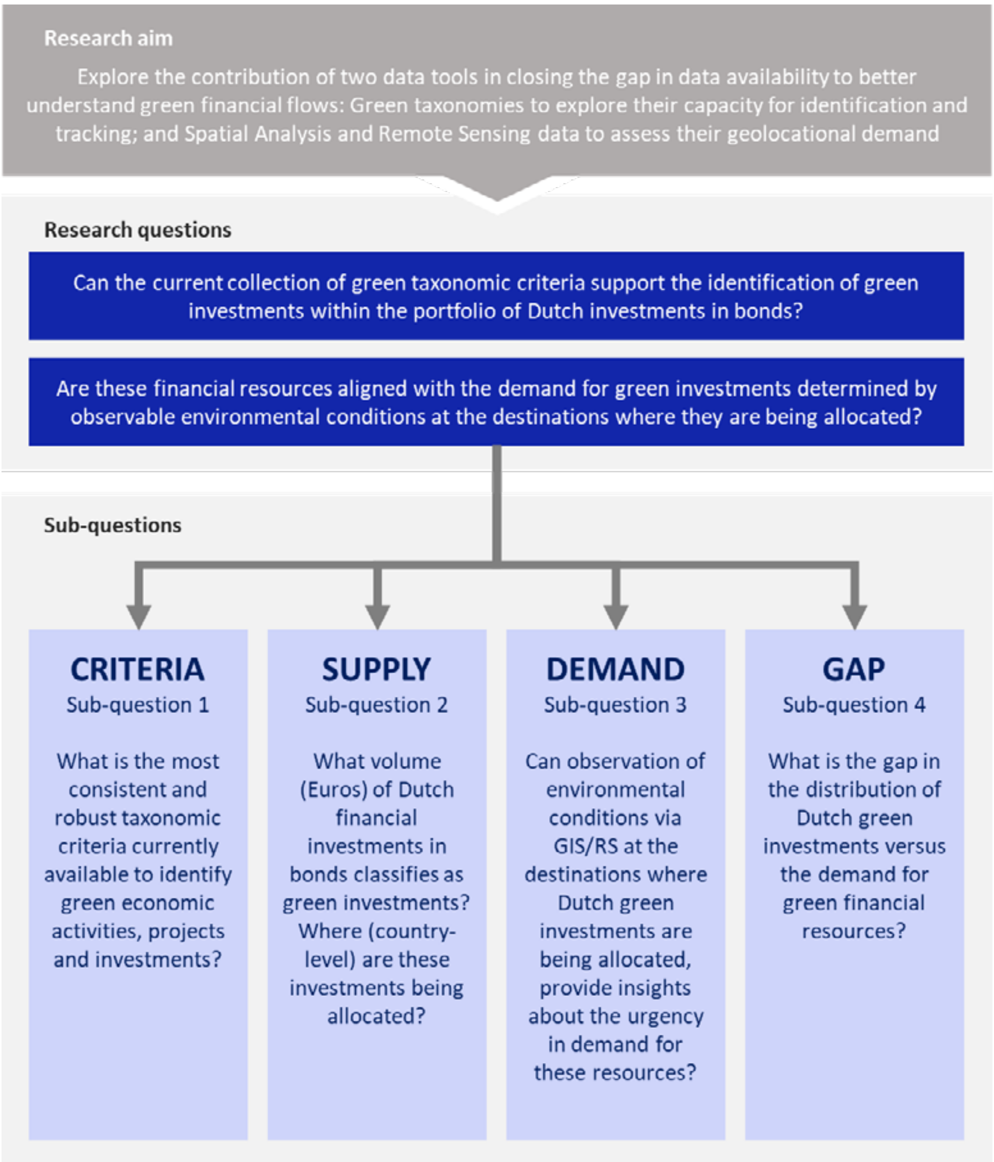
Over the past years, multiple green taxonomy approaches have been developed to assess the alignment of investments with various sustainability goals. Through the systematic classification and definition of 'green' assets, these approaches aim to drive capital more efficiently towards to high priority sustainable projects (World Bank, 2020). Several countries and jurisdictions that are scaling up sustainable financial investments, are in the process of establishing taxonomies for green finance (ICMA, 2021). However, important challenges must be addressed to guarantee their successful deployment. Some of the most significant challenges include: the lack of harmonization between taxonomies leading to higher transaction costs and market segmentation, low data availability based on consistent methodologies, capacity constraints to secure proper implementation and compliance to these mechanisms, and the absence of complementary mechanisms to secure optimal performance (e.g. brown taxonomies).

This research aims to contribute to closing the gap in data availability by exploring the contribution of two building blocks: a harmonized green taxonomies analysis to explore the identification and tracking of green investments, and spatial analysis based on remote sensing data to assess geolocational demands for green investments. According to the International Capital Market Association (ICMA), "*a green taxonomy is a classification system identifying activities, assets, and/or project categories that deliver on key climate, green, social or sustainable objectives with reference to identified thresholds and/or targets*" (Plaff et al., 2021). By providing a systematic and science-based classification and definition of economic activities that deliver positive environmental objectives, capital can be located and tracked more efficiently across these priority projects and infrastructure (World Bank, 2020). Spatial Analysis and Remote Sensing corresponds to the "*detecting, monitoring and processing of an area's physical data by measuring its reflected and emitted radiation at a distance (typically from satellite or aircraft)*" (United States Geological Survey, 2021). This type of data has the potential to support the green financial sector. Evaluation and interpretation of aerial photography and satellite imagery can be used to assess and manage climate change risks, as well as to enable evidence-based allocation of financial resources in accordance to spatial observation of environmental conditions. The following sections describe the first steps of an analysis to contribute to these challenges. We study the corporate bond portfolios of Dutch investment funds focusing on corporate bonds issued by the Top 500 companies (in terms of revenue) operating across 38 OECD countries.

4.1 Methodology

Figure 4 describes the aim of this research and its targeted questions: two overarching questions and a set of four sub-questions represent the main objective of this paper.

Figure 4: Green taxonomies methodology

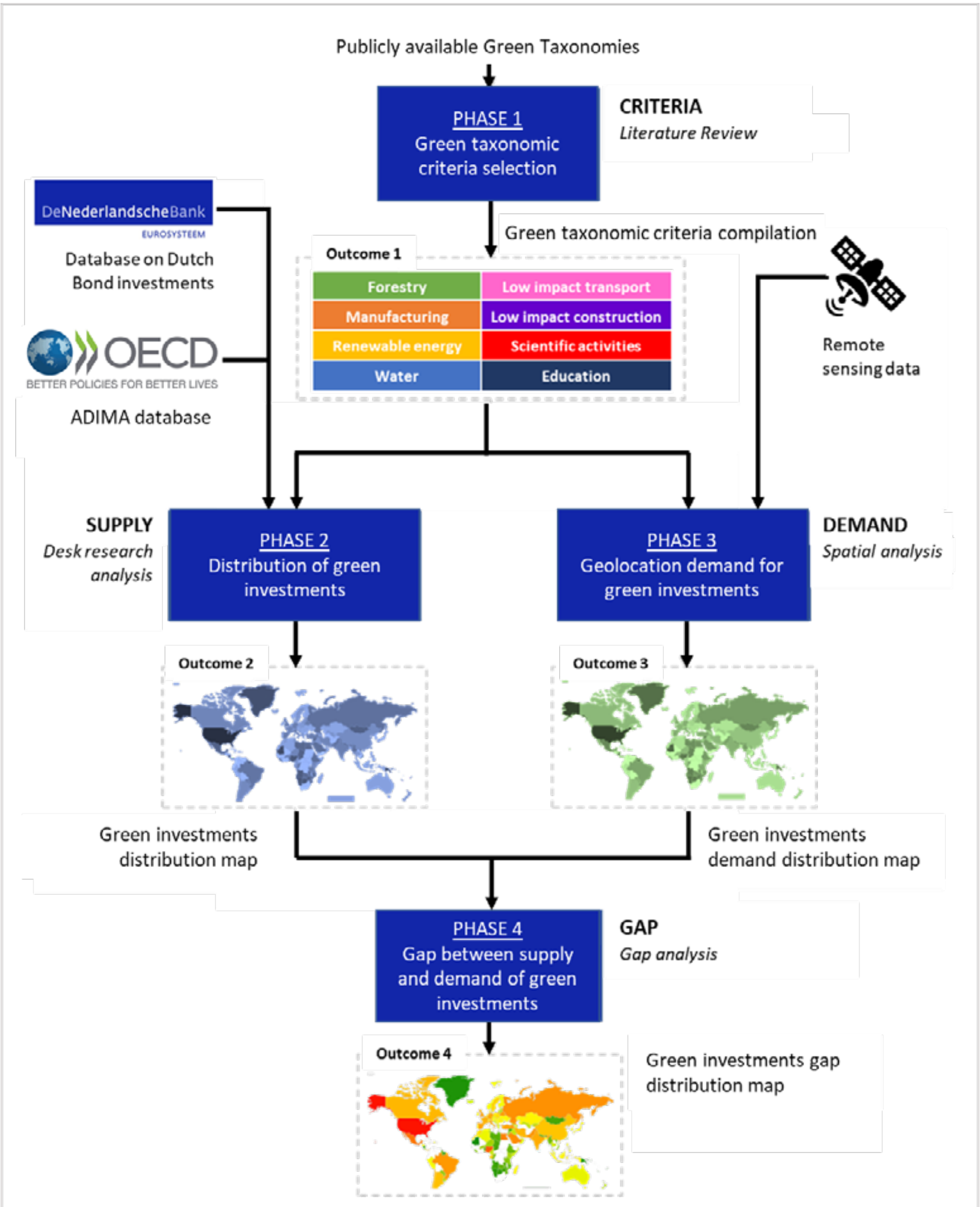


We explore the level of harmonization between publicly available green taxonomies by conducting a literature review. The evaluation of the green taxonomies is conducted to prioritize and select the most suitable and robust taxonomic criteria available. Suitability is determined by assessing all identified green taxonomies (GTs) against 3 criteria: (i) the GT has an official and publicly available file published (in English) by the national government or organization responsible for its design; (ii) the GT has concrete taxonomic criteria describing economic activities and assets that positively contribute to environmental objectives, as well as their performance thresholds; (iii) the GT is independently designed and does not constitute an adaptation of a previous one. GTs meeting these criteria are then prioritized and scanned to assess the robustness in their taxonomic criteria. This assessment is conducted by applying the Framework of Classification Principles for Green Taxonomies designed by Ehlers et al. (2021). GTs developed with a clear structure and in accordance with scientific criteria were considered as robust and selected for further analysis. Finally, the selected GTs were fully scanned to review the complete structure of the taxonomy, the list of economic activities and assets suggested to deliver on the environmental objectives, and in-depth specifications, screening criteria or performance thresholds that are required to classify as ‘green’. All identified criteria were then grouped together and signalled according to the level of compliance between the assessed GTs.

4.2 Data

Figure 5 presents a flow diagram describing how the 4 phases of analysis of the methodology are performed. The diagram describes the data inputs used for each phase, as well as results and outcomes delivered and their interactions across phases. Phase 1 is described in the methodology section above. The phases correspond to the sub questions in Figure 4. For phases 2, 3 and 4 below, we focus on the data and results of a case study on investments and demand for solar energy facilities.

Figure 5. Data sources flow diagram. Phase 1 maps and comprises most robust set of publicly available green taxonomic criteria; Phase 2 contrasts taxonomic criteria to identify and geographically locate investments classified as green; Phase 3 uses spatial observation data at destinations of green investments to determine demand for resources to finance green activities; Phase 4 compares the distribution of green investments with the demand for green investments.



For phase 2, we test the applicability of the selected green taxonomic criteria by applying it to Dutch investment funds' investments in corporate bonds for December 2020 and determine the share of climate-aligned assets. Information from the publicly available database Analytical Database on Individual Multinationals and Affiliates (ADIMA) was linked to the corporate bond data to provide information on the geographical location of affiliates of corporate bond issuers. The ADIMA database corresponds to a new data framework offering information on both the physical and digital presence of top 500 multinational enterprises operating within the OECD region at country-level (OECD, 2022). Corporate bonds are matched to the ADIMA database by using the LEI (Legal Entity Identifier) code. This selection provided a sample of corporate bonds issued by (an affiliate of) a top 500 company with locational information from any of the OECD countries. Corporate bonds are classified as 'green' if the economic activity of the issuer was compliant to the list of green taxonomy criteria from Phase 1. The analysis was conducted through a manual inspection of the issuer's economic activity reported by Bloomberg. Finally, the supply of green investment is then classified for every country. For the solar facilities case study, total country-level investments are classified according to their level of investment in Table 2.

Table 2. Classifications for country-level investments on solar energy facilities.

Classification	Investment	Project financing
Very low investment	€0,00 Mi - €3,75 Mi/year	0,25 10MW solar plant
Low investment	€3,75 Mi - €7,50 Mi/year	0,5 10MW solar plant
Medium investment	€7,50 Mi - €15,00 Mi/year	1 10MW solar plant
High investment	€15,00 Mi - €30,00 Mi/year	2 10MW solar plant
Very high investment	€30,00 Mi - €85,00 Mi/year	≥ 2 10MW solar plant

The breaks in between these classifications are determined according to the average cost of a medium-sized photovoltaic (PV) power plant of 10 MW. The average size of small to big was determined against the network of solar power plants installed in the USA (EIA, 2019) and an average cost of EUR $1,00 per watt capacity (average value between USD $0,75 to USD $1,25) was used as reported by Solar Energy Industries Association (SEIA, 2020). Finally, these classification are linked to the number of PV powerplants that could be financed with the totality of investments in solar energy allocated per country.

For phase 3, the demand for green investments on electricity generation from solar energy is determined according to the potential for photovoltaic (PV) power output from countries pertaining to the OECD. Potential PV power output in every country of the world has been calculated by Solar Irradiance data in collaboration with the Energy Sector Management Assistance Program (ESMAP) of the World Bank, and released in the form of consistent high-resolution data sets via an online tool: Global Solar Atlas. In the Global Photovoltaic Power Potential by Country (2020) report, the PV power potential is described as "*the conversion of the available solar resource to electric power considering the impact of air temperature, terrain horizon, and albedo, as well as module tilt, configuration, shading, soiling, and other factors affecting the system performance*", and measured in kilowatt hours per installed kilowatt peak (kWh/kWp). This indicator is produced through standard GIS operations produced from statistical evaluation of satellite-based imagery (compilation from sensors GOES-East and GOES-West by NOAA, Meteosat PRIME and IODC by EUMESAT, MTSAT and Himawari-8 by JMA, MACC-II/CAMS atmospheric data by ECMWF, MERRA-2 atmospheric data by NASA, GFS data by NOAA) containing data layers of: Global Horizontal Irradiance (GHI), air temperature at 2 meters, index of seasonal variability, wind and snow, atmospheric pollution, and dust.

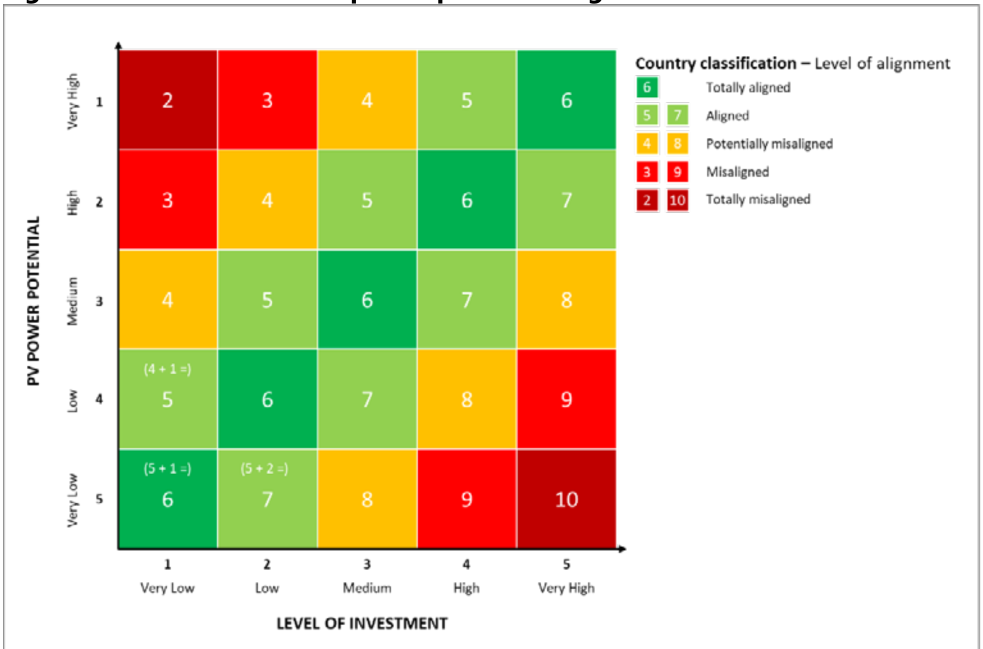
Based on this data, the demand for investment in electricity generation through solar energy was then classified at a country-level according to its average PV Power potential. This classification is given in Table 3. The breaks in between these classifications are identical to the thresholds described in the Global Photovoltaic Power Potential by Country Report (2020).

Table 3: Classification of average PV power potential per country.

Classification	Investment
Very low potential	0,00 – 2,80 kWh/m^2
Low potential	2,80 – 3,40 kWh/m^2
Medium potential	3,40 – 4,20 kWh/m^2
High potential	4,20 – 4,80 kWh/m^2
Very high potential	4,80 – 8,00 kWh/m^2

Finally, for Phase 4, we conduct a qualitative gap analysis on green investments allocated to OECD countries. Each variable is reclassified into a new numeric value. The 5 clusters of solar investment ranging from Very Low Investment to Very High Investment are assigned a number from 1 to 5 (ascending order). The 5 clusters of PV power potential ranging from Very Low PV Power Potential to Very High PV Power Potential are assigned a number from 5 to 1 (descending order). Numeric values assigned to each variable are added together following a matrix structure described in Figure 6. The resulting number is then assigned a classification describing the level of alignment between the size of the investment and the potential for electricity generation from solar energy for every country, according to 5 clusters: (i) Totally misaligned; (ii) Misaligned; (iii) Potentially misaligned; (iv) Aligned; (v) Totally aligned. Final results are then plotted into a map describing the level of alignment between investments on solar energy and PV power potential across OECD countries. All data is merged and contained within a Geodatabase in ArcGIS.

Figure 6: Investment vs. PV power potential alignment matrix



4.3 Results

The pool of green taxonomies that is part of the analysis consists of documents produced by diverse jurisdictions establishing comprehensive classifications of sustainable finance and assets. This analysis takes into account both the official – i.e. produced and legislated by governments and central banks (relevant examples including the EU Green taxonomy, the Green Bond Catalogue of the People's Bank of China, Green Taxonomy of Malaysia) – and market-based taxonomies produced by private enterprises (e.g. the Climate Bonds Initiative taxonomy and the ISO Green Debt Instruments). Figure 7 presents the final outcome of the study of a total of 21 taxonomies and sustainable finance definitions that are identified globally and the 3 taxonomies that provide the best reference of green taxonomic criteria based on the methodology described in section 4.1. The 3 taxonomies that are prioritized and selected as the most consistent and robust collection of green taxonomy criteria are: the European Green Taxonomy (EUGT), China's Green Bond Catalogues (CGBC) and the Climate Bonds Initiative Taxonomy (CBIT). The limitations identified in the remaining 18 GTs that were studied are: 6 GTs remain still under construction in their corresponding jurisdictions and no official version has yet been made public; 7 GTs do not contain concrete taxonomic criteria but rather define guidelines or decision frameworks for the identification of GIs; and 5 GTs have been developed based on previous taxonomies and constitute an adaptation of criteria according to local context and needs. Figure 7 provides details on how the remaining 3 GTs differ in terms of their criteria for activities/assets where full consensus is not reached. In this case, either green activities/assets are categorized as reaching partial consensus (at least one GT mentions it and others do not include it) or categorized as controversial (contradictions in environmental objectives exist).

