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Addressing climate change data needs: the central banks' contribution

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Addressing climate change data needs: the global debate and central banks' contribution

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Addressing climate change data needs: the global debate and central banks’ contribution

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Executive summary

Improving climate risk data has become a universally acknowledged imperative. This priority is shared by central banks, which in recent years have been actively exploring ways to enhance their policymaking frameworks to better address the impact of climate change. The focus has been on assessing the broad spectrum of data-related issues and developing adequate solutions.

While important initiatives are under way at both national and international levels to identify and address climate risk-related information needs, **significant challenges remain in terms of data availability, reliability and comparability.** Data gaps are particularly pronounced for forward-looking indicators of physical climate risks, as well as for the assessment of progress associated with net zero transition policies.

Moreover, **the climate risk landscape is constantly evolving**, indicating that environmental impacts will materialise gradually over time and may follow non-linear patterns. Climate risk outcomes will depend on the development of both physical risks (such as increased flooding and heatwaves) and transition risks (such as bank exposures to carbon-intensive sectors). These outcomes will be influenced by evolving national priorities, which will, in turn, significantly affect policies and progress.

The identified data-related challenges call for **ambitious statistical strategies to successfully bridge existing data gaps.** While information should be available at different aggregation levels to reflect the variety of stakeholder needs, specific attention has to be given to developing global climate metrics that are essential for rigorous impact and policy evaluation. Ideally, such metrics should be publicly

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available, reliable, comprehensive and comparable. Furthermore, the importance of exchanging national experiences in addressing a truly universal issue like climate change cannot be overstated. This serves as a reminder that global progress cannot be achieved without active and close cooperation between critical national and international stakeholders.

Central banks have already taken many steps to address climate data issues, leveraging their unique perspective as both producers of official statistics and users of robust and trustworthy evidence in fulfilling their public mandates. A driving factor is that climate change is expected to gradually affect their core policies, especially in the areas of monetary and financial stability, as well as their roles as asset and reserve managers and supervisors of payment systems. In particular, climate change may affect inflation by disrupting supply chains, reducing output in key sectors such as agriculture and increasing overall production costs. Additionally, both transition and physical risks could pose significant challenges to the pursuit of central banks' financial stability mandates. Climate risk is also a crucial consideration for central banks tasked with the microprudential supervision of financial institutions, potentially necessitating a revision of regulatory frameworks to ensure that vulnerabilities in the financial system are properly identified, monitored and mitigated. Lastly, a growing number of central banks are taking specific policy actions to support the development of green finance as a means of mitigating the impact of climate change.

Looking ahead, and reflecting their important roles in today's economies, **central banks can be instrumental in spurring global efforts to overcome climate data gaps.** They are well placed to take stock and make sense of the growing related data available from different sources and in various formats. They can also more actively contribute to the compilation of necessary analytical indicators, particularly in the context of their oversight role of the financial system. Additionally, central banks have been actively fostering coordinated data work on climate risk within national data ecosystems, especially in collaboration with their counterparts in national statistical offices.

In addition, **a key part of central banks' efforts to close climate risk-related data gaps will continue under the umbrella of international initiatives**, employing a multifaceted approach. A first objective is to finalise data compilation exercises organised globally, particularly in the context of the G20 Data Gaps Initiative (DGI). A second focus is to develop common methodologies and experimental indicators, including forward-looking ones, by promoting harmonised statistical frameworks and practices. Third, enhanced information-sharing (including data, frameworks and methodologies) is essential for accurately assessing the environmental footprint of economic activities in today's globalised world. Lastly, technological innovation offers promising solutions to overcome climate-related data gaps, and central banks have been playing an active role in utilising new data sources and tools in this endeavour.

1. Introduction

There is widespread recognition of the need to facilitate the exchange of experience between the various stakeholders involved and the general public on **the challenges**

and prospective solutions that can enhance climate resilience strategies, with a primary focus on bridging existing and large information gaps.

In this context, **improving climate risk data** – and data on a wider range of environmental, social and governance (ESG) topics more generally – has become a universally acknowledged imperative. This priority is shared by central banks which, in recent years, have actively considered ways to enhance their policymaking frameworks to better tackle the impact of climate change, identify a broader spectrum of data-related challenges and develop potential remedies in close coordination with all involved stakeholders (IFC (2022)).

Indeed, **important ongoing initiatives, both at the national and international levels, are contributing to identify and address climate risk-related data needs**. These initiatives focus, in particular, on better measuring the climate impact of economic activities, monitoring the contribution of climate finance and government expenditure to mitigate climate change, and developing forward-looking physical and transition risk indicators.

Yet **key data challenges remain**, not least because the climate risk landscape and national priorities are constantly evolving. First, this calls for clear and **ambitious statistical strategies for successfully bridging existing information gaps** – by developing adequate methodological concepts and technical solutions, identifying the most relevant indicators, developing international collaborations to concretely make progress on data collections and ensuring that policy actions can effectively benefit from the information revealed by these data.

Second, **the exchange of national experiences is essential for tackling a truly global issue like climate change**. For its part, the central banking community has worked to identify best practices in adopting climate risk resilience and data initiatives, integrating internationally recognised methodological concepts, extracting insights from the information collected and developing adequate, evidence-based policy actions.

Lastly, **global progress cannot be achieved without active cooperation between critical national and international stakeholders** – especially multilateral institutions, central banks, financial regulators, finance ministries, statistical offices, academia and the private sector – in their efforts to address climate risk data issues and adopt broader climate risk strategies. Such cooperation can, in particular, be very effective to better leverage innovation collectively so as to benefit from the growing availability of innovative data sources and artificial intelligence (AI) techniques.

It is in this context that the Irving Fisher Committee on Central Bank Statistics (IFC) of the Bank for International Settlements (BIS) organised a dedicated workshop on "Addressing climate change data needs: the global debate and central banks' contribution" with the Central Bank of the Republic of Türkiye, the Bank of France and Deutsche Bundesbank in May 2024.[2]

This overview aims to shed light on the various issues highlighted above, benefiting from the **unique perspective of central banks as both producers of reference official statistics and users of robust and trustworthy evidence to**

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[2] The workshop built upon previous IFC work in this area (IFC (2021)).

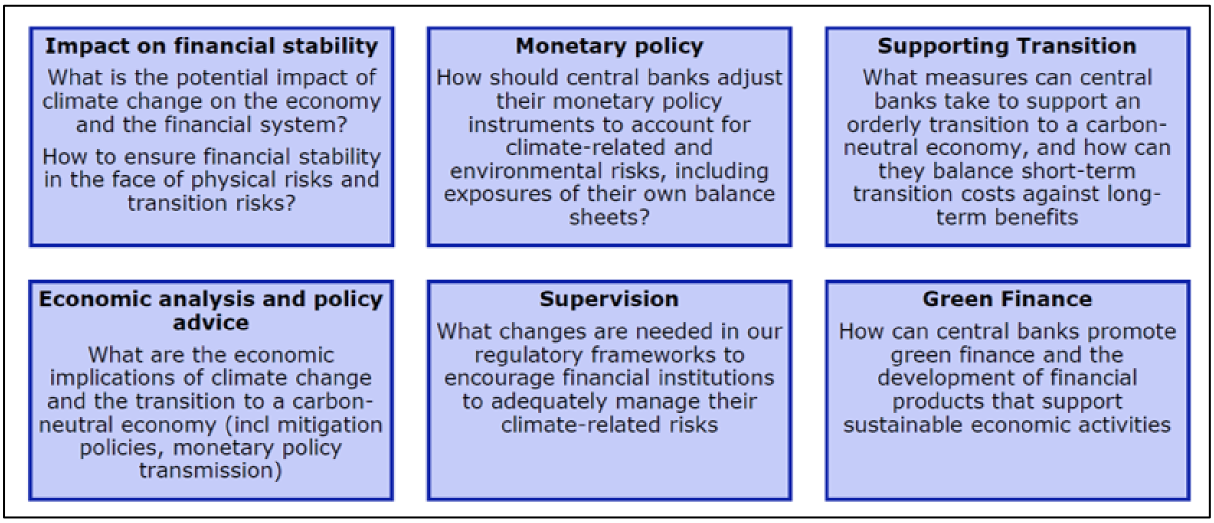
support their policies. It starts with a discussion of why central banks need climate risk-related data (Section 2) and a review of the most pressing information gaps (Section 3). It then analyses the various possible contributions of central banks in supporting national strategies for overcoming climate risk data gaps (Section 4) and takes stock of the main international initiatives pursued in this context (Section 5). Finally, looking forward, it provides a brief overview of the possibilities offered by new data sources and innovative techniques (Section 6).