Figure 7: Three consistent and robust green taxonomies and the further classification of activities/assets

Energy | Buildings | Transport | Water | Land & sea | Pollution | Industry | Services

Activity/asset	EUGT	CGBC	CBIT
Nuclear	Y	Y	Y
Natural gas	Y	Y	D
Clean fossil fuels (CCS)	D	Y	D
Hydropower	Y	Y	Y
Solar	Y	Y	Y
Wind	Y	Y	Y
Biofuels (biogas, biomass)	Y	Y	Y
Marine renewables	Y	Y	Y
Geothermal	Y	Y	Y
Power transmission & distribution	Y	Y	Y
Power storage	Y	Y	Y
Heat pumps	Y	Y	Y
Green buildings/ energy	Y	Y	Y
Urban development	Y	Y	N
Private passenger	Y	Y	Y
Public passenger	Y	Y	Y
Freight rail	Y	Y	Y
Road freight	Y	Y	Y
Aviation (infrastructure)	Y	Y	Y
Waterborne transport	Y	Y	Y
Water supply	Y	Y	Y
Waste water management	Y	Y	Y
Flood prevention	N	Y	Y
Forestry	Y	Y	Y
Agriculture	N	Y	Y
Fisheries and aquaculture	N	Y	Y
Ecosystems & biodiversity	Y	Y	Y
Preparation & storage	N	Y	Y
Re-use	N	Y	Y
Recycle	N	Y	Y
Treatment	N	Y	Y
Waste to energy	N	N	Y
Landfill	N	N	Y
Manufactory key components	Y	Y	Y
Manufactory energy efficient eq.	Y	Y	Y
Clean steel	Y	Y	D
Clean aluminium	Y	N	D
Clean cement	Y	Y	D
Hydrogen	Y	Y	D
Clean up (CCS)	D	Y	Y
Information & communication	Y	N	Y
Research, development, innovation	Y	Y	N
Consulting, auditing, monitoring	Y	Y	N

FULL CONSENSUS
Activity or asset is signaled as aligned to environmental objectives by all taxonomies
23 activities/assets

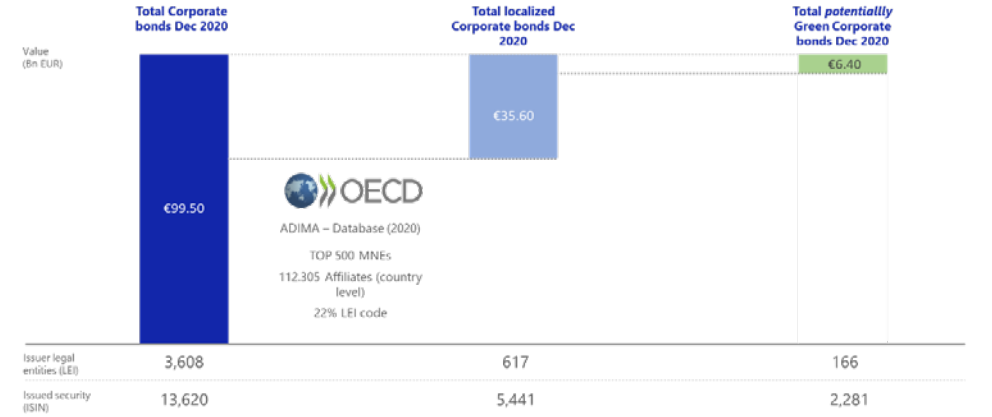
PARTIAL CONSENSUS
Activity or asset is signaled by at least one taxonomy. Other taxonomies do not signal
13 activities/assets

CONTROVERSY
At least one taxonomy signals as contrary to environmental objectives or requiring further research
7 activities/assets

Y Signaled as compliant
N Not mentioned / Pending
D Discarded / Requiring research
C In consultation / validation

Figure 8 shows the results for *potentially* green corporate bonds (incl. partial consensus and controversy categories). Narrowing down the sample to issuers pertaining to the Top 500 companies (in terms of revenue) operating within the OECD region that could be linked to a LEI code, results in a list of 618 private entities. The individual assessment of economic activities performed by these companies resulted in the identification of 35 bond issuers exclusively conducting economic activities that fully comply with green taxonomic criteria. A group of 131 issuers where identified to have a partial alignment to green taxonomic criteria. A partial alignment was established when bond issuers conducting a diverse array of economic activities, performed at least one activity that was considered as green. This added to a total amount of 166 bond issuers (pertaining to 81 MNEs) with a potential compliance. At the closing of December 2020, these issuers had consolidated a total value of EUR €6,40 Bi provided by Dutch investment funds. EUR €1,9 Bi of the total value of investments are identified to be directed towards 'controversial' economic activities such as: natural gas, nuclear energy, CCS, hydrogen, clean aluminium, steel and cement. When investments for these activities were removed 17 MNEs issuing potentially green corporate bonds no longer complied with the taxonomic criteria.

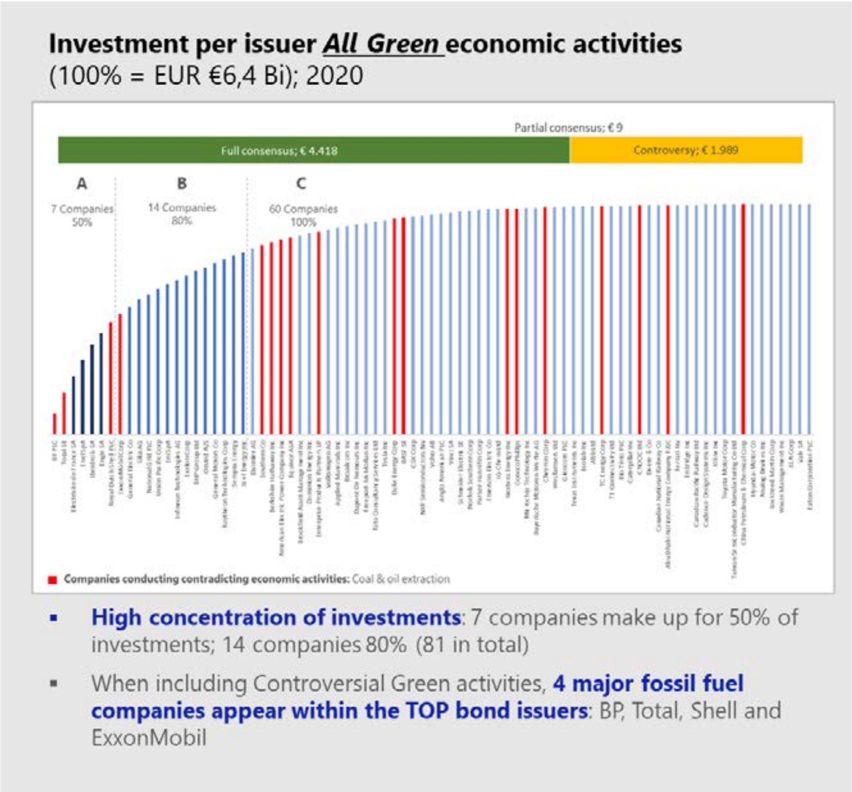
Figure 8: Consolidation of investments on potentially green corporate bonds. Portfolio of investments made by Dutch investments funds by December 2020.



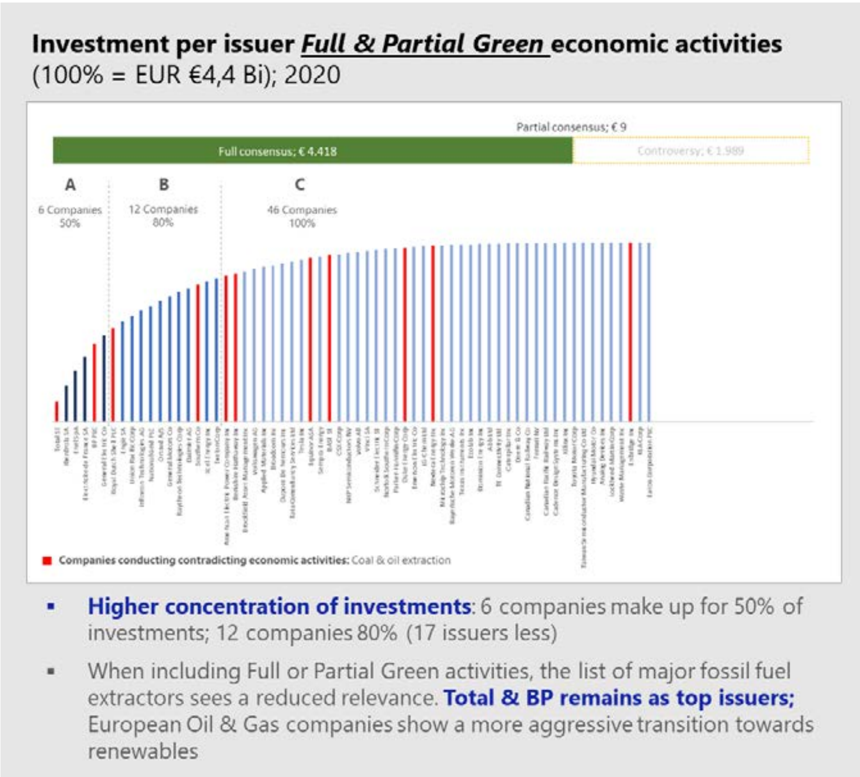
When investments for controversial activities were removed 17 MNEs issuing potentially green corporate bonds no longer complied with the taxonomic criteria. Investments across green issuers where identified to be highly concentrated with only 6 to 7 companies (depending on the inclusion of controversial green activities) consolidating up to 50% of all corporate bond investments provided by Dutch investment funds at the end of 2020. A closer observation of the list of potentially green issuers resulted in the identification of 18 companies conducting economic activities that were contradicting to the delivery of positive environmental impacts, while at the same time they conduct activities compliant to green taxonomic criteria. These are companies identified to conduct activities in the field of oil and coal extraction, processing and commercialization, as well as companies dedicated to mineral extraction and mining. Top MNEs with a contradicting profile included BP PLC, Total SE, Royal Dutch Shell PLC, Exxon Mobile Corp (see Figure 9a/b).

Figure 9a/b: Accumulated distribution of investments on potentially green corporate bonds per issuer (2020)

9a:



9b:

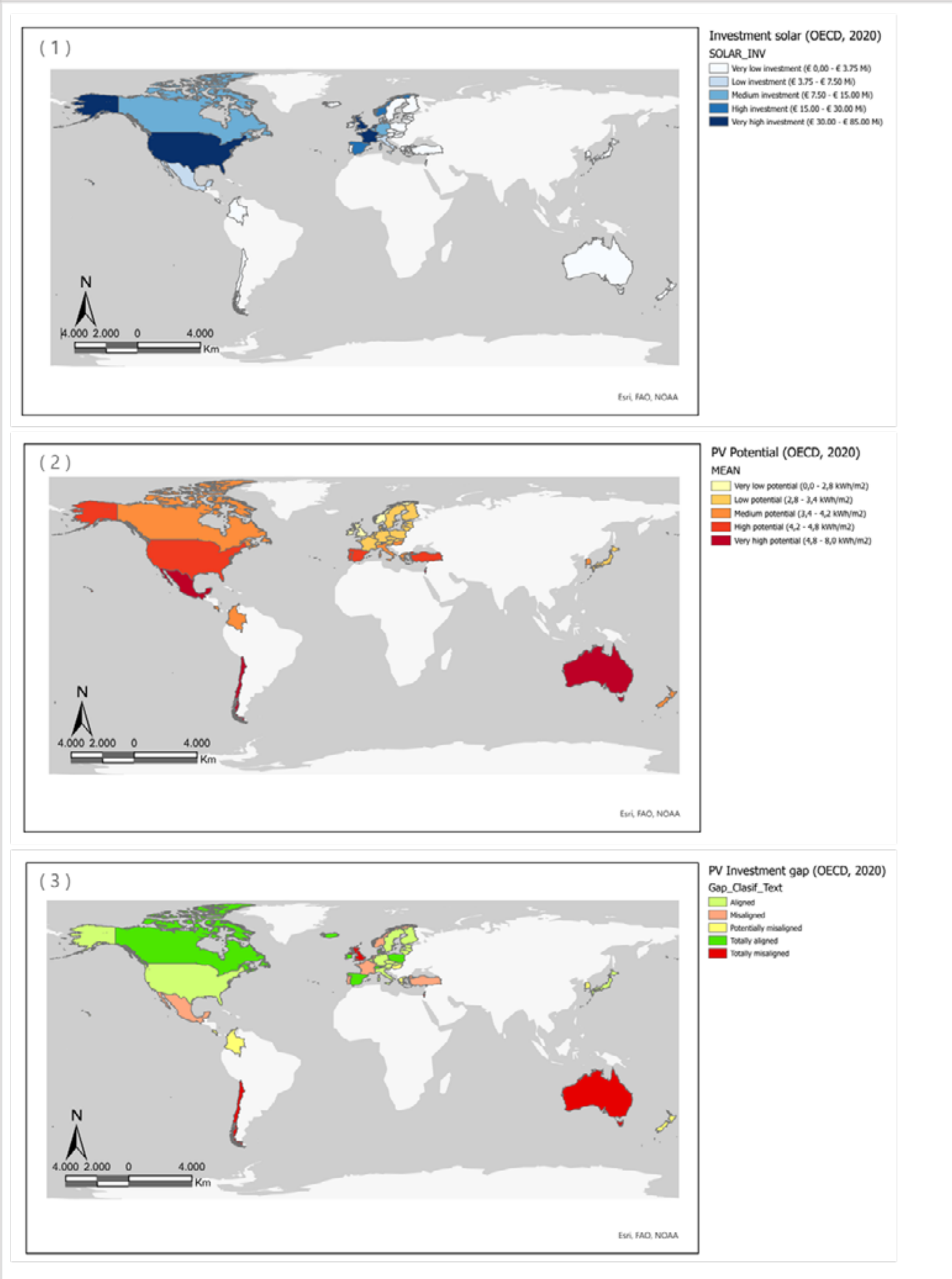


Solar energy case study

Looking at the results at a more granular level, we find that solar energy is identified amongst the top 5 subsectors consolidating the highest amounts of potentially green investments, within the clean energy generation and distribution sector. Figure 10 offers the Phase 2, 3 and 4 results of a closer analysis of the regional distribution of these solar investments made by Dutch investment funds.

The results identify 5 countries as top destinations for these financial resources, concentrating over 80% of the potentially green investments: France, the Netherlands, Great Britain, USA and Spain. The remaining countries receiving potential investments on solar energy did not exceed the EUR15 Million/year for 2020 (per country). Very low (below EUR 1,75 Million/year) to no investments on solar where identified in eastern European countries, middle eastern countries (Israel), South America (Chile, Colombia) and Pacific region (Australia, Japan and South Korea). Contrasting against the potential for PV power generation across the OECD countries, the countries most suited for the generation of energy from this renewable source where countries located in latitudes closer to the equator with desertic ecosystems: Chile, Mexico, Israel and Australia. This distribution between investment and PV power potential resulted in the identification of only two countries with high potential receiving high levels of investment: USA and Spain. The Netherlands, France and Great Britain instead were identified as countries with high concentrations of investments, misaligned however with the local potential for power generation from this renewable source. On the other side, all countries identified to have very high potential did not show significant concentrations of green investments, and here classified as totally misaligned, which was the case for Mexico, Chile, Israel and Australia. Remaining countries were classified as aligned in their investments mostly given to low potentials for PV power generation and limited amounts of investments allocated into these countries.

Figure 10. (1) Supply of solar energy investments across OECD territory; (2) Average PV power potential across OECD territory; (3) Alignment between investment and potential for solar power in OECD territory (2020)



To understand the exact reasons behind misalignment can only come from a further in-depth evaluation of local conditions of the renewable energy market. In its yearly Renewable Energy Report, the International Energy Agency (IEA) makes a revision of the outlook for PV power generation per country (IEA, 2021). In line with results obtained from this research, the Netherlands and France are identified as countries with high concentrations in investments derived from a strong push in the transition towards renewables by local government. Public policy within these two markets promotes investments in the solar energy system through a portfolio of mechanisms that contemplate from taxing incentives to regulation enforcing the installation of PV panels on new warehouses or other similar infrastructure. Also for countries with high PV power potential and low investment, as is the case for Mexico and Australia, the report describes a significant reduction in the concentration of investment also determined mostly by local regulatory frameworks and decisions, including the delays in permissions granted from the government to install PV power plants to increasing their operational requirements.

5. Conclusion

In this paper, we introduce new experimental indicators for transition risk, physical risks and green taxonomies based on the preliminary results of three MSc research projects performed at de Nederlandsche Bank (DNB).

Transition risk:

We assess the impact of a hypothetical carbon tax on the portfolios of financial institutions. Following the recommendation of the Task Force on Climate-related Financial Disclosures (TCFD) for financial institutions to implement scenario analysis and stress testing to evaluate the financial risks related to climate change, a stress test is performed to quantify the transition risks related to the implementation of a global carbon tax for financial institutions. An impact ratio is constructed as the costs related to the carbon tax relative to the profits that the financial institutions are exposed to through their portfolios. It thus captures the risks a financial institution faces in terms of potential reductions in portfolio returns when a certain carbon tax is introduced. The method is illustrated through an example for Dutch pension funds.

While the analysis here is performed based on the OECD TiVA model, future research should determine whether an application of (the most recent version of) Exiobase can extend the scope to other greenhouse gases and other environmental pressures. Also, the recent developments of the FIGARO (Full International and Global Accounts for Research in input-Output analysis) model at Eurostat could be explored as another option. The benefit here is that the FIGARO tables will be updated on an annual basis, while Exiobase only receives sporadic updates. Ideally, limitations regarding the setup of emissions in IO-models will be addressed by the financial sector's closer involvement in developing new methodologies. For instance, the GHG protocol Scope 1,2,3 subdivision could be considered to closer match the data that is already available at third-part data providers and would allow for mixed approaches (i.e. substituting aggregated IO-data only when company-level data is unavailable).

Physical risk:

Bridging the damage data gap would lead to physical risk models that can be used as a tool to predict and mitigate the risk for damage due to extreme weather events. The models in this research are fit solely based on open-access data. This led to only 35 and 36 historical damage records being available for storms and floods, respectively. If, for instance, damage data on a more granular level, for example on ZIP-code level, were available, this could improve the fit of the models. We strongly suggest that such data, after being anonymised, should become more publicly available. This directly relates to Network for Greening the Financial System's (NGFS) recommendation to improve data availability in the financial sector. Central banks are advised to try to construct such a damage database and to further research in what way physical risk models can be improved. For instance, the effect of climate change on physical risk could be added to the models.

In more general terms, the label 'physical risks' bunches all types of risks/hazards ((i.e. river and coastal floods, forest fires, landslides, subsidence, windstorms, heatwaves and droughts) together. The goals/tipping points for these risks/hazards are typically less well defined than for carbon emissions. We should thus be aware that we might not be able to deliver very detailed or robust results in this field in the short or medium run, that is compared to what we will be able to do for transition risk. There are of course quite a lot of geographical information system datasets on exposure and the likelihood/occurrence of hazards that we could employ. However, to calculate the risks in monetary terms, we need the factors that translates different hazards to damage ratios for different asset classes and sectors. This paper shows that the historical granular data to model these factors is very much lacking in the public domain. In addition, these factors will also be affected itself by climate change and adaptation and thus differ widely across asset classes sectors.

Green taxonomies:

Our results demonstrate that the current data available at De Nederlandsche Bank (DNB) combined with publicly available data can at best be used to flag investments that can potentially be classified as 'green'. A potential classification allows for a preliminary assessment that includes the sizing of a maximum value of green investments and the generation of preliminary insights about the distribution of these assets across countries, economic activities and bond issuers. Limitations were driven mostly by data availability and the need for further in-depth analysis including data from multidisciplinary fields on the drivers of green financial investments. The methodology suggested in this research, however, represents one step forward in the tracking and assessment of green investments and can help narrow down further research into this field. As green taxonomies move from the development phase into phases of consolidation and maturity, additional information and developments will likely provide elements to extract greater potential from the data and methodologies used in this research.

Our results show that overall, there is substantial scope for financial institutions and central banks to better leverage publicly available data sources and models to develop climate risk proxies. In particular, the results are promising for the transition risk and green taxonomy applications, while for physical risk the performance of the models could be improved if more granular data (e.g. historical damage data on ZIP-code level) were to be made publicly available. For transition risk, a better alignment of IO-models with the GHG protocol could future benefit applications. The three MSc research projects that allowed us to write this paper are available upon request.

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How proxies and publicly available data can be used to construct new indicators for transition risk, physical risks and green taxonomies

Justin Dijk, Derek Dirks, Willemijn Ouwersloot, Juan Pablo Trespalacios Miranda

DeNederlandscheBank
EUROSYSTEEM

OBJECTIVE

Introduce **new experimental indicators** for transition risk, physical risks and green taxonomies based on the **preliminary results** of three MSc research projects performed at de Nederlandsche Bank (DNB)

Explain **methodologies, data and assumptions** used in the construction of experimental indicators

Share **conclusions** reached so far and discuss **next steps**

BACKGROUND

Giving the urgency of climate change, the financial sector **does not have the luxury to wait** until 'perfect' or better data becomes available, and should consider **using the alternatives that are currently available.** – NGFS Bridging the Data Gaps

Given the **urgency** with which these indicators are needed, and the **practical barriers** that will need to be overcome, the EG CCS stresses that **feasibility** is a key variable in the prioritisation - STC EG Climate Change Statistics

Until significant progress is made in this area, […] a recommendation is to **make better use of proxies, modelled data, aggregates and estimates** […]. - NGFS Bridging the Data Gaps

OVERVIEW

1. **Transition risk -** Financial risk of the transition to a less carbon-intensive economy (thesis finished July 2021)
   Derek Dirks

2. **Physical risks -** Modelling physical risks due to storms and floods with an application to real estate (thesis finished Aug 2021)
   Willemijn Ouwersloot

3. **Green Taxonomies –** Some preliminary results (thesis finished April 2022)
   Juan Pablo Trespalacios Miranda

These projects have been inspired by the priorities identified by the ECB STC Expert Group on Climate Change and Statistics (EG CCS), and aim to feed the discussion & eventual production of new financial sector climate statistics by the STC.