2. Why do central banks need climate risk-related data?

Central banks around the world are increasingly recognising the need for robust evidence to assess climate-related risks in pursuing their public mandates (Tamez et al (2024)). The reason is that climate change is expected to gradually affect their core policies, especially in the areas of monetary and financial stability, in addition to their activities as asset and reserve managers. Climate risk is also an important factor to consider for those central banks tasked with the microprudential supervision of financial institutions such as commercial banks or insurance companies (Dafermos (2021)). Lastly, a growing number of central banks are taking specific policy actions to support the development of green finance as a means of mitigating the impact of climate change (Graph 1).

Central banks' activities related to climate change

Graph 1



Impact on financial stability
What is the potential impact of climate change on the economy and the financial system?
How to ensure financial stability in the face of physical risks and transition risks?

Monetary policy
How should central banks adjust their monetary policy instruments to account for climate-related and environmental risks, including exposures of their own balance sheets?

Supporting Transition
What measures can central banks take to support an orderly transition to a carbon-neutral economy, and how can they balance short-term transition costs against long-term benefits

Economic analysis and policy advice
What are the economic implications of climate change and the transition to a carbon-neutral economy (incl mitigation policies, monetary policy transmission)

Supervision
What changes are needed in our regulatory frameworks to encourage financial institutions to adequately manage their climate-related risks

Green Finance
How can central banks promote green finance and the development of financial products that support sustainable economic activities

Source: Fortanier (2025).

Climate risk and monetary policy

Climate risk can have significant implications for monetary policy, particularly reflecting the expected impact of supply-side disruptions and (structural) changes in economic activity on inflation. Extreme weather events such as droughts, hurricanes, flooding and wildfires can reduce agricultural output, disrupt supply chains or damage infrastructure, leading to **higher costs** for the production of various goods and services, **at least on a transitory basis** (Box A and NGFS (2021)).

Box A

Economic implications of climate risk

Climate change poses the risk of large economic shocks, potentially affecting nearly every sector. In particular, extreme weather events, rising sea levels and shifts in climate patterns may have adverse effects on physical infrastructure and on the production of specific goods, in turn undermining economic performance. While costly mitigation measures could provide some relief and protect economic agents from excessive losses (though their insurability conditions may worsen), businesses may face an increase in their ongoing operational costs. They would also have to deal with a higher degree of uncertainty, associated for instance with potentially disrupted supply chains in specific sectors and more volatile market conditions generally. Governments may also have to spend more on both prevention and disaster response, putting further pressures on public resources. Lastly, climate change could also amplify credit risk, as extreme weather events and long-term climate shifts would impair borrowers' ability to repay loans, especially in vulnerable industries/geographical areas, in turn giving rise to potentially large financial stability issues.

Specific segments of the economy, such as agriculture, are likely to be markedly affected by climate change. For instance, recent estimates suggest that the impact of climate change on wheat production in Türkiye could be quite large, as it will suffer from evolving rainfall patterns and extreme temperatures. For example, excessive heat and drought, especially during the spring and summer months, may significantly reduce crop yields and food security in the short, medium and long term. The extent of their impact will depend on the climate scenario and time horizon, with possible important underlying non-linearities. Timely and detailed climate data, such as temperature and precipitation trends, will therefore be essential for carefully monitoring the consequences of climate change on agriculture.

Moreover, the economic and financial systems are highly interconnected, making any assessment and mitigation of climate change a complex task. For example, a recent analysis of Poland's banking portfolios shows that the share of credit exposure to greener sectors has risen slightly over time, with a parallel fall in "dirty" exposures. At the same time, banks' exposure to environmental, social and governance (ESG) transition risks has remained substantial, and an important share of climate-sensitive loans could raise operating costs for banks, reduce asset values and worsen borrowers' creditworthiness. These findings, which are consistent with studies about other countries, matter not only at the level of the individual financial institutions involved, which have to manage their climate-related exposures and refine their business strategies accordingly, but also from a more macro-financial stability perspective.