1. Transition risk

1. TRANSITION RISK – objective

Objective:

- To show the use of IO-models' country-sector level data on environmental externalities as a proxy for company level emissions data.
- IO-models can be employed to go beyond carbon/GHG emissions (air pollution, water pollution, etc.), cf. Exiobase application in Smeets et al. 2021 (DNB working paper).
- Emissions data of companies is often not available (particular for data beyond carbon emissions).

exiobase

OECD
BETTER POLICIES FOR BETTER LIVES
Trade in Value Added

1. TRANSITION RISK – methodology and data

Methodology:

Impact ratio per sector (unit: $\frac{\$}{\$} = \%$): $$\frac{Emissions\ (CO_2) * CO_2\ tax\ rate\ (\$/CO_2)}{Profits\ (\$)}$$

To determine the impact of different tax scenarios on the portfolio of financial institutions, i.e. the risk a financial institution faces in terms of potential reductions in portfolio value/returns per sector due to a particular carbon tax scenario.

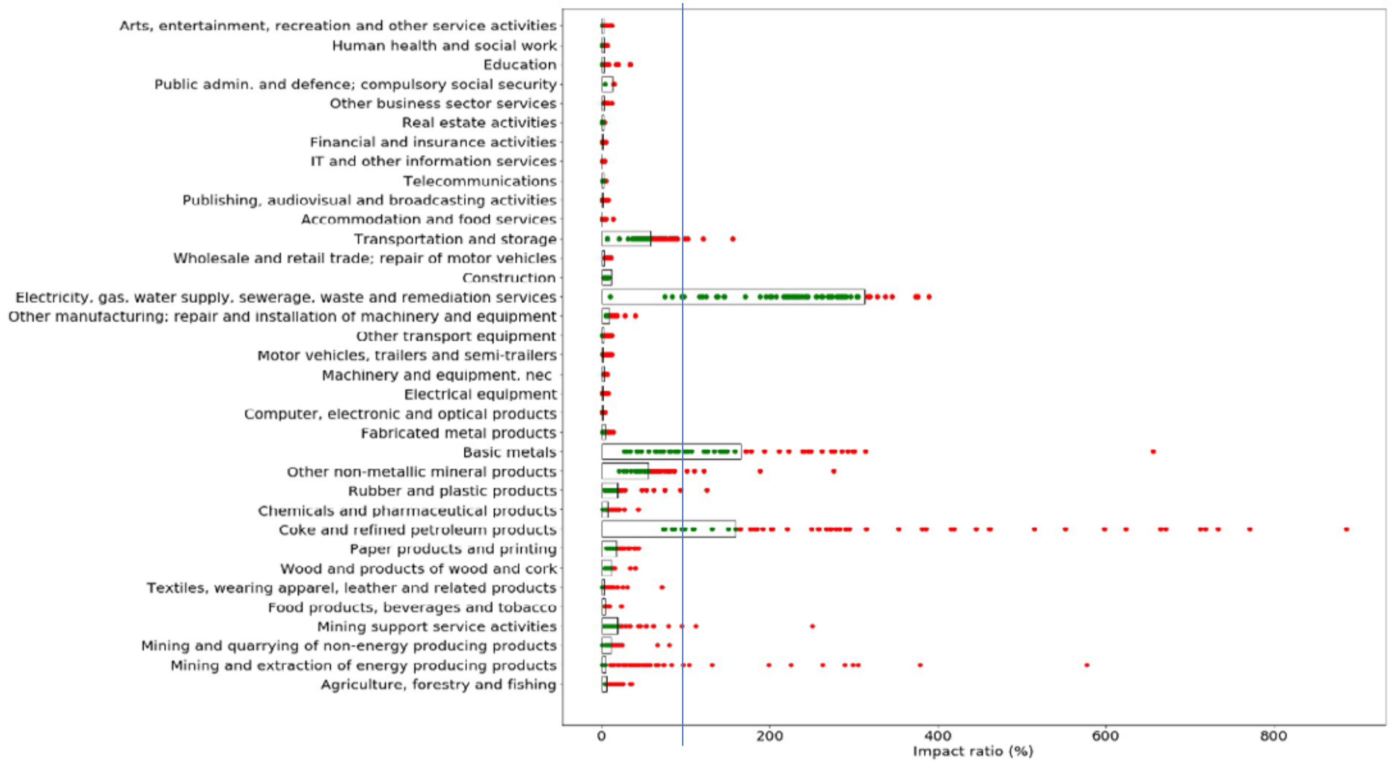
Data:

- Direct and indirect investments of Dutch pension funds in corp. bonds and equity (Security Holding Statistics by Sector; ISIN level);
- Company level data from Refinitiv Thomson Reuters EIKON (profits, revenue and Enterprise Value; ISIN level) to determine emissions and profits (ownership approach);
- OECD trade in Value-Added (TiVA) database combined with the Trade in embodied CO_2 (TeCO_2) database to determine carbon intensities (Scope 1,2,3) per sector and OECD country; 64 countries, 36 industries (ISIC Rev. 4);
- Social cost of carbon literature to determine optimal Pigouvian tax rates for different scenarios.

1. TRANSITION RISK – results

Main result: An impact ratio of 4,4 to 20,4% (low to high tax scenario) is estimated for the entire Dutch pension fund sector.

Individual pension funds: Impact ratio of individual Dutch pension funds by sector (dots) compared to a sector neutral benchmark (bars)*



- Figure shows results for the (medium) €119 per tonne CO_2 scenario
- In nearly every sector, individual pension funds can improve on their impact ratio compared to the benchmark (in red)
- Large differences: Many pension funds have sector positions where profits are insufficient to bear the env. damage cost.

> 100% Profits are insufficient to bear env. damage costs

* Investments are 'sector neutral' (hypothetical portfolio with investment weights equal to EV/sum of sector EV; within the dataset)

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2. Physical risks

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2. PHYSICAL RISKS – objective

Objective:

- To assess the use of open access data, particularly (macro) historical damage data in calibrating physical risk models.
- The models in this research are fit solely based on open-access data. This led to (only) 35 and 36 historical damage records being available for storms and floods in Germany, respectively.
- More granular data is typically proprietary or only available upon subscription (e.g. through (re)insurers).

2. PHYSICAL RISKS – methodology and data

Methodology:

- Calibrate several models to estimate damage due to storms and floods. Use micro-scale damage functions to approximate the available macro-scale hazard damage data for the sample period 1979 through 2019.
- Simulation of storms: Perform a simulation (1000 years of storms) to determine outcome of typical risk measures (e.g. Expected Annual Loss) of a Dutch financial institution's real estate portfolio in Germany.
- Stress test for flood: Estimate the total damages in the district of Ahrweiler, Germany (recently hit by the July 2021 floods).

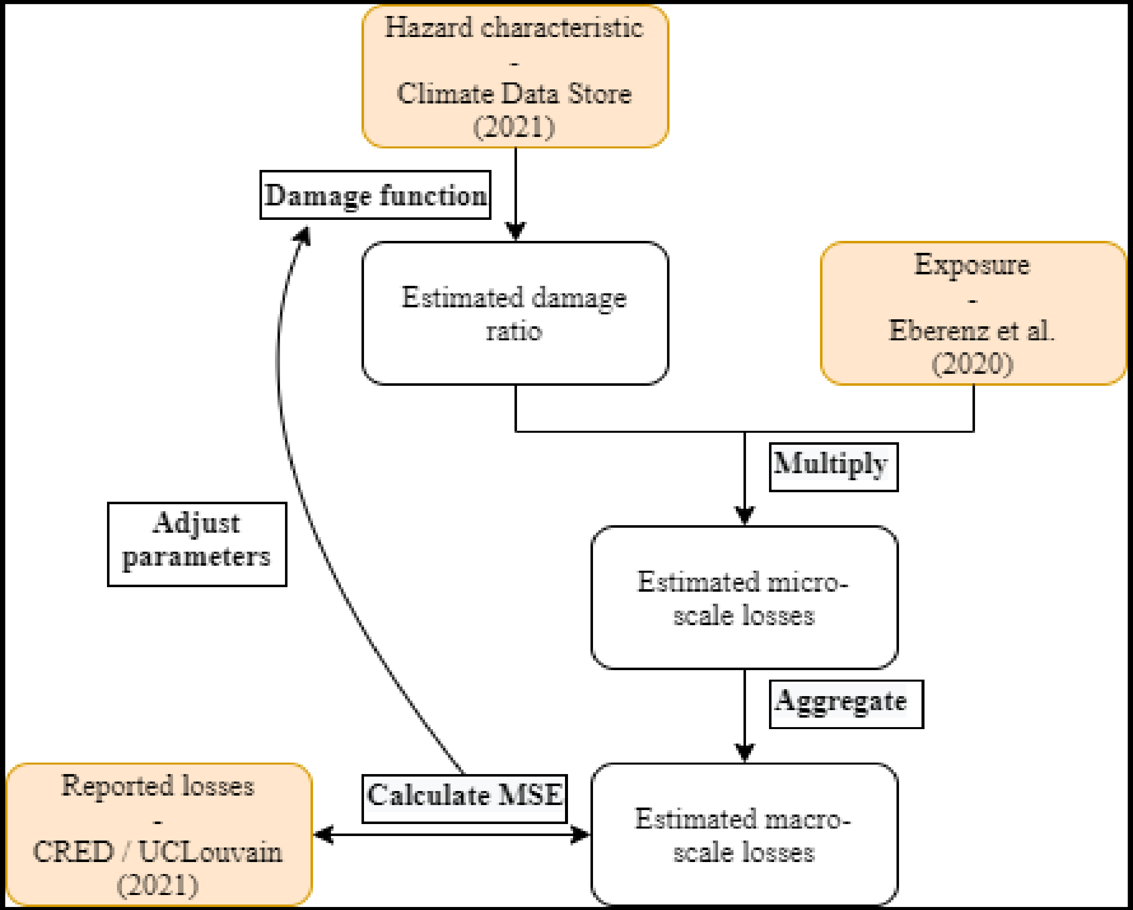
Data:

- Assets: Survey data of a German real-estate portfolio of 1 Dutch financial institution (incl. location information).
- Assets: Eberenz et al. (2020) "Lit population" (LitPop), an asset exposure dataset using a combination of nightlight intensity and geographical population data (661,392 grid cells (1 square kilometer each) for Germany).
- Damage: Center for Research on the Epidemiology of Disasters' (CRED, Leuven) Emergency Event Database (EM-DAT), an international disaster database; country-lev. data on 35 storms in Germany, duration and total monetary damage.
- Damage: Prapotny et al. (2018) HANZE database of historical damaging floods in Europe; data on 36 floods with the affected NUTS regions, the duration and the total monetary damage.
- Hazard characteristics: Climate Data Store; 1184 locations in Germany with hourly wind gust speed and total precipitation (to model storm damage as a function of wind gust speed & flood damage as a function of precipitation).

2. PHYSICAL RISKS – methodology and data

Methodology:

- Calibrate several mode … unctions to approximate the available macro-sc …
- Simulation of storms: … l risk measures (e.g. Expected Annual Loss) …
- Stress test for flood: Es … by the July 2021 floods).



Data:

- Assets: Survey data c … n information).
- Assets: Eberenz et al … ation of nightlight intensity and geogra … nany).
- Damage: Center for R … Database (EM-DAT), an international disaste … onetary damage.
- Damage: Prapotny et … 36 floods with the affected NUTS region …
- Hazard characteristic … ed and total precipitation (to model storm damage as a function of wind gust speed & flood damage as a function of precipitation).

2. PHYSICAL RISKS – results

Main result: The models perform badly, most likely due to the lack of sufficiently granular data on historical damages to calibrate them. The applications that can be delivered, assuming better historical damage (are made public and) can be used in the future, are however very promising.

Simulation (storms): Risk metrics and their values in percentages of the total portfolio worth. The metrics are based on a simulation of damages due to 1000 years of storms.

Risk metric	Value
$\widehat{\text{EAL}}$	1.340%
$\widehat{\text{VaR}}_{0.99}$	40.583%
$\widehat{\text{ES}}_{0.98}$	41.445%

- The simulation shows that very interpretable risk metrics can be calculated and risk mitigation matters could be taken. Current results are however unreliable due to model performance.

Stress test (flood): Left: map of Ahrweiler. Right: heat map of estimated damages in Ahrweiler.

- Aggregating all expected losses for the region, we obtain a total expected loss of 5.8 million Euros for Ahrweiler (very low; unreliable?). The application shows the possibility to forecast total damages when an extreme weather event hits. With a better calibrated damage function, those forecasts will be more reliable (and likely much higher).

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3. Green taxonomies

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EUROSYSTEEM

3. GREEN TAXONOMIES - objective

Research objective

Explore the contribution of two data tools in closing the gap in data availability to track and understand flows of green financial assets : Green taxonomies and Spatial Analysis and Remote Sensing data & analysis

Object

Dutch Investment Funds' (IF) exposures to Corporate Bonds **(Dec 2020)**

Research questions

Can the current collection of **green taxonomic criteria** support the identification of green investments within the portfolio of corporate bonds investments made by Dutch IFs?

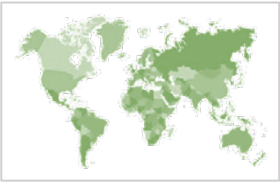
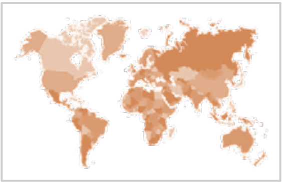
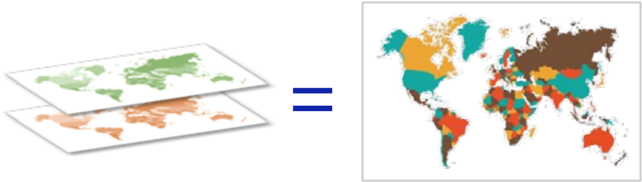
Are these financial resources aligned with the demand for green investments determined by **spatial observation of environmental conditions** at the destinations where they are being allocated?

Sub-questions

Taxonomic criteria	Supply	Demand	Gap
(i) What is the most consistent taxonomic criteria currently available to identify green economic activities, projects and investments?	(ii) What volume (Euros) of Dutch financial investments in bonds classifies as green investments? Where (country-level) are these investments being allocated?	(iii) Can observation of environmental conditions via GIS/RS at the destinations where investments are allocated, provide insights about the urgency in demand?	(iv) What is the gap in the distribution of green investments versus the demand for green financial resources?

3. GREEN TAXONOMIES - methodology

Methodology consists of four phases of analysis

Phases	1. Green taxonomic criteria selection (CRITERIA)	2. Green bonds distribution (SUPPLY)	3. Green investments geolocational demand (DEMAND)	4. Gap in green investments (GAP)
Detail	a. Mapping of green taxonomies and sustainable finance definitions globally b. Prioritization and selection of most consistent green taxonomic criteria	a. Classification of Dutch investments in corporate bonds compliant with green taxonomic criteria b. Mapping of potential locational distribution of green investments	a. Analysis of potential demand for green investments according to remote observation of environmental conditions at the destinations where green investments are allocated	a. Perform a geolocational gap analysis between the supply of green investments and their demand
Data & tools	EU TAXONOMY; China Green Bond Catalogue; Climate Bonds Initiative; The Green Bond Principles Publicly available pool of Green Taxonomies	DeNederlandscheBank EUROSYSTEEM Dutch Corporate Bonds portfolio OECD ADIMA - Database	ArcGIS Pro GIS processing software WORLD BANK GROUP; ESMAP; SOLARGIS Public satellite-based imagery	ArcGIS Pro GIS processing software
Outcome	 Green taxonomic criteria compilation	 Dutch Green Bonds distribution map	 Green investment demand distribution map	 Gaps in green investment distribution map

3. GREEN TAXONOMIES - methodology

Methodology consists of four phases of analysis

Phases

1. Green taxonomic criteria selection (Criteria)
2. Green bonds distribution (Supply)
3. Green investments geolocational demand (Demand)
4. Gap in green investments (Gap)

Phase #1 seeks to identify all green taxonomic criteria currently available and select the most robust and consistent

a. Mapping of green taxonomies

a.1 **Literature review** to map all green taxonomies and sustainable finance definitions available globally

- **Method:** Scoping (Pham M. et al. (2014)
- **Search query:** **"**Green Taxonomy", "Green Finance Definitions", "Sustainable Finance Definitions"
- **Search engines**: : Web of Science, Google Scholar

b. Prioritization & selection

b.1 Assessment of identified taxonomies and prioritization against 3 criteria:

- **C1. Available published** taxonomy
- **C2.** Provides **taxonomic criteria**
- **C3. Independent development**

b.2 Evaluation of selected taxonomies to **guarantee comparability** using classification framework developed by Ehlers T., et al., 2021)

c. Taxonomic criteria contrasting

c.1 Assessment of criteria of selected green taxonomies. Classification according to **level of consistency** between them

3. GREEN TAXONOMIES - methodology

Methodology consists of four phases of analysis

Phases

1. Green taxonomic criteria selection (Criteria)
2. Green bonds distribution (Supply)
3. Green investments geolocational demand (Demand)
4. Gap in green investments (Gap)

Phase #2 seeks to identify all green taxonomic criteria currently available and select the most robust and consistent

a. Data cleansing, merging & preparation of sample

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Dutch Corporate Bonds portfolio (Dec 2020)

ADIMA – Database (2020)

a.1 **Data cleansing:** eliminate errors, duplicates, missing data points

a.2 **Merge locational data** (COUNTRY-LEVEL) from ADIMA into DNB database

- **Attribute**: Legal Entity Identifier (LEI) of TOP **500 MNEs** from the OECD region

b. *Potential* compliance to taxonomic criteria

Bloomberg › Issuer's website

b.1 Evaluation of compliance to taxonomic criteria: **Activity-based (Yes, No, Partial);** not performance or complementing criteria

b.2 **Inspection** on issuers' official **website** (if necessary)

c. Resource allocation & consolidation

c.1 **Regional:** Bond's value of compliant MNEs allocated at country level:

1. **Affiliate:** ADIMA country
2. **MNEs:** Even distribution across ADIMA countries
3. **Affiliate w/subsidiary:** website locations

c.2 **Activity:** Even distribution across taxonomy compliant activities

d. Regional plotting solar investment

d.1 **Country classification per size of investment** (1)

Investment	Medium 10MW	Small 5MW
VERY HIGH	+ Than 2	+ Than 2
HIGH	2	2
MEDIUM	1	1
LOW	0,5	0,5
VERY LOW	0,25	0,25

Avg cost (2): USD

d.1 **Plotting**

ArcGIS Pro

(1) Energy Information Administration USA; (2) Solar Energy Industries Association (SEIA, 2020)

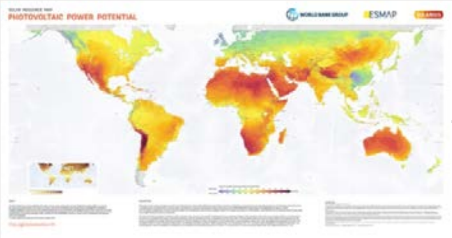
3. GREEN TAXONOMIES - methodology

Methodology consists of four phases of analysis

Phases

1. Green taxonomic criteria selection (Criteria)
2. Green bonds distribution (Supply)
3. Green investments geolocational demand (Demand)
4. Gap in green investments (Gap)

Phase #3



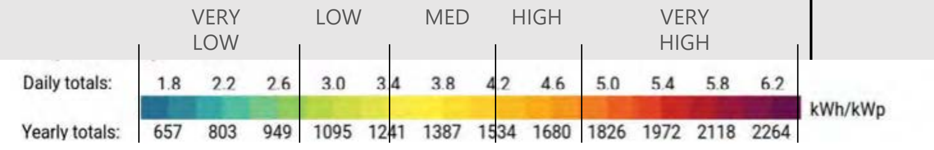
Gobal Photovolotaic Power Potential

WORLD BANK GROUP ESMAP SOLARGIS

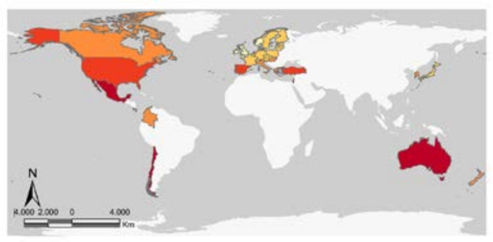
ArcGIS Pro

Clip → **PV Power Potential OECD** (Raster) → Zonal statistics MEAN → Join attribute → **Mean PV Power Potential** (Polygon) → Classify

OECD Political boundaries
(ArcGIS Live Map)



Average PV Power Potential
OECD,2020



3. GREEN TAXONOMIES - Methodology

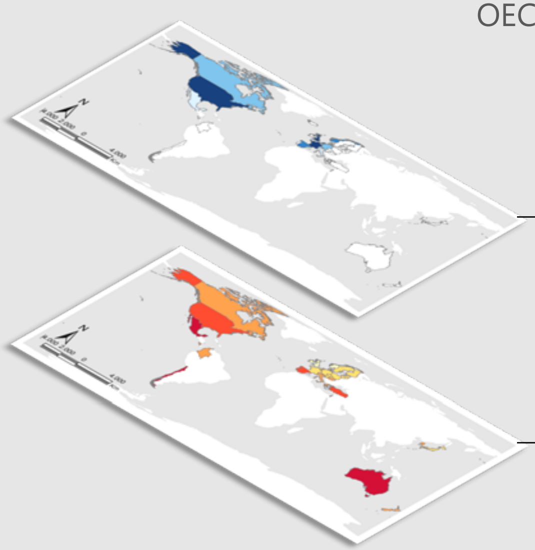
Methodology consists of four phases of analysis

Phases

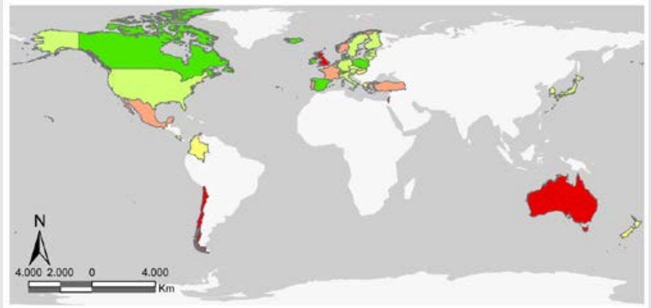
1. Green taxonomic criteria selection (Criteria)
2. Green bonds distribution (Supply)
3. Green investments geolocational demand (Demand)
4. Gap in green investments (Gap)

ArcGIS Pro

Investment Solar energy
OECD,2020



Average PV Power Potential
OECD,2020



Gaps in investment vs PV potential
OECD,2020

3. GREEN TAXONOMIES - Results – Phase #1

21 taxonomies and sustainable finance definitions are identified globally. 3 provide the best reference of green taxonomic criteria

Taxonomies / SF Definitions	C1. Publicly available	C2. Provides taxonomic criteria	C3. Independent development	Prioritized	Detail
1. EU Green Taxonomy	✓	✓	✓	✓	Most sophisticated official-sector taxonomy; to be applied on relevant financial market
2. China's Green Catalogues	✓	✓	✓	✓	Independent development; to be applied on relevant financial market
3. CBI Green Taxonomy	✓	✓	✓	✓	Globally recognized market-based taxonomy
4. Bangladesh Green Taxonomy	✓	✓	✗	✗	Based on previous taxonomies (EU GT); adaptations to local reality
5. Colombia Green Taxonomy	✓	✓	✗	✗	Based on previous taxonomies (EU GT, CBI, GBP); adaptations to local reality
6. Indonesia Green Taxonomy	✓	✓	✗	✗	Based on previous taxonomies (EU GT, China GC); adaptations to local reality
7. Mongolia Green Taxonomy	✓	✓	✗	✗	Based on previous taxonomies (China GT); adaptations to local reality
8. South Africa Green Taxonomy	✓	✓	✗	✗	Based on previous taxonomies (EU GT); adaptations to local reality
9. France Green Inv. Definitions	✓	✗		✗	Definitions of green investments
10. ICMA Green Bond Principles	✓	✗		✗	Pioneering instrument of green finance; provides guidelines to identify eligible project categories
11. Japan Green Taxonomy	✓	✗		✗	Provides guidelines to identify environmental objectives and eligible project categories
12. Malaysia CC Taxonomy	✓	✗		✗	Provides a framework for financial institutions to classify assets in terms of climate friendliness
13. MDBs-IDFC Principles	✓	✗		✗	Pioneering instrument of green finance; provides guidelines to identify eligible activities
14. Netherlands Green Schemes	✓	✗		✗	Range of financial instruments mostly in the form of grants and tax reliefs for green investments
15. OECD Rio Markers	✓	✗		✗	Tool to track finance aid for CCM, CCA, biodiversity and desertification from developed to developing countries
16. Australia Green Taxonomy	✗			✗	Initiative remains under discussion
17. Canada Green Taxonomy	✗			✗	Initiative under construction (delayed)
18. ISO 14040 – 1	✗			✗	Preview circulated for discussion and approval. Final version to be published in 2022
19. Kazakhstan Green Taxonomy	✗			✗	Initiative under construction
20. Mexico Green Taxonomy	✗			✗	Initiative under construction
21. Singapore Green Taxonomy	✗			✗	Initiative under construction

3. GREEN TAXONOMIES - Results – Phase #1

21 taxonomies and sustainable finance definitions are identified globally. 3 provide the best reference of green taxonomic criteria

	Energy											
	Nuclear	Natural gas	Clean fossil fuels (CCS)	Hydropower	Solar	Wind	Biofuels (biogas, biomass)	Marine renewables	Geothermal	Power transmission & distribution	Power storage	Heat pumps
EUGT	Y	Y	D	Y	Y	Y	Y	Y	Y	Y	Y	Y
CGBC	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
CBIT	Y	D	D	Y	Y	Y	Y	Y	Y	Y	Y	Y

	Buildings		Transport					
	Green buildings / energy	Urban development	Private passenger	Public passenger	Freight rail	Road freight	Aviation (infrastructure)	Waterborne transport
EUGT	Y	Y	Y	Y	Y	Y	Y	Y
CGBC	Y	Y	Y	Y	Y	Y	Y	Y
CBIT	Y	N	Y	Y	Y	Y	Y	Y

	Water			Land & sea			
	Water supply	Waste water management	Flood prevention	Forestry	Agriculture	Fisheries and aquaculture	Ecosystems & biodiversity
EUGT	Y	Y	N	Y	N	N	Y
CGBC	Y	Y	Y	Y	Y	Y	Y
CBIT	Y	Y	Y	Y	Y	Y	Y

	Pollution					
	Preparation & storage	Re-use	Recycle	Treatment	Waste to energy	Landfill
EUGT	N	N	N	N	N	N
CGBC	Y	Y	Y	Y	N	N
CBIT	Y	Y	Y	Y	Y	Y

	Industry							Services		
	Manufactory key components	Manufactory energy efficient eq.	Clean steel	Clean aluminum	Clean cement	Hydrogen	Clean up (CCS)	Information & communication	Research, development, innovation	Consulting, auditing, monitoring
EUGT	Y	Y	Y	Y	Y	Y	D	Y	Y	Y
CGBC	Y	Y	Y	N	Y	Y	Y	N	Y	Y
CBIT	Y	Y	D	D	D	D	Y	Y	N	N

FULL CONSENSUS
Activity or asset is signaled as aligned to environmental objectives by all taxonomies
23 activities/assets

PARTIAL CONSENSUS
Activity or asset is signaled by at least one taxonomy. Other taxonomies do not signal
13 activities/assets

CONTROVERSY
At least one taxonomy signals as contrary to environmental objectives or requiring further research
7 activities/assets

Y Signaled as compliant
N Not mentioned / Pending
D Discarded / Requiring research
C In consultation / validation

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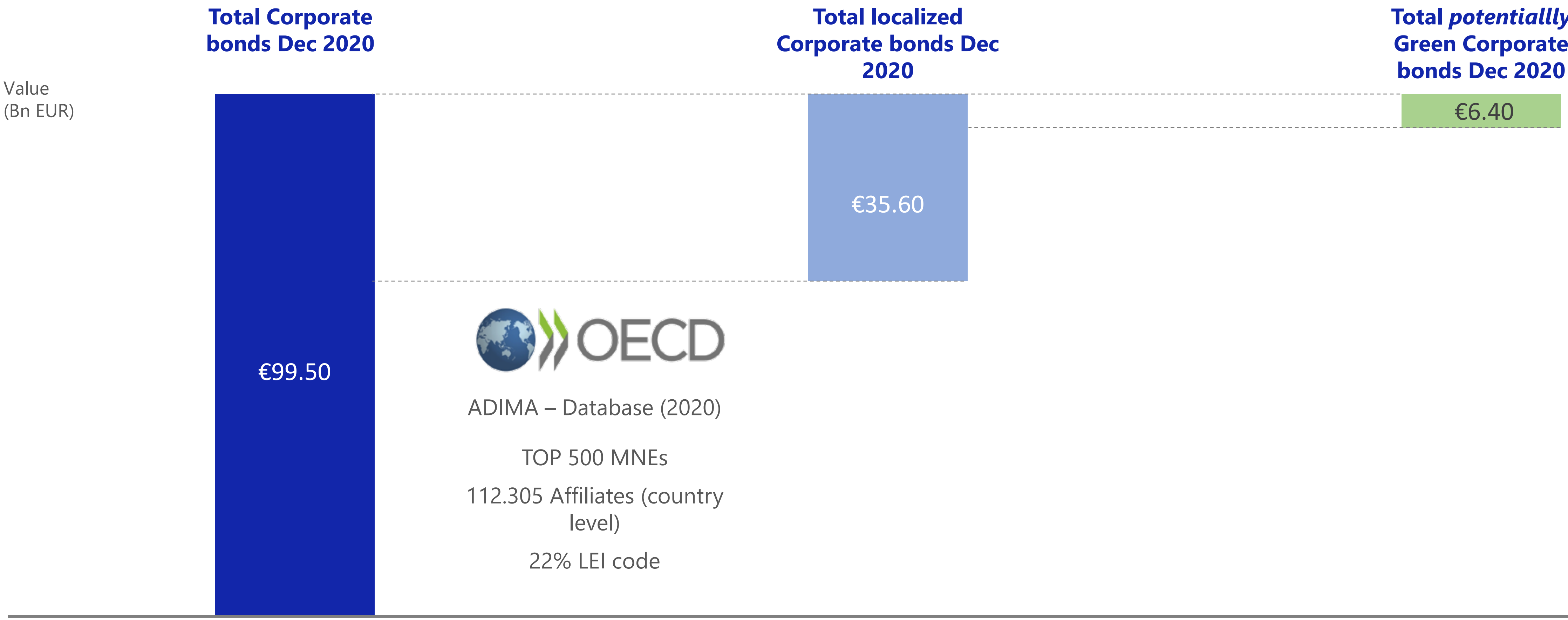
3. GREEN TAXONOMIES - Results – Phase #2

From the totality of investments made by Dutch IFs on Top 500 Corporate Bonds (Dec 2020), EUR6,40 Bi are compliant with green economic activities



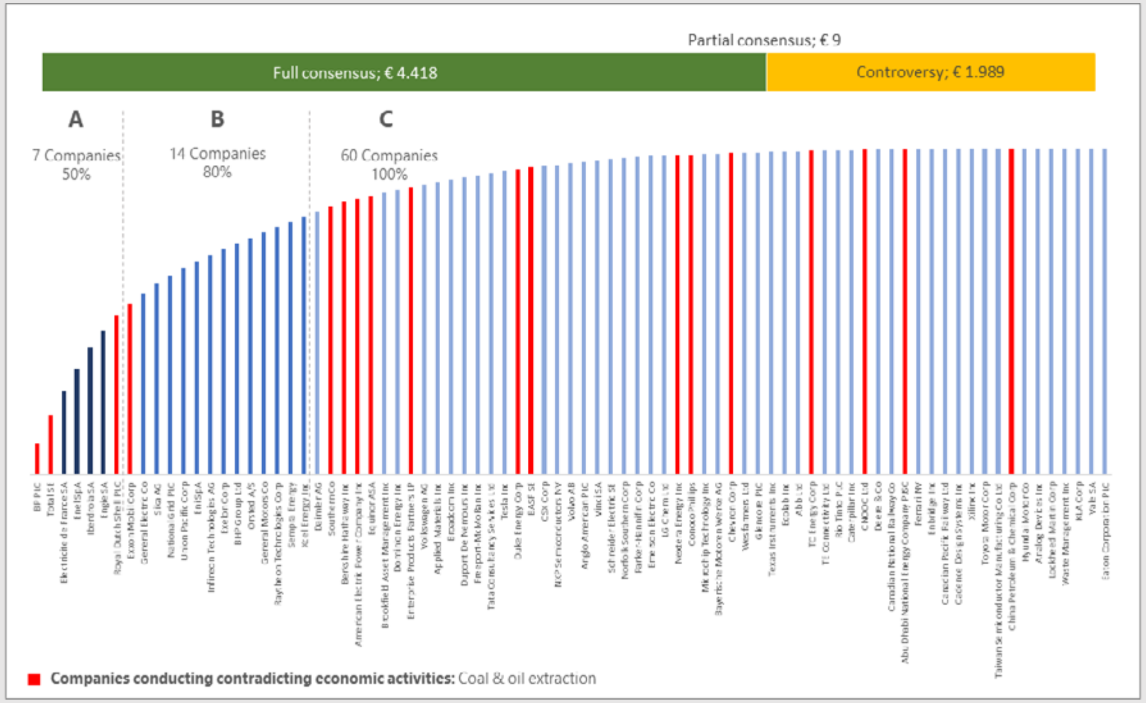
	Total Corporate bonds Dec 2020	Total localized Corporate bonds Dec 2020	Total potentiallly Green Corporate bonds Dec 2020
Issuer legal entities (LEI)	3,608	617	166
Issued security (ISIN)	13,620	5,441	2,281

MNE: Multi National Enterprise

3. GREEN TAXONOMIES - Results – Phase #2

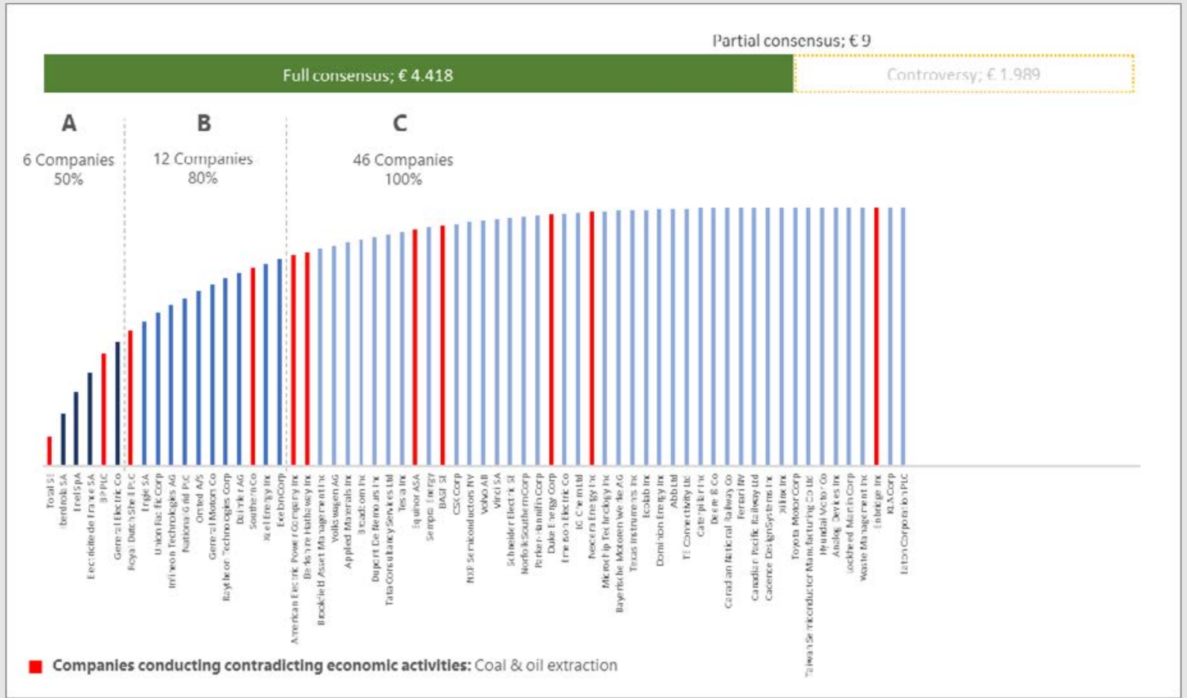
At the MNE level, 7 companies concentrate 50% of *green* investments

Investment per issuer *<u>All Green</u>* economic activities
(100% = EUR €6,4 Bi); 2020



- **High concentration of investments**: 7 companies make up for 50% of investments; 14 companies 80% (81 in total)
- When including Controversial Green activities, **4 major fossil fuel companies appear within the TOP bond issuers**: BP, Total, Shell and ExxonMobil

Investment per issuer *<u>Full & Partial Green</u>* economic activities
(100% = EUR €4,4 Bi); 2020

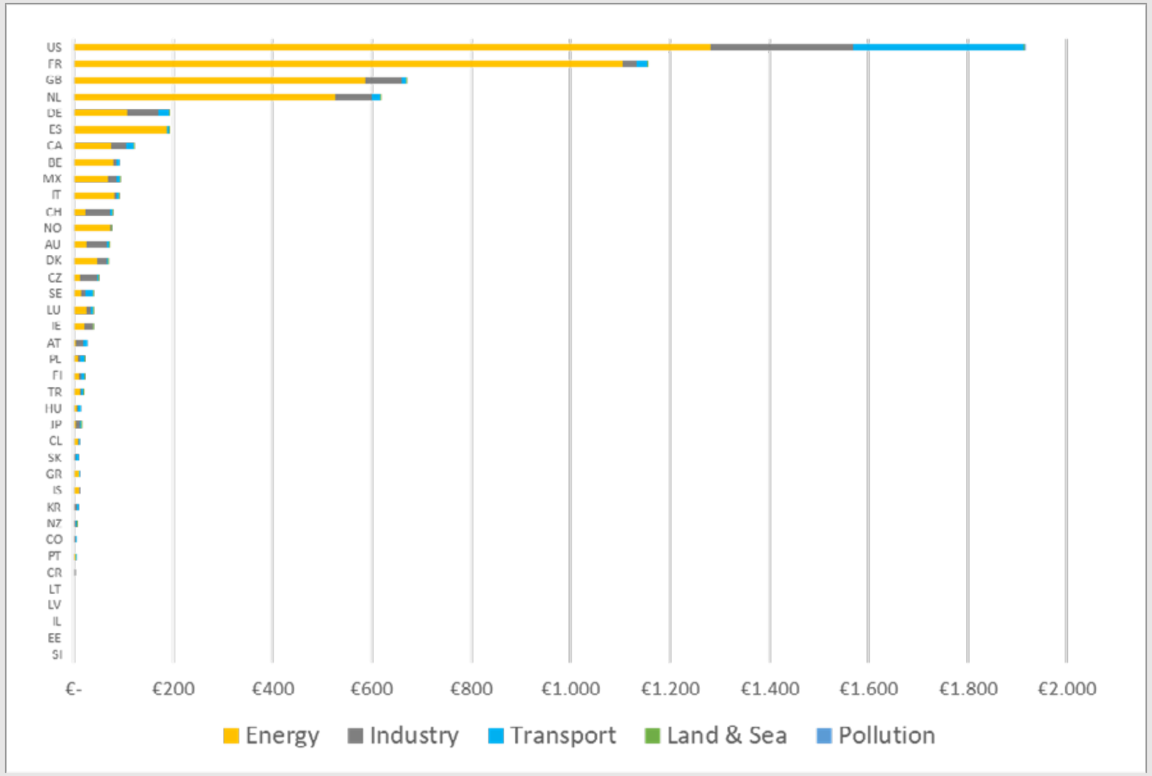


- **Higher concentration of investments**: 6 companies make up for 50% of investments; 12 companies 80% (17 issuers less)
- When including Full or Partial Green activities, the list of major fossil fuel extractors sees a reduced relevance. **Total & BP remains as top issuers;** European Oil & Gas companies show a more aggressive transition towards renewables

3. GREEN TAXONOMIES - Results – Phase #2

At country level concentration is even higher. Energy is the green economic activity consolidating the most green investment

Regional distribution of *green* investments in Corp Bonds
(100% = EUR €6,4 Bi); 2020



- At country level, concentration of investments is higher: 2 countries concentrate 50% of investments, while 4 make up for 80%
- Top 10 countries (90% of investments) are distributed across EU countries and North America (CA, US, MX)

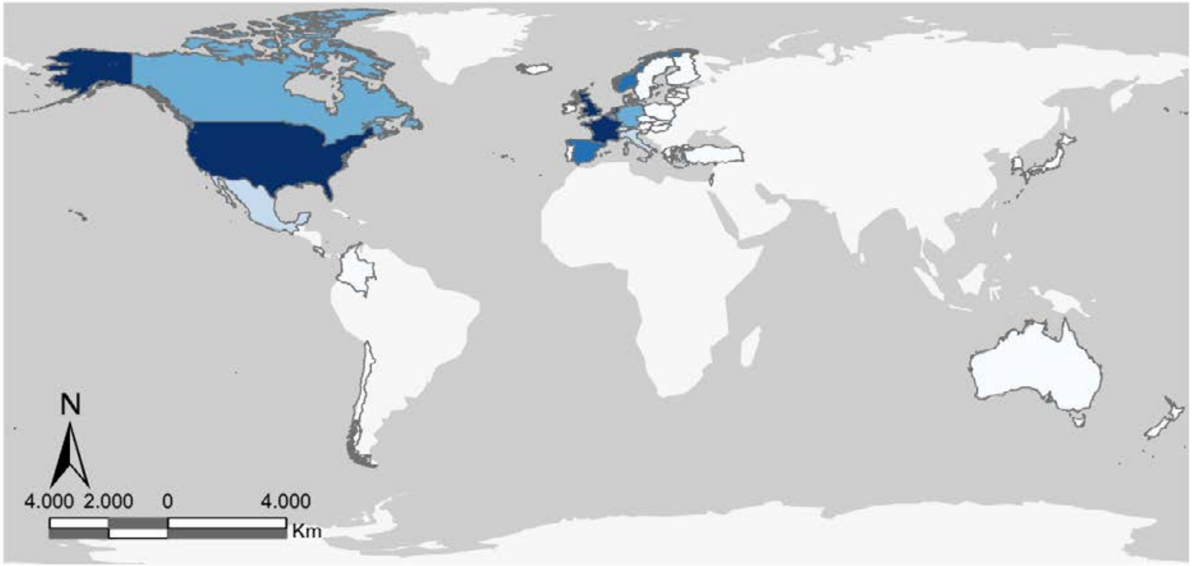
Breakdown of *green* investment per economic activity
(100% = EUR €6,4 Bi); 2020