Another important factor to consider is the impact of policy responses to climate risk. In the European Union, for instance, one critical development has been setting up the Carbon Border Adjustment Mechanism (CBAM), which will impose tariffs on carbon-intensive imports by 2026. This mechanism could raise production costs and disrupt global trade patterns, leading to new challenges in specific sectors/areas.

The above examples suggest that climate risk may extend far beyond environmental concerns into economic realities, posing deep challenges in terms of development as well as financial and monetary stability. National policy responses will also matter greatly, including through their global repercussions. In any case, access to comprehensive climate-related data will be essential for identifying the risks involved, assessing potential macroeconomic impacts and guiding policy responses.

At the same time, **the shift to a low-carbon economy could also be associated with more lasting shifts in price levels over the coming decades**, driven by factors such as a marked rise in carbon pricing, substantial public infrastructure investment, including the development of new energy sources, and the introduction of new regulations. These factors may put persistent upward pressures on production costs, particularly in carbon-intensive industries, and thus on consumer inflation. Hence, climate change may be a relevant factor challenging central banks' ability to maintain price stability in the longer run.

Moreover, climate risk introduces uncertainty that complicates decision-making. Should inflationary pressures from climate-related disruptions become more frequent, central banks may need to adjust their policy frameworks, for instance to better take into account the impact of supply side shocks in addition to the more traditional focus on demand side factors (Ehlers et al (2025)). Furthermore, climate considerations may need to be integrated into inflation-targeting frameworks, not least to properly address potential short-term inflationary shocks due to changes in price levels caused by structural adjustments in the economy (Bolton et al (2020)). And climate risk may also influence the design of central banks' monetary policy operations, for instance as regards their asset purchase programmes and collateral frameworks, as suggested by the experience of the European Central Bank (ECB (2023)).

All in all, the evolving impact of climate change on inflationary prospects may call for a fundamental review of central banks' tools and objectives to maintain monetary stability. Inaction could raise the risk of prolonged periods of price volatility, challenging central banks' credibility and effectiveness in achieving their public mandates (NGFS (2021)).

Climate risk and financial stability

Climate risk may also pose significant challenges to the pursuit of central banks' financial stability mandates (eg Campiglio et al (2018)). Specifically, physical risk events[3] – such as extreme weather conditions – can lead to asset devaluations, insurance losses and borrower defaults, particularly in those sectors highly exposed to climate change, such as real estate, infrastructure and agriculture. For instance, rising sea levels and flooding may reduce the value of properties in vulnerable areas, increasing credit risks for banks that own related specific assets or are indirectly exposed to corresponding loans. Meanwhile, transition risks – eg those stemming from shifts in government policies, technological advancements or changing consumer preferences – could lead to a rise in stranded assets, particularly in fossil fuel-intensive industries. The reason is that companies with high carbon footprints may suffer from unanticipated or premature write-downs, lowering equity valuations as investors reallocate capital towards greener alternatives, in turn raising potential instability in financial markets (Bolton et al (2020)).

To address these risks, central banks as well as other financial authorities are **increasingly incorporating climate risk analysis into their financial stability frameworks, with both a macroprudential and microprudential perspective.** At the macro level, they are developing scenario analyses for assessing the resilience of the overall financial system in the face of possible climate-related shocks. At the micro level, they are monitoring and identifying the vulnerabilities of individual banks or insurers under different climate scenarios. The aim is to better understand potential pressure points in the financial system and take proactive supervisory measures to

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[3] The consideration of physical risks by central banks has been discussed by Raga et al (2024), for example.

mitigate solvency risks when deemed appropriate (see ECB (2023) and Board of Governors of the Federal Reserve System (2024)).[4] Insights gained on the implications of climate change at the macro and micro levels may call for a careful review of the existing macroprudential and microprudential frameworks. Additionally, climate-related disclosure requirements for market participants would need to be refined further to enhance the quantity and quality of information available to authorities, financial investors and other stakeholders.

Supporting the development of sustainable finance

A growing number of central banks are taking specific actions to support the development of sustainable finance and, as an essential step, the availability of related data. The reason is that tracking financial investments in more environmentally friendly activities can be essential in assisting private and public agents to take informed decisions and make progress in achieving internationally agreed environmental commitments. In this context, attention is being placed on the promotion of green finance, with the aim of increasing the use of dedicated financial instruments (green bonds, equities and investment funds) to support sustainable development priorities.