- Economic activities related to generation, distribution & transmission of clean energy, are the ones consolidating the highest investments
- Natural gas (controversy) is the category with the highest level if investment

3. GREEN TAXONOMIES - Results – Phase #3

Investments in solar are concentrated in northern countries. PV power potential is higher in desertic regions closer to the equator

Regional distribution of *green* investments on solar energy
2020



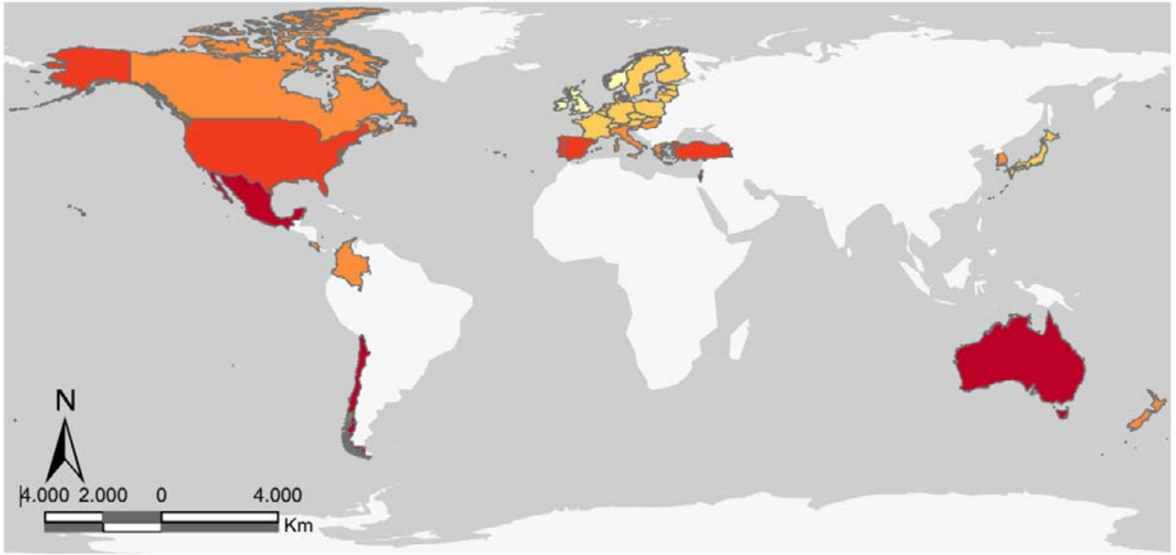
Investment solar (OECD, 2020)

SOLAR_INV

- Very low investment (€ 0,00 - € 3.75 Mi)
- Low investment (€ 3.75 - € 7.50 Mi)
- Medium investment (€ 7.50 - € 15.00 Mi)
- High investment (€ 15.00 - € 30.00 Mi)
- Very high investment (€ 30.00 - € 85.00 Mi)

- 5 countries consolidate +85% of total investments directed at producing electric power from PV technology. France is the major destination for investment (EUR 84 Mi)
- Countries with major investment are located in western Europe. US is the only Top 5 country outside this region

PV Power Potential (MEAN) per country
2020



PV Potential (OECD, 2020)

MEAN

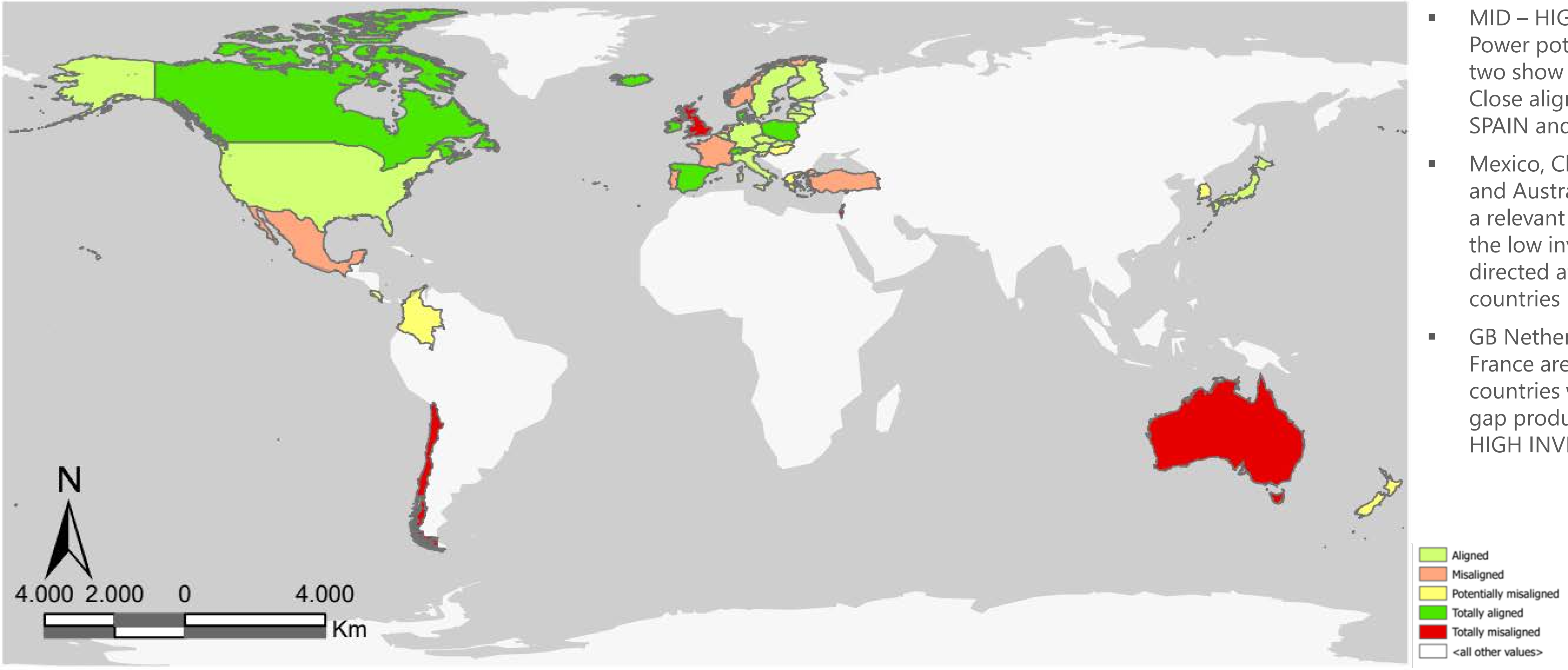
- Very low potential (0,0 - 2,8 kWh/m2)
- Low potential (2,8 - 3,4 kWh/m2)
- Medium potential (3,4 - 4,2 kWh/m2)
- High potential (4,2 - 4,8 kWh/m2)
- Very high potential (4,8 - 8,0 kWh/m2)

- Top values of solar resource and PV power potential are found in South America: Northwest Argentina, Bolivia, **Chile**
- Mexico: opportunity due to high PV potential and proximity of population
- Favorable mid rage: USA, Canada
- Low range: European countries

3. GREEN TAXONOMIES - Results – Phase #4

Important gaps between investments in solar energy and PV power potential are identified in the area of study

Regional alignment between investments and potential for electricity generation from solar
2020

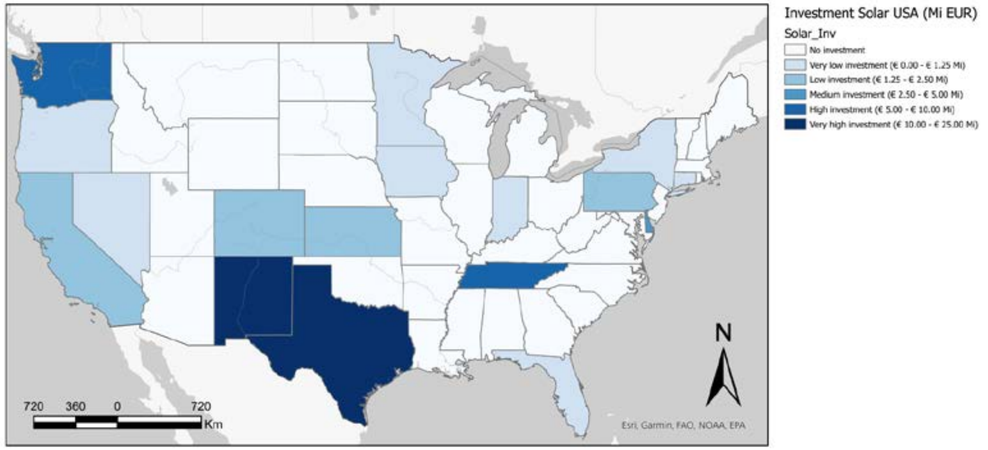


- MID – HIGH PV Power potential, only two show a Total or Close alignment SPAIN and USA
- Mexico, Chile, Israel and Australia there is a relevant gap due to the low investments directed at these countries
- GB Netherlands and France are top the countries with a big gap produced from HIGH INVESTMENTS

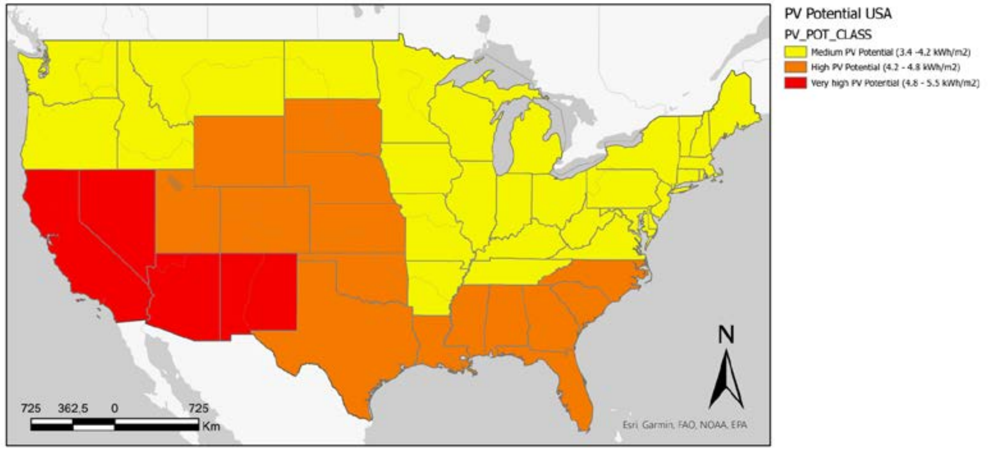
3. GREEN TAXONOMIES - Results – Phase #4

Methodology was replicated to provide more granularity for the USA (EUR €63 Mi, 2020), given data availability

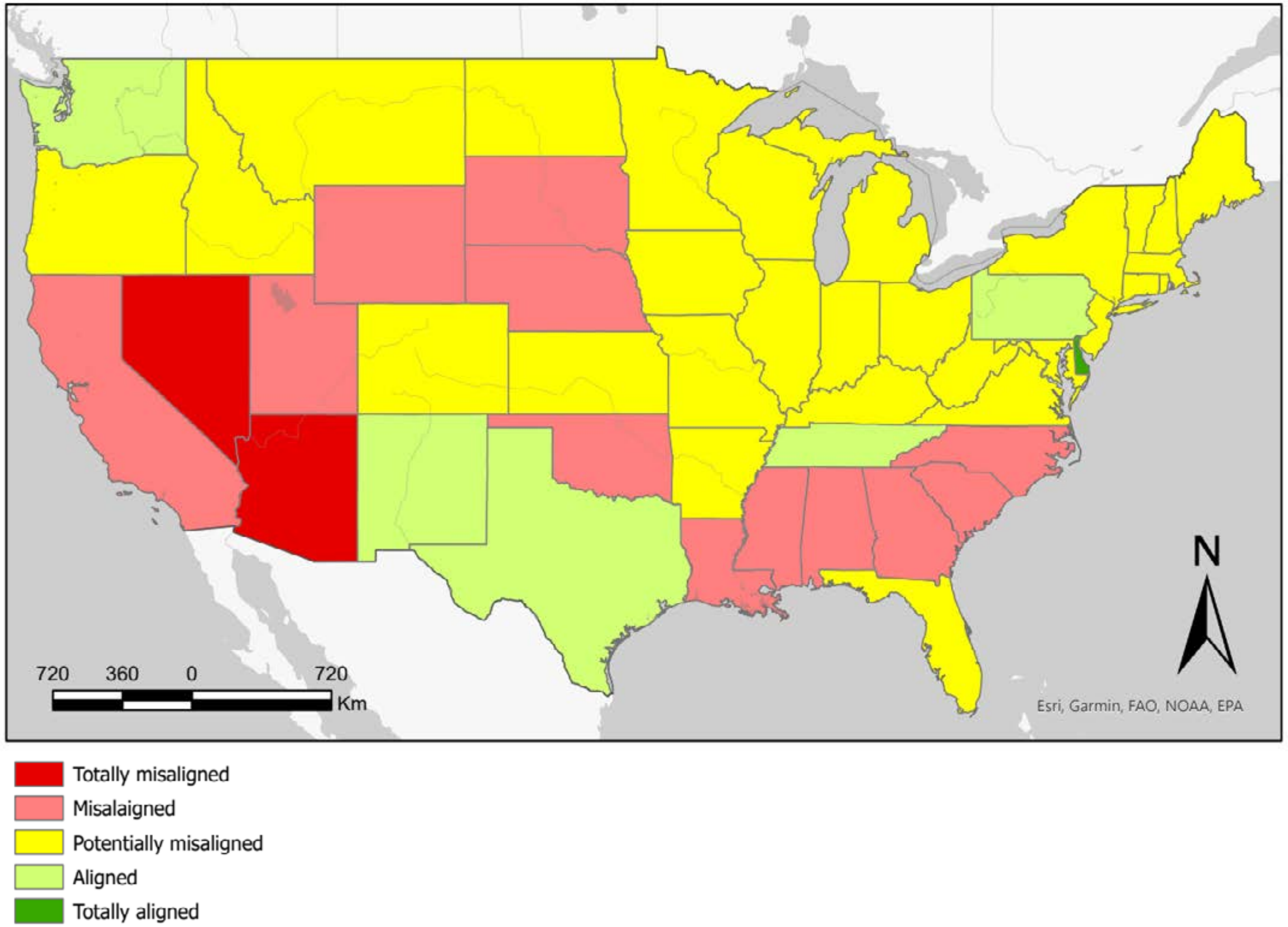
Regional distribution of investments on solar energy
USA 2020



PV Power Potential (MEAN) per country
USA 2020



Regional alignment in investments towards solar energy development
USA 2020



3. GREEN TAXONOMIES - Discussion

1 Out of ≥20 identified green taxonomies (GT), **3 provide the most robust set of taxonomic criteria** : EU Green Taxonomy, China Green Bonds Catalogue, Climate Bond Initiative Green Taxonomy. In line with literature (Ehlers T. et al, 2021)

- **a** Activities/assets, that can be clustered into **43 comparable clusters**. Important discrepancies are identified: **8 clusters show direct contradictions between GTs ("Controversies")** ; 13 clusters do not appear across the 3 GTs ("Partial consensus")

2 When applied to a sample of the Dutch Investment Funds' portfolio on Corporate Bonds (Top 500 enterprises within OECD in 2020 - with LEI code identifier in ADIMA database) **a total of EUR €6,40 Bi** (total sample value of EUR €35,60 Bi – 18% representativeness) **can be potentially flagged as *green investments (GIs)***

- **a** **Represents only a potential value; to vary as data gaps are minimized**: Value to reduce as full taxonomic criteria is applied **Current benchmark reported at 3,0-3,5% of total bond issuance** (European Commission)
- **b** **Outcomes can be used to signal potential trends**. High concentrations against all perspectives: Issuer level – 7 companies consolidating 50% of GIs ; Country level – 2 countries (US, FR) consolidating 50%; Economic activity level – Energy consolidating over 70% of GIs. Results in line with reported by Green Bonds Reports by CBI
- **c** **Discrepancies in taxonomic criteria cause significant variation in potential GIs.** EUR 1,99 Bi (30%) are associated to controversial economic activities/assets, natural gas consolidating the biggest share

3 **Power generation from solar energy has one of the highest concentration of GIs**, with potential tied to characteristics recorded through spatial observation (e.g. Solar radiation, temperature, cloudiness, etc. – contained in the PV Power Potential index)

- **a** **2 high PV power potential countries being receptors of high levels of investment** (US, ES); **relevant potential is being lost** however in countries with the highest PV power potential within OECD region (MX, CL, IL, AU). Gaps can be explained through understanding of local regulatory outlook (IEA Renewables Report 2020)

3. GREEN TAXONOMIES - Conclusions

1 **Green Taxonomies and Remote Sensing data are useful mechanisms for the identification and assessment of CBIs** directed at economic activities that deliver objectives on environmental objectives. Complete potential cannot be extracted due to current **limitations in data availability** and **complementary mechanisms**

2 **Green Taxonomies can be used to track Green CBIs, however,**

- **a** **Current available information (DNB) only serves for a potential *flagging*:** With current data disclosed to DNB, compliance to taxonomic criteria can only be established at level of economic activity/asset of issuer
- **b** **Additional data required:** Need to **for data on the performance indicators** of economic activity/assets (*Significant contribution criteria*); data to assess **complementary criteria** (*Do no significant harm, Minimal social safeguards criteria*)
- **c** **Need for harmonization**; the issues on **Natural Gas**, Nuclear energy, CCS, Hydrogen, Clean Al, Steal, Cement generate significant variability. Discrepancies generate uncertainty on the financial assets' capacity to deliver on green objectives

3 Remote sensing data provides a relevant tool to **follow and analyze the effectiveness in the allocation of these resources**

- **a** This research demonstrates this tool's utility to assess investment potential of **power generation from solar energy.** Other applications can be explored for economic activities with relation to observable environmental conditions: wind, mining, natural gas, agriculture, biodiversity, among others
- **b** **By itself it cannot completely explain the distribution of green investments**; needs to be complemented with political, regulatory, sociodemographic & market outlook information

How proxies and publicly available data can be used to construct new indicators for transition risk, physical risks and green taxonomies

Justin Dijk, Derek Dirks, Willemijn Ouwersloot, Juan Pablo Trespalacios Miranda

DeNederlandscheBank
EUROSYSTEEM

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Digital finance, development, and climate change[1]

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Abstract

Sub-Saharan African (SSA) countries are increasingly adopting digital finance, which generally represents a positive driver of development and growth. However, the digital finance sector is known to be a source of large CO2 emissions, thereby contributing to climate change, and SSA countries will likely be the ones that suffer most from climate change. This constitutes a negative channel through which digital finance could impair development. This article aims to disentangle these two channels to assess which effect prevails overall. We analyse the impact of mobile money and bitcoin on the Human Development Index (HDI). We find that mobile money mitigates the negative impact of CO2 emissions. Globally, through its interaction with CO2 emissions, mobile money has a positive impact on development. In contrast, we find weak evidence concerning bitcoin. On its own, bitcoin has a negative impact on HDI.

JEL Classification: Q43; Q54; G23; E42; O14; O16; O55

Keywords: CO2; climate change; economic development; growth; Africa; energy; digital finance; mobile money; cryptocurrency

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1. Introduction

Common wisdom views digital finance as a factor contributing positively to growth, development, and financial inclusion. However, some tools in digital finance are known to emit significant amounts of CO2, and the recent exponential increase in their adoption thus raises climate change issues.

We thus have two contradictory effects. One is positive and direct (digital finance fosters growth and development), and the other is negative and indirect (digital finance contributes to climate change, which is especially harmful to developing countries). This article aims to disentangle these two effects and assess which effect is more influential.

We deliberately restrict the study to sub-Saharan African (SSA) countries for two reasons. First, these countries are among those projected to suffer most from climate change (Burke et al., 2015). Second, these countries are also where digital finance is experiencing a sharp increase and is viewed as a way to bypass an inadequate banking sector and facilitate financial inclusion and financial development (Aron & Muellbauer, 2019).

We also restrict our consideration of digital finance to two particular forms. The first is the use of cryptocurrencies based on proof-of-work and blockchain technology, such as bitcoin, because they are currently viewed as the tool with the highest CO2 emissions among forms of digital finance (de Vries, 2019). Of course, bitcoin is less used in SSA countries than in other countries, but the impact of CO2 is by nature a global externality; hence, it is interesting to study these countries' contribution to this externality. Second, we study the mobile money industry (mobile payments and banking). This sector is not a heavy CO2 emitter at present in comparison with transport, for example; however, the sector is projected to grow massively, and furthermore, the contribution to CO2 emissions of mobile money is not negligible if one takes into account the whole production and life cycle of products (e.g., electricity to recharge batteries) and network infrastructures needed to use them (cables and data centres); see (Belkhir & Elmeligi, 2018).

Our data coverage starts in 2010 due to the nature of the research object: bitcoin was launched in 2009, and the first data became available from 2010; the first mobile money tools in Africa emerged in Kenya in approximately 2005, and data for most African countries became available from approximately 2010. As a result, we analyse the 2010-2018 period for 46 countries.

Concerning the Human Development Index (HDI), we find that mobile money mitigates the negative impact of CO2 emissions. Globally, through its interaction with CO2 emissions, mobile money thus has a positive impact on development. In contrast, we find weak evidence concerning bitcoin. In itself, bitcoin has a negative impact.

Our approach is novel in the sense that the interrelations of development, digital finance and climate change have rarely been studied by academics. Whereas the separate importance of digital finance for financial inclusion and development, on the one hand, and climate change, on the other, are fuelling important debates, we posit that the interaction between those two aspects must also be at the centre of attention.

Our results have important consequences for researchers, development organizations, policymakers, and the mobile phone and digital finance industry at large. For researchers, this study helps to better clarify the nexus between development and CO2 emissions and a purported driver of prosperity such as digital finance. Prosperity requires energy and hence needs CO2 emissions. However, those frequently come with negative environmental externalities that may have a detrimental impact on development. It is thus important to assess whether digital finance, and which tools within digital finance, can help support a sustainable development path. It follows that decisionmakers should integrate the carbon intensity of each financial development tool under review and trade off growth or development benefits against climate change costs and that the digital finance industry should consider proof-of-stake cryptocurrencies (which run on a carbon-lighter technology than that underpinning bitcoin) or lighter operating systems and longer-life smartphones.

This paper is organized as follows: The second section reviews the literature, the third section presents the data and methods, the fourth section presents the results, and the last section concludes.

2. Literature review

Financial development is now acknowledged as an ingredient of development and growth in developing countries (Demetriades & Hussein, 1996). Traditional variables used to measure financial development are, for example, the monetary aggregate M2, private credit, the size of the insurance industry, and stock market capitalization (Yue et al., 2019). However, the sign of the effect is less clear when CO2 emissions or energy is accounted for. As an example, (Ouyang & Li, 2018) analyse Chinese data and find, for some specifications, a negative impact of financial development on growth.

These mixed results call for greater precision in identifying the mechanism by which financial development is supposed to have an impact. More recent papers include, if not digital finance, at least information and communication technology (ICT) devices and mobile phones as factors in development and/or growth. Asongu (2013) shows that mobile phone penetration is positively related to the financial development of African countries. Philippon (2019) argues, in a theoretical model, that financial technology (fintech) democratizes access to financial services and reduce the cost of financial intermediation. Focusing on GDP growth, Cleeve & Yiheyis (2014) show that mobile penetration has a positive impact on growth. On a related basis, Mazzoni (2019) describes the status and prospects of energy access in Africa and highlights cases where mobile money offers an opportunity to access energy (electricity) [2] and financial services at the same time.

Fewer articles narrow their focus to the use of smartphones[3], on the one hand, as mobile money devices, or to bitcoin, on the other, as a potential factor related to development and/or growth. As argued in the introduction, we analyse mobile money as it is extremely fast growing in Africa[4] and because it is viewed as a way to "leapfrog" the need for a fully accessible traditional banking system (Aron & Muellbauer, 2019). We focus on bitcoin as the prototypical and most carbon-emitting technology amongst forms of digital finance. Our analysis also bears relevance for current discussions about central bank digital currencies that would adopt the same underlying technology (proof-of-work based on blockchain).

In regards to the related literature, first, Beck et al. (2015) build a dynamic general equilibrium model in which mobile money has a positive impact on output, mainly by alleviating transaction frictions in SME–supplier relationships. An application to Kenya covering the 2006-2013 period (one of the first countries to see a mass deployment of mobile money, with the emergence of the fintech firm M-Pesa) shows that mobile money was responsible for 0.33 to 0.47 percentage points of the average GDP growth in that period. Building on several GSMA reports (among them GSMA, 2019), Aron & Muellbauer (2019) argue that there are several reasons to expect a positive microeconomic impact of mobile money. It serves financial inclusion because the unbanked poor, who are an unprofitable target for commercial banks, can easily access an electronic account, deposit cash, and transfer electronic money at an affordable

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[2] Countries like Nigeria still have more than 60% of the population without access to electricity, which strongly constraints access to digital finance.

[3] For readability, we will use indifferently the terms mobile phones and smartphones in the remainder of the article.

[4] An IMF study directed by A. Sy from the African Department (Maino et al., 2019) shows that Africa is a global leader in mobile money adoption and use, and that in SSA the number of mobile money accounts per 1000 adults exceeds the number of traditional deposits accounts per 1000 adults, since 2015. About the complementarity between mobile money and financial accounts, see also Gourène & Soumaré, (2021).

cost. It also helps decrease the information asymmetry faced by conventional banks, as user transaction records can be used as individual credit scores that can eventually serve as a pathway to accessing formal financial services. Mobile money can facilitate services such as interest-bearing savings, small loans, or insurance products. Thompson (2017) analyses different channels for aid distribution[5] and concludes that benefit distribution via mobile money may lower transaction costs and enable more frequent payments. It could also improve the privacy, transparency, traceability, and security of disbursements.

In regards to the second literature stream, bitcoin has also been analysed in terms of its impact on development. Ammous (2015) argues that bitcoin could help secure remittances and increase the efficiency of microfinance. The traceability features of this technology could help facilitate distribution of development aid and help countries with weak national money integrate into international trade with potentially less unfavourable terms of exchange. Although its exchange rate is volatile, bitcoin may offer an inflation haven—i.e., serve as a store of value. The author above posits that currency devaluation, hyperinflation, banking failures, liquidity crises, and bank account confiscations are frequent events in many developing countries and that bitcoin could be more accessible and convenient for the poor than safe foreign currencies and precious metals. Parino et al. (2018) show a relatively high Spearman correlation (between 0.76 and 0.80) between bitcoin usage and HDI. However, the authors underline that they do not analyse causality.

Concerning the impact of digital finance on environmental degradation and CO2 emissions in particular, reducing greenhouse gas emissions is a challenge for sustainable development. SSA countries are among those that will suffer the most from the negative externalities of global warming (Burke et al., 2015)[6]. It is thus important to assess the impact of development tools on CO2 emissions.

We first review the ICT sector at large, and then we focus on mobile money and bitcoin.

Belkhir & Elmeligi (2018) implement linear and exponential extrapolations from 2007-2016 data to assess the global ICT footprint. Restricting their analysis to smartphones, the authors estimate that these devices would represent 11% of total greenhouse gas emissions (GHGEs) of the ICT sector in 2020. Under a business-as-usual scenario, smartphones alone would represent 1.4% of total global emissions in 2040, i.e., approximately 520 Mt CO2e[7]. These authors' measurement includes smartphone production, energy consumption of the device, and energy consumption of the infrastructure needed to operate the devices (servers, data centres)[8]. Asongu et al. (2017) provide one of the first studies to analyse the interaction between the positive effects of ICT on development and inequality with the potentially negative effect of CO2 emissions. They show that in some configurations, mobile phone penetration and internet penetration modulate the potentially negative effect of CO2. Their intuition is that ICT can prevent unnecessary transportation costs.

Beyond the ICT sector in general, some rare studies focus on the CO2 impact of mobile money and bitcoin in particular.

First, as mobile money represents only a fraction of the total use of smartphones, there are practically no studies that try to assess its specific impact[9]. In view of the estimation of 125 Mt CO2e in smartphone

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[5] In the context of, for example, the Payment for Ecosystemic Services (PES) and Reducing Emissions from Deforestation and forest Degradation (REDD+) programmes.

[6] For SSA countries, the authors predict a drop in GDP of –75% in 2100 under a business-as-usual scenario in comparison with projections based on constant 1980-2010 average temperatures.

[7] This figure is approximately 66% of the 2010-2018 average total CO2 emissions for all 46 SSA countries in our sample (773 Mt CO2e).

[8] One problem is that the average lifecycle of smartphones is around two years, adding to this impact the problem of electronic waste. E-waste from mobile phone has been proven to harm development in African countries (Moletsane R., Zuva, 2018).

[9] However, Jacolin et al. (2021) make one attempt to analyse mobile money using a dummy variable equal to 1 if mobile financial services are offered in the country.

emissions for 2020 from Belkhir & Elmeligi (2018), we can suppose only that mobile money will represent an important component of the corresponding figures for this indicator over the decades to come as long as it substitutes for cash. Second, the estimations for bitcoin vary from 19 to 29.6 Mt CO2e in 2018 (de Vries, 2019) to a range of 21.5 Mt CO2 to 53.6 Mt CO2 as of November 2018 in Stoll et al. (2019). With respect to its carbon footprint, bitcoin emits between 233.4 and 363.5 kg of CO2 per transaction in comparison with 0.4 to 3 g of CO2 per VISA transaction[10]. Using prediction models, Mora et al. (2018) build a scenario in which bitcoin is adopted as a means of payment at the same rate as broadly used technologies (i.e., credit cards) in the XXth century. Under this scenario, bitcoin alone could push global warming beyond 2°C in 2040-2050. Beyond bitcoin, it is urgent to raise the debate about the emissions entailed by such technologies[11] in whatever areas in which they apply.

3. Data and methods

3.1 Data

This study examines 46 countries in Africa for the period of 2010-2018, with 414 country-year observations. Our dependent variable is HDI, which measures the level of income as well as the level of basic living standards in health and education[12]. Digital finance is measured with a proxy for domestic usage of bitcoin (bitcoin client download statistics) and with mobile money variables (the number of registered mobile money accounts per 1,000 adults, the number of active mobile money accounts per 1,000 adults, the number of mobile money transactions per 1000 adults, and the value of mobile money transactions as a percent of GDP). We use the amount of fossil fuel CO2 emissions by country as a proxy for environmental degradation and contribution to climate change. Additionally, four control variables (foreign aid, private domestic credit, and foreign direct investment) are included in the model to prevent variable omission bias. Definitions and sources are in Appendix A, summary statistics are in Appendices B and D, and the correlation matrix is in Appendix C.

3.2 Hypotheses

We address our research questions by formulating the following hypotheses.

H1: Bitcoin helps mitigate the potentially negative impact of CO2 emissions on development.

[10] Proponents of this digital currency argue that this energy comes mainly from Chinese renewable hydropower; however, de Vries (2019) replies that this energy source has high seasonality, and that the consumption is balanced out with coal. Furthermore, turning to environmental degradation beyond energy use, the machines used to mine bitcoin have a limited lifetime and are specifically created for bitcoin mining (they immediately become e-waste after their use). This amounted to an average of 134.5 g of e-waste per bitcoin transaction in 2018, in comparison with an estimate of 0.0045 g of e-waste per VISA transaction.

[11] The same distributed ledger technologies based on blockchain have been applied to various fintech innovations in SSA countries (cf. Maino et al., 2019).

[12] The focus on HDI rather than GDP growth can also be justified by a climate policy concern: Van den Bergh & Botzen (2018) compute the emissions pathway for 2015-2050 with an allowance for countries with HDI<0.8 to increase their CO2 emissions while developed countries (HDI>0.8) restrain emissions such that the global temperature remains within 2°C. They find that HDI per ton of CO2 per capita continues to rise for rich countries as well, whereas when measured with GDP, the welfare costs of climate policy are likely to be overestimated.

H2: Mobile money helps mitigate the potentially negative impact of CO2 emissions on development.

We consider H1 (H2) to be valid if, when we account for the interaction between CO2 and bitcoin (mobile money), the total marginal effect of CO2 on HDI is significantly positive, provided that the direct unconditional effect of bitcoin (mobile money) on HDI is positive.

3.3 Model

To test our hypotheses, we use the following panel OLS fixed effect model (Greene, 2000, Baltagi, 2005):

$$HDI_{it} = \beta_0 + \beta_1 DF_{it} + \beta_2 CO2_{it} + \beta_3 CO2_{it}^2 + \beta_4 (CO2_{it}^2 \times DF_{it}) + \sum_{c=1}^{C} \gamma_c W_{cit} + \alpha_i + \varepsilon_{it} \qquad (1)$$

where HDI_{it} is the HDI of country i in year t; DF_{it} is the digital finance variable; $CO2_{it}$ is CO2 emissions; W_{cit} denotes the control variables; α_i is the country fixed effect, which controls for country-level unobserved heterogeneity; and ε_{it} is the stochastic error term.

We first have to disentangle the positive and negative impacts on CO2 emissions. We thus introduce a squared CO2 term to capture the nonlinearity in the relationship between CO2 and HDI. This allows us to check whether an inverted U-shaped relationship exists, i.e., whether β_2 is positive (illustrating that the development process needs to allow for CO2 emissions) and β_3 is negative (illustrating that pollution costs and the exacerbation of climate change can impair development). Second, we interact the digital finance variable with squared CO2 to detect whether digital finance mitigates the negative impact of CO2 emissions, in accordance with our main hypotheses.

The closest models to ours are those of Asongu et al. (2017, 2019), although we depart from these authors in several important aspects. First, we use explicit digital finance variables and not mobile phone or ICT variables at large. Second, we introduce nonlinearity in the CO2 and HDI relationship. Third, we interact our variable of interest with the squared term. Finally, we explicitly assess the significance of marginal effects, as explained later.

We believe that neither a time fixed effect nor a dynamic panel generalized method of moments (GMM) model would be appropriate in the present case. Our sample reflects a specific context in which all variables evolve slowly over time except the variables of interest (digital finance), which show a real boom in SSA countries for 2010-2018[13]. We derive from this context that a time fixed effect or a lagged dependent variable could unduly attract all significant effects and cannibalize the genuine effect of the boom in digital finance.

An important concern for our topic is the endogeneity problem: one could suppose that more developed countries are prone to producing more CO2 emissions. In that case, CO2 would be an endogenous explanatory variable (Wooldridge, 2010). The endogeneity problem, which can be caused by simultaneous causality (Shepherd, 2008), can produce biased and inconsistent panel OLS parameter estimates. Researchers often try to address these bias problems by using the instrumental variables (IV) approach and/or Hausman tests (Nakamura and Nakamura, 1998).

[13] These are the evolutions of annual averages between 2010 and 2018. HDI increased by +9.2% and CO2 emissions by +11.6% in this period. In contrast, bitcoin usage (the number of client downloads) multiplied by a factor of 200, the number of registered mobile money accounts by a factor of 6.5, the number of active mobile money accounts by a factor of 210, the number of mobile money transactions by a factor of 15.9, and the volume of mobile money transactions by a factor of 7.3 (from 3.5% to 25.4% of GDP, whereas at the same time, mean GDP grew by a factor of 1.062). The control variables moved slightly more than HDI and CO2 (between 17% and 43% in the same period), but these evolutions remain far lower to those of the digital finance variables. An earlier version of this article used GMM, and most variables were not significant or had unstable signs throughout the specifications.

The idea is to compare estimates from panel OLS with those of IV estimates. In our setting, the null of the Hausman test is that CO2 is exogenous. If this is the case, panel OLS is preferable to the IV approach[14].

As the interpretation of interaction variables is not straightforward (β_4 in equation (1) must be interpreted together with β_2 and β_3), we prefer to assess our main hypothesis through the overall marginal effect of CO2 emissions on HDI. This is computed as follows:

$$\frac{\partial HDI}{\partial CO2} = \beta_2 + 2\beta_3\overline{CO2} + 2\beta_4\overline{CO2} \cdot \overline{DF} \qquad (2)$$

where $\overline{CO2}$ and $\overline{DF}$ are the mean values in the sample for CO2 emissions and for the digital finance variable.

If, for a given specification, we find that β_1 is positive and significant and that the marginal effect computed in equation (2) is positive and significant, then we determine that we cannot reject the null hypothesis that bitcoin (H1) or mobile money (H2) helps mitigate the potential negative effect of CO2 emissions on development.

Finally, to provide policy-oriented conclusions, we propose a turning (or "tipping") point analysis. If the inverted U-shape holds for the relationship between CO2 and HDI, then it is important to know at which level of emissions a country can pass from the "positive" to the "negative" side of CO2 emissions. Because the computed turning point depends on the digital finance variable under study, it can provide insightful policy implications as to which financial tools should be prioritized. Tipping points have recently become widely used in the fields of climate change, ecology and health (Livina et al., 2015); we consider the latest panel techniques that have proven reliable in dynamic contexts with persistent data (cf. Bernard et al., 2011). Using equation (2), the turning point is the amount of CO2 emissions such that the right-hand side of equation (2) is zero, i.e.:

$$turning\ point = -\frac{\beta_2}{2\beta_3 + 2\beta_4 . \overline{DF}} \qquad (3)$$

This makes sense only if, as explained earlier, β_2 is positive and β_3 is negative.

4. Results

4.1 Development, digital finance, and environmental degradation

Table 1 presents our main results. Specifications with even (odd) numbers include (exclude) the control variables. Unsurprisingly, the R-squared values are systematically larger for specifications including the control variables. Specifications (1)-(2) are a base case without the digital finance variables. Specifications (3)-(4) study bitcoin, specifications (5)-(6) study the number of registered mobile money accounts, specifications (7)-(8) study the number of active mobile money accounts, specifications (9)-(10) study

[14] We build our IV model as follows. CO2 must first be explained by exogenous instruments (Wooldridge, 2010; Baum, 2006 and Ao, 2009). Natural resources endowments are a good candidate. For example, oil is an important factor in CO2 emissions for both Norway and Libya, whereas these two countries have very different HDI indices. Another resource of this type is forests. Thus, in the first stage, we run a regression of CO2 explained with oil (the percent of oil sector in GDP, from World Bank data) and forests (the percent of forestry in GDP, idem) and obtain significant coefficients with a R2 of 0.17. (We also attempt to introduce the coal sector, but the available data were not sufficient. We observe that like all variables in our sample except for the digital finance variables, *oil* and *forests* move slowly through time.) In the second stage, we run an IV regression from equation (1) but instrument CO2 with oil and forests.

the number of mobile money transactions, and specifications (11)-(12) study the volume of mobile money transactions.

First, we observe an inverted U-shape for the CO2 variable, as the CO2 coefficient is positive and the coefficient on its squared term is negative for each of specifications (1)-(12). These two variables have significant coefficients in all specifications (except the squared term in specification (8)). This seems to confirm that CO2 emissions have countervailing impacts—both positive and negative—on development. Based on these results, we believe that integrating the squared term for CO2 in the specifications is an improvement and that not including this squared term might explain the unstable results obtained in the literature (for example, in Asongu et al., 2017).

The results of the Hausman endogeneity tests favour panel OLS with fixed effects (those presented in the tables) instead of the IV approach. Most specifications exhibit p-values above 5% for the test statistic. The only exception is specification (1), which does not include our variable of interest and serves only for comparison purposes. However, for specifications (8) and (10), the p-value is only slightly above 5%; thus, these results must be interpreted with caution. We believe that this is related to the fact that these two specifications are also those with the fewest observations.

Concerning the control variables, their sign and significance are mostly in line with results in the literature. When significant, *aid* has a negative impact on HDI ((2) and (4)). In Asongu et al. (2017), this variable bears a negative—albeit not significant—sign in most specifications, and Asongu (2014) concludes that foreign aid negatively affects inequality-adjusted HDI (IHDI) in Africa. The conclusions of other studies (Clements, 2020; Pickbourn & Ndikumana, 2016) are less categorical and show that there is no consensus on the impact of foreign aid on development. *Credit* is positive only when mobile money variables are included and is significant in (6), (8) and (10). There seems to be a positive association between mobile money and access to credit that fosters development. In the literature, private domestic credit is viewed as a traditional driver of development (Mbate, 2013; Mlachila et al., 2016). Education is a component of HDI and has been documented to be associated with development (e.g., Gyimah-Brempong, 2011). Our variable *edu* is the pupil/teacher ratio, and it should have a negative coefficient. This is the case in half of the specifications, and when significant (in (2) and (4)), it is negative, as expected. Finally, foreign direct investment (*fdi*) is never significant (whereas it is significant and positive in half of the specifications in Asongu et al., 2017).

Let us now turn to the digital finance variables.

We observe that bitcoin, when control variables are included, has a direct negative impact on development (a negative coefficient for *cumulBTC* in specification (4)) and a positive impact when controls are excluded in (3). This unstable relation casts doubts on the impact of bitcoin on development. In contrast, all other money variables have a direct positive impact on development ((5) to (12)).