While green finance is still not well captured in existing macroeconomic statistical frameworks, important initiatives are under way. In particular, central banks in many jurisdictions have been making use of their large-scale security-by-security (SBS) databases to identify financial instruments such as green bonds and sustainability-linked bonds in a very granular way (IFC (2024b)). These databases make use of precise information both in the issuance and stock of **debt instruments**, which can be essential for policymakers to understand the scale, sources and direction of green financing. There is also increasing recognition of the need to better identify and measure **green equity**, at least with regard to listed corporate shares, and also to facilitate assessment of the environmental impact of the global supply chain, especially through **foreign direct investment** (FDI) (Box B).

Important work is under way to develop a more standardised methodology for compiling statistics on green finance. At the European level, the ECB has set up a framework to measure green equity securities using two keys SBS databases, namely the Centralised Securities Database (CSDB) and the Securities Holdings Statistics Database (SHSDB). The approach relies on the identification of granular securities through attributes such as issue dates, security status and type of climate finance debt instrument, following the methodological guidance provided in the context of the System of National Accounts (SNA).[5] It shows that the outstanding

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[4] Several other central banks, including the Bank of England, have undertaken financial stability analyses that integrate climate risk considerations.

[5] As reflected in the Handbook on Securities Statistics (HSS), with due consideration for the new methodological advancements developed in the 2025 revision of the international statistical standards. In addition, the approach has taken into account various initiatives – eg Climate Bonds Initiative (CBI) Climate Bonds Standards, International Capital Market Association (ICMA) Green Bond Principles, ICMA Social Bond Principles, ICMA Sustainability-linked Bond Principles, ICMA Sustainability Bond Guidelines or the European Green Bond Standard. The main objective is to identify the following characteristics: issuer sector, currency of denomination, maturity, interest rate type, type of climate finance security, assurance level and climate bonds standard.

amount of green securities in the euro area has nearly tripled in the past few years (Graph 2, left-hand panel).[6] The data also reveal a high degree of reliance on independent evaluations of the data reported ("external assurance"), with about 90% of these securities benefiting from second-party certification (Graph 2, right-hand panel).

Box B

Measuring FDI's carbon footprint

Climate risk-related data are usually analysed on the basis of the economic units that are located in specific jurisdictions, not least because they are used for supporting policy decisions taken by national authorities. Yet, **such a "residency-based" approach may be too restrictive to assess climate risk which, by definition, has a global dimension**. In particular, the climate data disclosed by corporate groups in their financial statements are provided on a "nationality basis" that typically spans across national borders, not least because of the foreign activities that take place outside the jurisdictions of the controlling parents (Tissot (2016)).

In this context, **increased attention is being put on assessing the impact of the global value chain and in particular on the role of foreign direct investment (FDI) on climate-related issues** (Duan and Jiang (2021)). On the one hand, FDI can help to reduce greenhouse gas (GHG) emissions by facilitating the transfer of greener technologies ("pollution halo hypothesis"). On the other hand, FDI can also lead to the use of pollution-intensive technologies in countries with lower environmental standards, increasing carbon emissions ("pollution haven hypothesis").

Addressing these issues **calls for adequately measuring FDI's carbon footprint**, but this is challenging and mostly done at the aggregate level in practice. For instance, work undertaken in the context of the third phase of the G20 Data Gaps Initiative (DGI-3) has underscored interest in using macro-level data (eg on gross fixed capital formation) and multi-regional input-output tables to split aggregate carbon emissions by FDI breakdowns.

But **more granular methods can be promising alternatives to aggregate approaches**. For example, a measurement of both inward and outward FDI carbon footprints has been conducted for France using granular data on listed companies' GHG emissions (collected from commercial data providers) combined with a financial data set from the Bank of France and direct investment enterprises data from the French National Institute of Statistics and Economic Studies (INSEE) and the European Central Bank. GHG data for the other, unlisted companies were inferred from their parent groups' characteristics. The study found that the carbon footprint of inward FDI is lower compared with outward FDI, likely due to France's strong reliance on low-carbon nuclear energy.

Substantial conceptual work remains to be done to tackle existing data limitations. These include inconsistencies in GHG emissions disclosed in corporate reports, the lack of carbon efficiency data for many countries, especially in developing regions, and the limited information available on the foreign affiliated entities of global groups. Addressing these issues calls, in particular, for improved international coordination in developing and validating the necessary methodologies and models.

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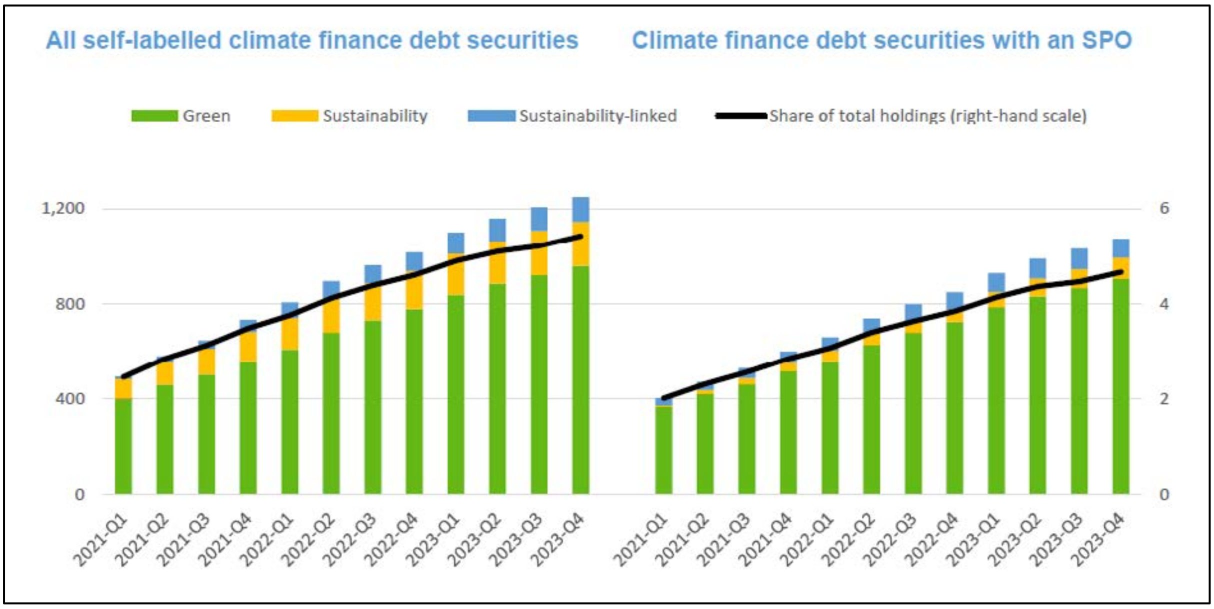
[6] The global issuance of climate finance debt securities has surged to over USD 500 billion annually over the past decade (IMF (2024)).

Euro area holdings of climate finance debt securities Graph 2



Left-hand scale (for all bars, in both the left- and right-hand panels): EUR billions, outstanding amounts at face value; right-hand scale: share of climate finance debt securities with a second party opinion (SPO) in all debt securities held in the euro area, in per cent (black line).

Holdings refer to all (ie self-labelled) climate finance debt securities (left-hand panel) and to those with an SPO (right-hand panel).

Source: Fusero et al (2025).

3. Climate risk data gaps

Data availability, reliability and comparability issues

Dealing with climate-related risks calls for having adequate information available at different aggregation levels, reflecting the variety of use cases at stake. At the micro level, financial and non-financial companies are asked to compile and disclose specific climate-related reports to meet evolving reporting standards or regulations, including for supervisory stress tests (Mohan (2024)). Such granular insights can also be used to support the measurement of the carbon content of economic output by sectors, a key element for monitoring the implementation of national climate objectives, such as those outlined in the Paris Agreement (IFC (2024a)). And, at the global level, there is an urgent need for more common, comprehensive and publicly available reference data for aggregate country emissions (eg OECD (2024)).