Moving beyond this direct impact, we investigate the marginal effects to assess the overall effect of the complementarity of digital finance and CO2 emissions in affecting development. The marginal effects are applicable (all coefficients involving CO2 are significant) in most specifications. In those cases, the marginal effects are positive and significant, with p-values below 1% in specifications (4), (5), (7), (9), (10), and (12) and just above 1% for (6). In (3), which concerns bitcoin without control variables, the interaction between bitcoin and CO2 emissions is not significant; hence, the marginal effect is not applicable. This is also the case for active mobile money accounts with controls in (8) and for the value of mobile money transactions without controls in (11).

For bitcoin (4), the overall marginal effect is positive and significant; however, as we explained above, the direct effect is negative. We interpret this as follows: Although both the negative aspect of environmental degradation (the negative sign for squared CO2) and bitcoin exert negative pressure on development, the unconditional positive direct effect of CO2 (emissions needed for development) is strong enough to lead to an overall positive marginal effect[15]. For this reason, we reject H1, as bitcoin is not responsible for this overall positive marginal effect.

In contrast, for mobile money in (5), (6), (7), (9), (10), and (12), the variable coefficient themselves are positive, and the marginal effects are, too: The interpretation is then straightforward[16]. As the overall marginal effect of the complementarity between mobile money and CO2 is positive, it illustrates that mobile money helps mitigate the negative aspect of CO2 emissions on development. Thus, we do not reject H2.

[15] Unsurprisingly, as HDI is an index taking values between 0 and 1, the coefficients appear to be small, as in Asongu et al. (2017). For readability, Table 1 stops at the third decimal. The (heretofore unreported) next decimals for specification (4) are as follows: It appears that the coefficient of the interaction term is extremely small (3.17 E-11), whereas the coefficient for the negative direct effect of bitcoin is a greater in absolute terms (-5.43 E-6). In addition, the coefficient for squared CO2 is greater in absolute terms (-0000.1), and finally, the coefficient for the direct effect of CO2 is the largest (0.00945); i.e., this last coefficient makes the most important contribution to the overall marginal effect, substantiating our interpretation.

[16] As an example, we report in this note the full decimals for registered mobile money accounts in specification (6): The coefficient of the interaction term is 4.16 E-10 and of CO2 squared is -5.13 E-6, while the direct positive effect of registered mobile money accounts is 0.0000181 and 0.0045 for CO2.

Table 1 Development (HDI), digital finance, and environmental degradation

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	HDI	HDI	HDI	HDI	HDI	HDI
CO2_t	0.008***	0.008***	0.006***	0.009***	0.004***	0.005**
	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.002)
CO2_t#CO2_t	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
aid		-0.001***		-0.001***		0.001
		(0.000)		(0.000)		(0.001)
credit		-0.000		-0.000		0.002**
		(0.000)		(0.000)		(0.001)
edu		-0.001*		-0.001**		0.000
		(0.001)		(0.000)		(0.000)
fdi		-0.000		-0.000		-0.000
		(0.000)		(0.000)		(0.000)
cumulBTC			0.000**	-0.000*		
			(0.000)	(0.000)		
cumulBTC#CO2_t#CO2_t			-0.000	0.000**		
			(0.000)	(0.000)		
NRMMA					0.000***	0.000***
					(0.000)	(0.000)
NRMMA#CO2_t#CO2_t					0.000***	0.000***
					(0.000)	(0.000)
Constant	0.422***	0.471***	0.437***	0.472***	0.462***	0.406***
	(0.016)	(0.027)	(0.015)	(0.026)	(0.016)	(0.044)
Observations	352	237	352	237	188	134
R-squared	0.307	0.474	0.364	0.488	0.667	0.701
Number of countries	44	42	44	42	35	29
Country fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
CO2 marginal effect (at means)	0.00736	0.00819	na	0.00912	0.00360	0.00441
Margin st. err.	0.00125	0.00151		0.00140	0.00111	0.00187
Margin p-value	3.66e-09	5.61e-08		6.92e-11	0.00121	0.0186
Hausman endog. test chi2	6.209	7.370	5.501	7.880	1.034	4.482
p-value	0.0449	0.195	0.139	0.247	0.793	0.612

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 1 gives fixed effect panel regressions for several specifications of our model for sub-Saharan African countries from 2010 to 2018. # is the multiplication operator. *CO2_t* is the amount of fossil fuel emissions of CO2 in million tons, *aid* is net official development assistance (ODA) received (percent of GNI), *credit* is domestic credit to the private sector by banks (percent of GDP), *edu* is the pupil-teacher ratio in primary education, *fdi* is foreign direct investment inflows (percent of GDP), *cumulBTC* is the cumulated number of downloads of bitcoin client software in a country, *NRMMA* is the number of registered mobile money accounts per 1000 adults, *NAMMA* is the number of active mobile money accounts per 1,000 adults, *NMMT* is the number of mobile money transactions per 1,000 adults, and *VMMT* is the value of mobile money transactions (percent of GDP). The *CO2 marginal effect* gives the overall variation in HDI due to the variation in all CO2 variables, computed at the means, and which we consider significant if *Margin p-value*<0.05. When at least one of the CO2 variables is not significant, we consider the marginal effect not applicable (*na*). The *Hausman endogeneity test* compares panel OLS versus instrumental variable (IV) coefficients and determines that panel OLS is preferable if *p-value*>0.05.

Table 1, continued

VARIABLES	(7) HDI	(8) HDI	(9) HDI	(10) HDI	(11) HDI	(12) HDI
CO2_t	0.009***	0.008***	0.006**	0.007**	0.007**	0.009***
	(0.003)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)
CO2_t#CO2_t	-0.000**	-0.000	-0.000**	-0.000**	-0.000***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
aid		0.000		0.001		-0.000
		(0.001)		(0.001)		(0.001)
credit		0.003***		0.002**		0.001
		(0.001)		(0.001)		(0.001)
edu		-0.000		0.000		0.000
		(0.000)		(0.000)		(0.000)
fdi		0.000		0.000		-0.000
		(0.000)		(0.000)		(0.000)
NAMMA	0.000***	0.000				
	(0.000)	(0.000)				
NAMMA#CO2_t#CO2_t	-0.000***	-0.000**				
	(0.000)	(0.000)				
NMMT			0.000***	0.000***		
			(0.000)	(0.000)		
NMMT#CO2_t#CO2_t			-0.000*	-0.000**		
			(0.000)	(0.000)		
VMMT					0.001***	0.000***
					(0.000)	(0.000)
VMMT#CO2_t#CO2_t					-0.000	-0.000***
					(0.000)	(0.000)
Constant	0.387***	0.321***	0.438***	0.369***	0.416***	0.382***
	(0.032)	(0.051)	(0.032)	(0.051)	(0.041)	(0.048)
Observations	134	97	165	114	168	119
R-squared	0.613	0.673	0.534	0.644	0.496	0.589
Number of countries	28	23	32	28	33	28
Country fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
CO2 marginal effect (at means)	0.00857	na	0.00510	0.00608	na	0.00771
Margin st. err.	0.00257		0.00197	0.00233		0.00259
Margin p-value	0.000845		0.00973	0.00902		0.00287
Hausman endog. Test chi2	2.664	12.95	0.154	11.01	0.159	10.14
p-value	0.446	0.0734	0.926	0.0512	0.984	0.119

Robust standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 1 gives fixed effect panel regressions for several specifications of our model for sub-Saharan African countries from 2010 to 2018. # is the multiplication operator. *CO2_t* is the amount of fossil fuel emissions of CO2 in million tons, *aid* is net official development assistance (ODA) received (percent of GNI), *credit* is domestic credit to the private sector by banks (percent of GDP), *edu* is the pupil-teacher ratio in primary education, *fdi* is foreign direct investment inflows (percent of GDP), *cumulBTC* is the cumulated number of downloads of bitcoin client software in a country, *NRMMA* is the number of registered mobile money accounts per 1,000 adults, *NAMMA* is the number of active mobile money accounts per 1,000 adults, *NMMT* is the number of mobile money transactions per 1,000 adults, *VMMT* is the value of mobile money transactions (percent of GDP). The *CO2 marginal effect* gives the overall variation in HDI due to the variation in all CO2 variables, computed at the means, and which we consider significant if *Margin p-value*<0.05. When at least one of the CO2 variables is not significant, we consider the margin effect not applicable (*na*). The *Hausman endogeneity test* compares panel OLS *versus* instrumental variable (IV) coefficients and determines that panel OLS is preferable if *p-value*>0.05.

4.2 Analysis of turning points

Because we have shown an inverted U-shaped relationship between CO_2 emissions and HDI, it is important to compute the turning (or tipping) point, which represents the amount of CO_2 emissions that separates the positive and negative net impacts of CO_2 emissions. For CO_2 values below that point, the positive effect prevails: It is necessary to pollute to develop. Beyond that point, the negative effect prevails: Environmental degradation negatively impacts development, probably through health expenses and income losses.

It is thus important to assess whether the turning point that we compute from the regression in Table 1 is within realistic bounds; otherwise, this could mean that our model is misspecified.

Table 2 gives the turning points computed from Table 1 (regressions (1)-(12)) and, when applicable, (3)-(12) by means of the respective digital finance variables. We set aside our base case specifications ((1) and (2)) for which the turning point values are beyond the sample range. Of the 10 remaining specifications, eight are within the sample range, and only two specifications ((7) and (8)) are beyond this range, one of which ((8)) is the regression with the fewest observations. We conclude that this shows that our model is correctly specified.

Furthermore, these computed thresholds make economic sense and can be useful to decisionmakers or policymakers. Whereas the analysis in Table 1 casts doubts on the use of bitcoin as a tool for preserving development while mitigating the negative impact of CO_2 emissions, it is worth noting that with specifications (3) and (4), the threshold at which CO_2 emissions begin to impair development is quite high (near the maximum observed in the sample) but realistic. This is the same when the digital finance variable is the number of registered mobile money accounts ((5) and (6)). Unsurprisingly, CO_2 emissions are highly skewed, and only South Africa approaches thresholds beyond 400 Mtons of CO_2 emissions, while most countries are at approximately 3 to 4 Mtons of CO_2 (see Appendices B and D for descriptive statistics). In turn, for a large majority of countries, there is room for the use of digital finance tools without fears of reaching the point at which CO_2 emissions become unfavourable. More precisely, in view of (5) and (6), countries can seek to provide individuals and firms with mobile money devices without fearing that the contribution of these devices to CO_2 emissions will compromise development. Instead, the mitigating role of mobile money, probably through avoided use of transport and other factors highlighted in the arguments noted in the literature review section, outweighs the sector's contribution to emissions.

This is less true for specifications (9)-(12), for which the turning points are lower (from 115.3 to 146.7 Mtons of CO_2). We interpret this result as follows: In terms of the *prevalence of equipment* (the number of registered accounts), the threshold at which emissions become problematic is quite high, whereas based on the *intensity of usage* of such equipment (the number and value of transactions), the level at which emissions are problematic is much lower. The interest of a country, strictly concerning the positive complementarities between digital finance and CO_2 emissions, lie in the population being widely equipped but not using their devices excessively intensively. However, again, only Nigeria approaches the aforementioned threshold, and for a large number of countries, the thresholds are high enough to inspire confidence in the promotion of mobile money.

Table 2 Turning point analysis

Table 1 regression number	(1)	(2)	(3)	(4)	(5)	(6)
Digital finance variable	No	No	CumulBTC	CumulBTC	NRMMA	NRMMA
CO2 turning point	527	521.4	477.1	455.8	458.4	462
Within sample range	No	No	Yes	Yes	Yes	Yes
Control variables	No	Yes	No	Yes	No	Yes
Observations	352	237	352	237	188	134
Number of countries	44	42	44	42	35	29

Table 1 regression number	(7)	(8)	(9)	(10)	(11)	(12)
Digital finance variable	NAMMA	NAMMA	NMMT	NMMT	VMMT	VMMT
CO2 turning point	599.1	646.4	146.7	115.3	130.4	124.5
Within sample range	No	No	Yes	Yes	Yes	Yes
Control variables	No	Yes	No	Yes	No	Yes
Observations	134	97	165	114	168	119
Number of countries	28	23	32	28	33	28

Table 2 computes the turning points of CO2 based on the coefficients presented in Table 1. The maximum sample observation for CO2 is 484.2, and the 99th percentile is 472.7. When applicable, the turning point is computed by means of the digital finance variable. See Table 1 and the descriptive statistics table for other figures. *cumulBTC* is the cumulated number of downloads of bitcoin client software in a country, *NRMMA* is the number of registered mobile money accounts per 1,000 adults, *NAMMA* is the number of active mobile money accounts per 1,000 adults, *NMMT* is the number of mobile money transactions per 1,000 adults, and *VMMT* is the value of mobile money transactions (percent of GDP).

Analysing Table 2 jointly with the table of descriptive statistics by country (Appendix D), we derive that even countries already well equipped with mobile money devices (e.g., Kenya, with 1,035 registered accounts per 1,000 adults on average) have room to increase this level without reaching the point at which CO2 emissions impair development (e.g., 18.6 Mtons maximum emissions for Kenya in 2010-2018, whereas the turning point is 462 Mtons with RMMA including controls).

4.3 Robustness checks

We use several variants to check the consistency of our results.

First, we lag all right-hand-side (RHS) variables to further correct for potential endogeneity bias. One might think that current HDI is influenced by past explanatory variables. We explore whether previous-year RHS variables have different signs and significance from our those in our baseline approach. The results[17] are qualitatively identical. The CO2 variables, digital finance variables, and the interaction term bear the same signs and, most of the time, the same significance level. The marginal effects of CO2 also have the same signs and significance. The only *caveat* is that there are only 9 specifications out of 12 (against 11 out of 12 in our baseline results) for which the Hausman test concludes in favour of panel fixed effects over IV estimation. We also compute the CO2 turning points in this context and again find very similar results.

Second, we use different variables for CO2 emissions to check whether our results are biased by the specific variable that we use. We replace CO2 total emissions with CO2 emissions per capita, carbon intensity (emissions per dollar of GDP) and CO2 emissions from electricity and heat. Taken as a whole, these variants show that our results are mostly stable: At worst, we find less evidence or no evidence in some specifications, but we never find contradictory evidence. We still confirm the rejection of H1 about bitcoin. For H2 and mobile money, the interaction term is also less often significant and/or the p-value of the marginal effect is sometimes above 10%, but we still find (less numerous) cases when we cannot reject H2 and no contradictory evidence and thus confirm that mobile money helps mitigate the negative effect of CO2[18].

Third, to check that our main result is not biased by the marginal effect of CO2 being computed at the means, we compute for all 12 specifications in Table 1 the CO2 marginal effect at the median (p50), at the 25% lowest CO2 emissions (p25), and at the 75% lowest CO2 emissions. By definition, except for margins, the results are simply those in Table 1. Hence, margins are not applicable for regressions (3), (8) and (11). We confirm that all marginal effects are positive and significant[19]. Due to the distribution of CO2 emissions, we find that margins are lowest when computed at the 25th percentile and highest when computed at the means; however, they are stable overall. Consequently, we confirm our main results for different computations of margins.

5. Conclusions

Our research was designed to address the question of whether policy- or decisionmakers or citizens should encourage the spread of digital finance to promote development. We attempt to disentangle the advantages of digital finance in terms of development from its costs through its contribution to CO2 emissions. The results contrast depending on the digital finance device.

For bitcoin, we cannot show evidence of a contribution to development. Its direct effect is negative, and its contribution to mitigating the negative impact of CO2 emissions is very low. These results confirm previous alerts concerning the environmental cost of decentralized blockchain technology applied to money.

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[17] The results are available from the authors upon request.

[18] Finally, we also run the specifications with both RHS lags and alternate CO2 variables and confirm that we find qualitatively similar results. The results are available from the authors upon request.

[19] These results are available from the authors upon request.

Concerning mobile money devices, we do not reject the hypothesis that they help mitigate the potentially negative impact of CO_2 emissions on development. Incidentally, we show an inverted U-shaped relationship between CO_2 emissions and development. Our data allow us to distinguish between the prevalence of equipment (the number of registered and active mobile money accounts) and the intensity of usage (the number and volume of mobile money transactions) of such devices.

Concerning the prevalence of equipment, all countries except South Africa have room to increase this level because they all have CO_2 emissions far below the turning point at which CO_2 emissions become unfavourable to development, even in already widely equipped countries such as Kenya or Tanzania.

Concerning the intensity of usage, the turning points are lower (from 115.3 to 146.7 Mtons of CO_2). We interpret this as an acknowledgement that the intensity of usage of mobile money devices is more related to the negative impact of CO_2 emissions on development than the prevalence of mobile money equipment per se. South Africa again lies above the turning points for all years. However, the second nearest country (Nigeria) emits 90.4 Mtons of CO_2 on average, which again leaves room to promote the intensity of usage without risking an approach to the turning point in the medium term.

The contributions of this article are as follows: (1) To the best of our knowledge, this is the first attempt to explicitly study the impact of digital finance (bitcoin and mobile money equipment and usage) on development; (2) we test the interaction of digital finance with the potentially negative impact of CO_2 emissions on development; and (3) we study the inverted U-shaped relationship between CO_2 emissions and development and discuss the level of its turning point.

Of course, our approach has limitations and calls for future improvements. In particular, the way we take bitcoin usage into account could be discussed. In SSA countries, the overall usage of bitcoin is scarce. However, given the level of usage in some developed countries, the externalities of bitcoin usage could be taken into account even for SSA countries. The level of energy used to make the bitcoin network work is largely independent of the intensity of usage in SSA countries, and thus, the detrimental impact of bitcoin on SSA countries' development should stem from its global CO_2 emissions and not the national usage considered in our approach. However, this perspective may worsen the bitcoin's negative impact and hence may not change our general conclusion. Furthermore, it is still interesting to study countries' contribution to bitcoin usage, even if this contribution is small, precisely because domestic usage is much easier for a given country to handle than international usage. While the latter could be influenced by international agreements or information campaigns, it is easier to discourage usage in one country.

Importantly, we do not recommend not using cryptocurrencies at all but simply take into account their ecological costs. In this respect, cryptocurrencies based on centralized blockchain, with a certifying authority, are supposed to be much less energy demanding than decentralized blockchain (Pfister, 2019), thus leaving open the question of central bank digital currencies. Concerning mobile money, the scarcity of some metals used in mobile, or smartphone production should also be taken into account—though this aspect is beyond the scope of this article.

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Appendix A. Variable definitions

	Variables	Description of Variables	Sources
Digital Finance	BTC	Bitcoin client download statistics	Sourceforge https://sourceforge.net/projects/bitcoin/files/stats/map?dates=2008-06-23+to+2019-09-21
	cumulBTC	Cumulated number of downloads of bitcoin client software in a country	Calculated by using BTC numbers
	Variables for Mobile Money		
	NRMMA	Number of registered mobile money accounts per 1,000 adults	International Monetary Fund
	NAMMA	Number of active mobile money accounts per 1,000 adults	International Monetary Fund
	NMMT	Number of mobile money transactions per 1,000 adults	International Monetary Fund
	VMMT	Value of mobile money transactions (% of GDP)	International Monetary Fund
Climate Change	CO2_GDP	Tons of in fossil fuel CO2 per $1,000 of 2010 GDP by country	https://edgar.jrc.ec.europa.eu/overview.php?v=booklet2018
	CO2_t	Million tons of fossil fuel CO2 emissions by country	https://edgar.jrc.ec.europa.eu/overview.php?v=booklet2018
	co2eah	CO2 emissions from electricity and heat production (% of total fuel combustion)	World Bank
	co2pc	Metric tons per cap of fossil fuel CO2 emissions by country-year	Calculated by using the formula co2pc=CO2_t*1000000/pop
Economic Indicator (Dep. Var.)	HDI	Human Development Index	http://hdr.undp.org/en/data
Control Variables	edu	Education quality: Pupil-teacher ratio, primary	World Bank: World Development Indicators
	fdi	Foreign direct investment, net inflows (% of GDP)	World Bank
	aid	Foreign aid: Net official development assistance (ODA) (% of GNI)	World Bank: World Development Indicators
	credit	Private credit: Private credit by deposit money banks and other financial institutions to GDP (%)	World Bank

Dep. Var.: Dependent Variable

Appendix B: Descriptive statistics

Variable	Obs	Mean	Std Dev	Min	Max
			Economic Indicator		
HDI	414	0.5165725	0.0996996	0.319	0.801
			Digital Finance		
BTC	236	155.5	860.8383	1	11622
cumulBTC	414	560.0942	2488.209	0	20570
NRMMA	215	448.8944	458.6397	0.0583731	1823.354
NMMT	191	12383.7	21558.05	0.0000439	195972.7
VMMT	195	12.45509	19.57556	0.0001792	142.3912
NAMMA	156	198.6319	222.93	0	940.2841
			Climate Change		
co2eah	118	24.52693	19.72449	0	70.38403
CO2_GDP	352	0.1722635	0.1312096	0.0182169	0.7580574
CO2_t	352	17.57605	70.33093	0.1330203	484.204
co2pc	352	1.078093	2.07447	0.0260396	12.88304
			Control Variables		
edu	279	39.78043	13.17043	12.54703	84.32027
fdi	409	5.718765	10.691	-6.10498	103.3374
aid	406	7.671188	7.62106	0.0035144	77.86814
credit	348	33.13999	90.88847	0.347333	972.205

Appendix C: Correlation matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1) HDI	1.000														
(2) co2eah	0.4419	1.0000													
(3) CO2_GDP	0.4091	0.6107	1.0000												
(4) CO2_t	0.4559	0.5693	0.8783	1.0000											
(5) co2pc	0.6740	0.6626	0.8616	0.9338	1.0000										
(6) BTC	0.3386	0.4431	0.6530	0.7522	0.6966	1.0000									
(7) cumulBTC	0.4544	0.5688	0.8561	0.9917	0.9172	0.7426	1.0000								
(8) NRMMA	-0.0162	0.1267	-0.2912	-0.1849	-0.1788	-0.0950	-0.114	1.0000							
(9) NMMT	-0.1600	0.0704	-0.1752	-0.1251	-0.1888	-0.0251	-0.0500	0.8856	1.0000						
(10) VMMT	-0.1990	0.0227	-0.2112	-0.1206	-0.2033	-0.0265	-0.0465	0.8947	0.9901	1.0000					
(11) NAMMA	0.1367	0.3821	-0.1807	-0.2005	-0.0610	-0.1295	-0.1507	0.8005	0.6405	0.6190	1.0000				
(12) edu	-0.5169	-0.5016	-0.3239	-0.1855	-0.4339	-0.1534	-0.1909	0.0659	0.1954	0.2416	-0.1689	1.0000			
(13) fdi	-0.4587	-0.4012	-0.3337	-0.1875	-0.3056	-0.1100	-0.1777	-0.0417	-0.0262	0.0005	-0.3290	0.1337	1.0000		
(14) aid	-0.8678	-0.3850	-0.3417	-0.3726	-0.5371	-0.2680	-0.3730	0.1620	0.2915	0.3197	-0.0961	0.3368	0.6327	1.0000	
(15) credit	0.5259	0.5178	0.9051	0.9635	0.9572	0.7087	0.9459	-0.2618	-0.2100	-0.2109	-0.2071	-0.3150	-0.2847	-0.4326	1.0000

Appendix D: Descriptive statistics by country

Country	Mean CO2 t	Median CO2 t	Min CO2 t	Max CO2 t	Mean co2pc	Mean HDI	Mean RMMA	Min RMMA	Max RMMA	Mean NMMT	Min NMMT	Max NMMT	Mean VMMT	Min VMMT	Max VMMT
Angola	27.5	27.1	23.7	32.1	1.0	0,55	4	0	9	52	2	164	0.0%	0.0%	0.1%
Benin	5.6	5.2	4.8	7.1	0.5	0,50	625	64	1 347	11 121	408	30 022	19.8%	0.4%	41.5%
Botswana	5.9	6.3	3.5	7.9	2.8	0,70	655	3	1 411	7 067	4	21 278	1.6%	0.0%	5.2%
Burkina Faso	2.8	3.1	1.9	3.4	0.2	0,41	302	8	881	17 183	1 495	45 628	29.7%	1.6%	58.2%
Burundi	0.3	0.3	0.2	0.3	0.0	0,42									
Cabo Verde	0.7	0.7	0.3	1.0	1.3	0,64									
Cameroon	8.3	8.0	7.2	9.8	0.4	0,53	217	5	455	7 781	2	39 645	5.9%	0.0%	30.2%
Central African Republic	0.4	0.4	0.4	0.5	0.1	0,36	2	1	3	1	1	1	0.0%	0.0%	0.0%
Chad	0.7	0.7	0.4	1.0	0.1	0,40	2	2	2	1	0	2	0.0%	0.0%	0.1%
Comoros	0.2	0.2	0.1	0.2	0.2	0,53									
Congo, Democratic Republic of	3.7	3.5	3.1	5.5	0.1	0,44									
Congo, Republic of	5.2	5.3	4.5	5.5	1.1	0,59	239	200	277						
Cote d'Ivoire	10.0	10.2	7.3	12.5	0.4	0,48	759	120	1 695	20 354	4 873	39 354	22.6%	7.8%	40.6%
Djibouti	1.1	1.0	0.9	1.4	1.2	0,47									
Equatorial Guinea	3.4	2.9	2.5	4.7	3.1	0,59									
Ethiopia	11.2	11.4	6.9	14.9	0.1	0,44									
Gabon	6.2	6.2	5.8	6.6	3.4	0,68	21	21	21						
Gambia, The						0,45									
Ghana	15.0	15.3	11.4	18.6	0.6	0,58	850	239	1 774	27 381	1 144	79 242	28.8%	0.8%	74.3%
Guinea	2.2	2.4	1.4	2.7	0.2	0,44	213	8	624	9 790	20	32 336	10.6%	0.0%	33.3%
Guinea-Bissau	0.4	0.4	0.3	0.5	0.2	0,45	325	125	586	739	262	1 821	0.6%	0.1%	1.8%
Kenya	15.1	14.3	12.5	18.6	0.3	0,56	1 035	689	1 548	35 000	13 038	56 469	39.6%	23.1%	47.8%
Lesotho	0.6	0.7	0.2	0.8	0.3	0,49	748	347	995	18 429	455	40 780	10.0%	0.2%	21.8%
Liberia	0.9	1.0	0.6	1.1	0.2	0,46	366	16	961	1 441	473	3 673	1.0%	0.6%	1.3%
Madagascar	3.5	3.8	2.2	4.2	0.1	0,51	170	11	413	1 633	4	5 830	6.0%	0.0%	20.5%
Malawi	1.4	1.4	1.3	1.6	0.1	0,47	51	21	81	690	55	1 325	1.4%	0.1%	3.4%
Mali	0.8	0.8	0.6	1.0	0.0	0,41	343	21	733	13 851	1 453	25 640	21.0%	3.0%	33.8%
Mauritania	2.6	2.7	2.1	3.0	0.7	0,51	34	14	53				0.6%	0.1%	1.9%
Mauritius	3.8	3.8	3.7	4.0	3.1	0,78	112	5	200	63	60	70	0.0%	0.0%	0.0%
Mozambique	5.4	4.9	3.7	7.8	0.2	0,42	330	187	488	7 826	356	15 962	5.9%	0.2%	18.4%
Namibia	3.8	3.8	3.1	4.3	1.7	0,62	430	3	1 358	1 665	2	7 287	1.3%	0.0%	5.7%
Niger	2.0	2.1	1.4	2.5	0.1	0,35	161	63	272	2 407	913	3 910	3.7%	1.3%	4.8%
Nigeria	90.4	90.2	85.4	95.1	0.5	0,52	65	37	106	301	25	453	0.6%	0.0%	1.5%
Rwanda	0.9	0.9	0.8	1.1	0.1	0,51	785	34	1 494	19 871	116	40 489	12.2%	0.2%	22.1%
Sao Tome and Principe	0.1	0.1	0.1	0.2	0.8	0,58									
Senegal	8.1	7.9	7.0	9.7	0.6	0,50	372	14	783	10 924	1 316	32 902	6.7%	0.6%	20.3%
Seychelles	1.0	0.9	0.9	1.1	10.5	0,79	26	21	29	619	168	1 093	0.1%	0.0%	0.1%
Sierra Leone	1.1	1.1	0.7	1.3	0.2	0,42									
South Africa	468.8	470.2	445.8	484.2	8.7	0,69	121	73	173	162	90	206	0.0%	0.0%	0.1%
South Sudan						0,43									
Sudan	18.1	17.3	16.0	21.1	0.5	0,49	95	19	225	215	0	405	0.1%	0.0%	0.2%
Tanzania	11.4	11.4	7.1	14.7	0.2	0,51	1 11	423	1 823	25 457	730	46 998	30.8%	2.2%	51.9%
Togo	2.5	2.4	2.2	2.8	0.3	0,49	349	21	834	4 864	30	13 558	8.2%	0.0%	20.7%
Uganda	4.5	4.5	3.7	5.0	0.1	0,51	756	102	1 089	31 657	1 752	83 617	35.8%	2.4%	71.0%
Zambia	3.8	4.0	2.2	5.0	0.2	0,56	568	13	1 443	1 111	87	4 764	0.6%	0.1%	2.1%

Descriptive statistics 2010-2018 by country for CO2_t (emissions in million tons), co2pc (emissions per capita), HDI, and variables for which our main hypothesis is not rejected and for which the turning points are within the sample range, as indicated in Table 2: RMMA (number of registered mobile money accounts per 1,000 adults), NMMT (number of mobile money transactions per 1,000 adults) and VMMT (value of mobile money transactions as % of GDP).

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Digital Finance, Development, and Climate Change

- Work in progress –

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What we do

- Test the role of : ….
  - Mobile money
  - Bitcoin

… on development, in Sub-Saharan African countries,

… through their impact on CO2 emissions

- It is important because …
  - Policy implications : picking the right tool among those available for financial development
  - If we show an impact, it follows that the ecological cost of means of payment (or savings instruments) has to be included in the policy makers' cost - advantage analysis

The main idea:

* "leapfrogging" the banking system (Aron, 2017)

* SS Africa could jump directly from cash to digital finance, without incurring the cost of installing a complete banking industry infrastructure: *positive* impact

Particularly interesting in Africa because mobile money has boomed in the 2010s

Contradictory effects of Digital Finance

The **positive** effects of Digital finance :

Comes from previous arguments (efficiency of payments, etc.)

But also through :

a disminished transportation cost of people and of cash,

the avoidance of building/maintaining a banking infrastructure

→ Thus Digital Finance can help reduce CO_2 emissions

The **negative** effects come from its own contribution to CO_2 emissions

Which effect is the strongest?

Mobile Money and development

- **Increases GDP growth & HDI:**

- Beck et al, 2015: theoretical model and test on Kenya: MM improves growth by ≈ 0.4 b.p

- Also, several works of Asongu et al (e.g., 2017): **ICT sector** overall positive impact on HDI

- **More efficient payments and more secure savings (Aron & Muelbauer, 2019)**

- **Better aid transfers**

- Thompson, 2017: MM avoid long chains of project actors, where aid incur high transaction costs and is susceptible to elite capture and corruption.

- Interhouseholds aid improved with mobile money following climatic events (Aker et al, 2016 in Kenya following droughts)

Bitcoin and development

- **Avoid distrust towards domestic currencies & provide an international means of payments**
- Ammous 2015, Nguyen 2016: survey of arguments for indicating better GDP growth prospects for developing countries:
- more efficient remittances transfers and aid distribution, [cf. Salvador, 2021]
- fosters international trade
- Permits international supralegal contracts
- **A negative impact through monetary policy?**
- **Correlation with GDP and HDI**
- Obviously, it is plausible that the correlation reflects inverse causality. Parino et al (2018) shows that the nb. of BTC client downloads is correlated with GDP (ρ = 0,63 to 0,71) and with HDI (ρ = 0,77 to 0,80)

Limits of Digital Finance w.r.t. development

- Limited by literacy and access to electricity (and of course to smartphone or computer devices)
  - Ex: only 33% literacy in Mali, 2017.
  - Electricity: 93% Gabon, 15% Burkina Faso
  - Mobile phone accounts: from 15% (Erytrea) to > 100% (Ghana)
- **Contribution to climate changes through CO2 emissions** in the world.
- Comparison :
- ICT : 6% tot. CO_2 2007 → 14% 2040 (Belkhir et al 2018)
- Per transaction (De Vries 2018 etc.):
  - VISA : 0,4 g CO_2, bank card : 3g
  - Cheque 15 g
  - 40€ of cash : 22 g
  - Bitcoin: 233 to 363 **kg**

DATA SET

- **yearly data 2010–2018, 46 countries, 414 observations**
- Dependent variable: Human Development Index (HDI), from UN.
- Mobile Money and Financial Services: IMF
- Bitcoin client download stats: Sourceforge
- CO_2: Edgar JRC (European Commission)
- All others: World Bank

COUNTRIES

Sub-Saharian African (SSA) countries

We deliberately restrict the study to SSA countries for two reasons.

- First, those countries are among those to *suffer the most from projected climate change* (Burke et al., 2015).
- Second, these countries are also the place where *digital finance is experiencing the sharpest increase* in the 2010s (Aron & Muellbauer, 2019)

VARIABLES

Digital Finance variables:

- ✓ Bitcoin clients download statistics.
- ✓ Mobile Money (Number of registered mobile money accounts /1000 adults, number of active mobile money accounts/1000 adults, value of mobile money transactions as % GDP, number of mobile money transactions/1000 adults)

CO2 emission variables:

- ✓ Fossil CO2 totals by country (in M tons), which include sources from fossil fuel use (combustion, flaring), industrial processes (cement, steel, chemicals, and urea) and product use,
- ✓ Variants: Fossil CO2 per 1000$ of GDP by country, CO2 from electricity and heat

Control variables

- ✓ Education quality,
- ✓ Foreign aid,
- ✓ Private domestic credit,
- ✓ Foreign direct investment.

MODEL

- Close to Asongu *et al.* (2017, 2019)
  - Assess whether Mobile Phone mitigates the impact of CO_2 on HDI
  - However, the sign of CO_2 variables is unstable
  - The results are mixed
- *Our paper differs in that*:
  - Our interest variable is Digital Finance
  - We study non-linear effect of CO_2 on HDI
  - Interact Digital Finance with the square term
  - Explicitly assess the p-value for marginal effects

HYPOTHESIS

- H1: **Bitcoin** helps mitigating the potentially negative impact of CO_2 emissions on development
- H2: **Mobile Money** helps mitigating the potentially negative impact of CO_2 emissions on development

- With country i and year t:

$$HDI_{it} = \beta_0 + \beta_1 DF_{it} + \beta_2 CO2_{it} + \beta_3 CO2_{it}^2 + \beta_4 (CO2_{it}^2 \times DF_{it}) + \sum_{c=1}^{C} \gamma_c W_{it} + \alpha_i + \varepsilon_{it}$$

- With W a set of control variables, α the country fixed-effect. Robust std. err., country-level cluster.
- We expect non-linearity for CO2 ($\beta_2 > 0$ and $\beta_3 < 0$), and expect β_4 to be significant.
- We **assess our results with the overall marginal effect** of CO2 on HDI:

$$\frac{\partial HDI}{\partial CO2} = \beta_2 + 2\beta_3 \overline{CO2} + 2\beta_4 \overline{CO2} \cdot \overline{DF}$$

- Do not reject H1 (H2) when this effect is significant and >0 <u>and</u> β_1 effect of BTC (MM) significant and >0
- Endogeneity: Hausman test
  - Instrumental Variable vs OLS Panel
  - If p>0.05 : OLS Panel is preferable

Preliminary tests results

	Reg.1	Reg.2	Reg.3	Reg.4	Reg.5	Reg.6
VARIABLES	HDI	HDI	HDI	HDI	HDI	HDI
CO2_t	0.008***	0.008***	0.006***	0.009***	0.004***	0.005**
	[0,001]	[0,002]	[0,001]	[0,001]	[0,001]	[0,002]
c.CO2_t#c.CO2_t	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***	-0.000**
	[0,000]	[0,000]	[0,000]	[0,000]	[0,000]	[0,000]
aid		-0.001***		-0.001***		0.001
		[0,000]		[0,000]		[0,001]
credit		-0.000		-0.000		0.002**
		[0,000]		[0,000]		[0,001]
edu		-0.001*		-0.001**		0.000
		[0.001]		[0,000]		[0,000]
fdi		-0.000		-0.000		-0.000
		[0,000]		[0,000]		[0,000]
cumulBTC			0.000**	-0.000*		
			[0,000]	[0,000]		
c.cumulBTC#c.CO2_t#c.CO2_t			-0.000	0.000**		
			[0,000]	[0,000]		
NRMMA (Number of Registered Mobile Money Transactions per 1000 adults					0.000***	0.000***
					[0,000]	[0,000]
c.NRMMA#c.CO2_t#c.CO2_t					0.000***	0.000***
					[0,000]	[0,000]
Constant	0.422***	0.471***	0.437***	0.472***	0.462***	0.406***
	[0,016]	[0,027]	[0,015]	[0,026]	[0,016]	[-0.044]
Observations	352	237	352	237	188	134
R-squared	0.307	0.474	0.364	0.488	0.667	0.701
Number of cnum	44	42	44	42	35	29
Country Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
CO2 marginal effect (at means)	0.00736***	0.00819***	Na	0.00912***	0.0036***	0.00441**
Margin st. err.	0.00125	0.00151		0.0014	0.00111	0.00187
Margin p-value	3.66e-09	5.61e-08		6.92e-11	0.00121	[0,0186]
Hausman endog. test chi2	6.209	7.370	5.501	7.880	1.034	4.482
P-value	0.0449	0.195	0.139	0.247	0.793	0.612
Robust standard errors in parentheses	*** p<0.01, ** p<0.05, * p<0.1					

	Reg.7	Reg.8	Reg.9	Reg.10	Reg.11	Reg.12
VARIABLES	HDI	HDI	HDI	HDI	HDI	HDI
CO2_t	0.009***	0.008***	0.006**	0.007**	0.007**	0.009***
	[0.003]	[0.002]	[0,002]	[0,003]	[0,003]	[0,003]
c.CO2_t#c.CO2_t	-0.000**	-0.000	-0.000**	-0.000**	-0.000***	-0.000***
	[0,000]	[0,000]	[0,000]	[0,000]	[0,000]	[0,000]
Aid		0.000		0.001		-0.000
		[0.001]		[0.001]		[0.001]
Credit		0.003***		0.002**		0.001
		[0,001]		[0,001]		[0,001]
Edu		-0.000		0.000		0.000
		[0.000]		[0.000]		[0.000]
Fdi		0.000		0.000		-0.000
		[0.000]		[0,000]		[0,000]
NAMMA(Number of Active Mobile Money Transactions per 1000 adults)	0.000***	0.000				
	[0,000]	[0,000]				
c.NAMMA#c.CO2_t#c.CO2_t	-0.000***	-0.000**				
	[0,000]	[0,000]				
NMMT(Number of Mobile Money Transactions per 1000 adults)			0.000***	0.000***		
			[0,000]	[0,000]		
c.NMMT#c.CO2_t#c.CO2_t			-0.000*	-0.000**		
			[0,000]	[0,000]		
VMMT(Value of Mobile Money Transactions - % of GDP)					0.001***	0.000***
					[0,000]	[0,000]
c.VMMT#c.CO2_t#c.CO2_t					-0.000	-0.000***
					[0,000]	[0,000]
Constant	0.387***	0.321***	0.438***	0.369***	0.416***	0.382***
	[0,032]	[0,051]	[0,032]	[0,051]	[0,041]	[0,048]
Observations	134	97	165	114	168	119
R-squared	0.613	0.673	0.534	0.644	0.496	0.589
Number of cnum	28	23	32	28	33	28
Country Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
CO2 marginal effect (at means)	0.00857***	Na	0.00510***	0.00608***	Na	0.00771***
Margin st. err.	0.00257		0.00197	0.00233		0.00259
Margin p-value	0.000845		0.00973	0.00902		0.00287
Hausman endog. test chi2	2.664	12.95	0.154	11.01	0.159	10.14
P-value	0.446	0.0734	0.926	0.0512	0.984	0.119
Robust standard errors in parentheses	*** p<0.01, ** p<0.05, * p<0.1					

Turning Points Analysis

Table 1 regression number	(1)	(2)	(3)	(4)	(5)	(6)
Digital finance variable	**No**	**No**	**CumulBTC**	**CumulBTC**	**NRMMA**	**NRMMA**
CO2 turning point	527	521.4	477.1	455.8	458.4	462
Whithin sample range	No	No	Yes	Yes	Yes	Yes
Control variables	No	Yes	No	Yes	No	Yes
Observations	352	237	352	237	188	134
Number of countries	44	42	44	42	35	29
Table 1 regression number	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**
Digital finance variable	**NAMMA**	**NAMMA**	**NMMT**	**NMMT**	**VMMT**	**VMMT**
CO2 turning point	599.1	646.4	146.7	115.3	130.4	124.5
Whithin sample range	No	No	Yes	Yes	Yes	Yes
Control variables	No	Yes	No	Yes	No	Yes
Observations	134	97	165	114	168	119
Number of countries	28	23	32	28	33	28

Results

- We show a non-linear impact of CO_2 on HDI, with turning points mostly within observed range
- ***We reject H1***: Bitcoin helps mitigating the potentially negative impact of CO_2 emission on development.
  - Because, Bitcoin's direct effect is negative, and its contribution in mitigating the negative impact of CO_2 emission is very low.
- ***We do not reject H2***: Mobile money helps mitigating the potentially negative impact of CO_2 emission on development.
- Robust to:
  - 1 lag RHS variables ;
  - other CO_2 variable ;
  - other computations for margins

Discussion

- Need to better take into account the fact that BTC is an externality for SSA countries (low countries contributions)
- Concerning mobile money, the scarcity of some metals used in mobile or smartphones production should also be taken into account – though this aspect is beyond the scope of this article.

Many thanks for your attention