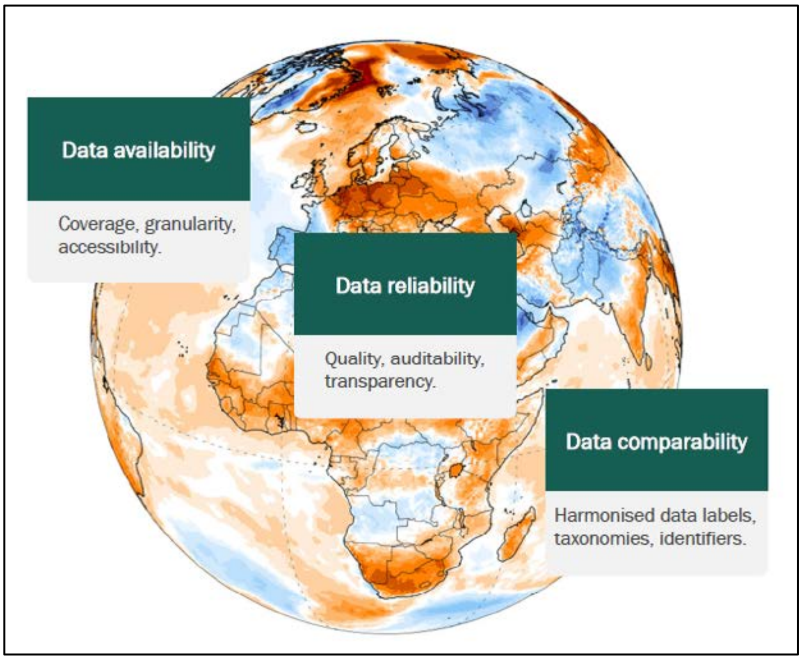
Irrespective of the granular or aggregate levels considered, **three main challenges** are faced in addressing the various stakeholders' climate-related data needs (Graph 3). These challenges relate to:

- **data availability**;
- **data reliability**; and

- **data comparability**.

These three challenges are particularly pronounced for forward-looking indicators of physical climate risks as well as for assessing the risks and opportunities associated with net zero transition policies (NGFS (2022)).

Addressing climate-related information needs – main data challenges Graph 3



Source: Izmir workshop on "Addressing climate change data needs: the global debate and central banks' contribution".

First, as regards data availability issues, there are significant gaps related to non-listed financial instruments and, more generally, for assessing risks in emerging markets and developing economies. While adequate climate-related financial analyses require detailed, entity-level or asset-level insights, actual data collections often focus on listed instruments (equities and bonds), ie information that is readily available in the public domain. At the same time, other key asset classes, such as loans and private equity, are often blind spots. Moreover, even for well covered financial instruments, such as listed corporate debt securities, climate-relevant data collection is geographically uneven, with far greater availability for Europe and North America compared with the Asia-Pacific and Latin America regions, and even more so with Africa.

Addressing these availability gaps calls for enhanced corporate disclosure requirements and capacity-building efforts. There are already (quasi-) mandatory firm-level disclosure initiatives by the International Sustainability Standards Board (ISSB) at the global level, with additional complements across jurisdictions, for instance the Corporate Sustainability Reporting Directive (CSRD) in the European Union. Additionally, simplified disclosure requirements have been developed in various places to facilitate data collections from small and medium-sized enterprises (SMEs) (ADB (2025)). Specific actions have also been taken to strengthen climate-related disclosure at the firm level, for instance in the context of the Corporate Climate Governance (CCG) Facility of the European Bank for Reconstruction and Development

(Haralampieva and Chawla (2024)). In this context, emerging data sources and technologies, such as geospatial data and AI/machine learning-assisted analytics, will likely play an increasingly important role to help bridge climate-related disclosure gaps. For example, satellite data are already being used to support the monitoring of methane emission reductions and assess physical climate risks at the asset level (see Section 6).

A second key challenge relates to the reliability of climate-related data, which is essential for supporting meaningful policy action, including by correctly identifying aggregate risks and preventing the provision of misleading information to investors (ie greenwashing). From this perspective, metadata transparency and the credibility of underlying methodologies are crucial, yet often lacking. For example, the quality of data on carbon offset markets[7] is notoriously weak, not least because the necessary methodological concepts are still being developed, implying that companies' climate offset pledges often lack transparent metrics and targets. This calls for providing clear guidance, standards and certification to ensure the reliability of related data and analyses.

Third, comparing climate-related data across jurisdictions, sectors and entities can be challenging due to different assumptions and design choices. A primary example is the reconciliation of climate ratings across various data providers, as they tend to adopt different methodological approaches when scoring the degree of sustainability of financial instruments. For example, Graph 4 displays the climate alignment ratings for eight selected corporates, illustrating that such evaluations vary widely. These differences can stem from different choices in the metrics considered themselves (eg absolute vs intensity-based emissions), the time focus (short or long term) and the emissions coverage (eg scopes 1, 2 and 3),[8] all of which can significantly influence the resulting assessments (Noels and Jachnik (2022)). Ensuring transparency regarding these factors is essential to support "apple-to-apple" comparisons. At the same time, further work should be pursued by the international community to converge towards interoperable taxonomies and sustainability disclosure standards as a key foundation for enhancing the comparability of the underlying data.

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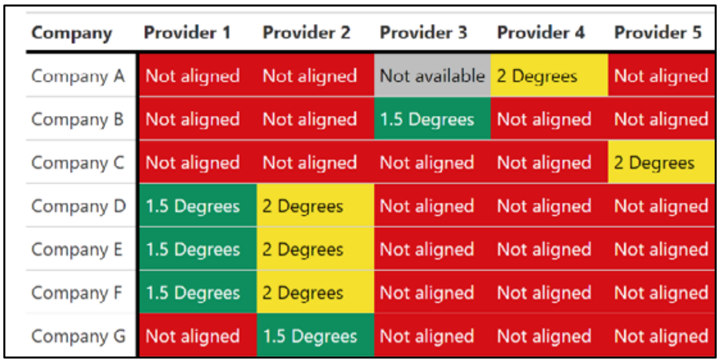
[7] Carbon credits, also known as carbon offsets, are permits that allow the owner to emit a certain amount of carbon dioxide or other greenhouse gases. See Advisory Expert Group on National Accounts (2022) for planned enhancements to the recording of emission trading schemes in the SNA.

[8] For a description of these concepts, see Box B in IFC (2024a).

Climate ratings vary widely across rating providers

Graph 4



Company	Provider 1	Provider 2	Provider 3	Provider 4	Provider 5
Company A	Not aligned	Not aligned	Not available	2 Degrees	Not aligned
Company B	Not aligned	Not aligned	1.5 Degrees	Not aligned	Not aligned
Company C	Not aligned	Not aligned	Not aligned	Not aligned	2 Degrees
Company D	1.5 Degrees	2 Degrees	Not aligned	Not aligned	Not aligned
Company E	1.5 Degrees	2 Degrees	Not aligned	Not aligned	Not aligned
Company F	1.5 Degrees	2 Degrees	Not aligned	Not aligned	Not aligned
Company G	Not aligned	1.5 Degrees	Not aligned	Not aligned	Not aligned

The graph displays typical climate alignment ratings for eight listed corporates, illustrating that such evaluations can vary widely across rating providers. For example, provider 1 comes to a fairly favourably conclusion for companies D to F, suggesting alignment with a scenario of a global rise in temperatures by 1.5 degrees Celsius in 2050, but not for the other companies (assessed as "not aligned" with even a two-degree scenario). In addition, data gaps matter, as they impair the consistency or prevent the assignment of ratings (for instance here with provider 3 for company A).

Source: Noels and Jachnik (2025).

Measuring physical and transition risks: a long way to go

The measurement of physical risks is a case in point, illustrating the importance of climate risk-related data gaps. Ideally, physical risks should be measured at the asset level. However, such granular data do not exist in many places; and when they do exist, it is difficult to allocate assets to their ultimate owners. Certainly, some micro information is already collected to study specific types of climate-related risks at the local level (eg flooding risk or the impact of storms), sometimes through the use of innovative information sources or tools (Section 6). Yet a common feature across jurisdictions is the absence of precise data to support broader analyses covering different risk types across geographical areas. Because of these shortcomings, physical risk analyses tend to rely in practice on a mix of micro and aggregate data.

A second key information gap relates to transition risk analyses, reflecting both data availability and modelling challenges. Indeed, developing forward-looking climate transition risk metrics has proved to be a complex exercise, reflecting disparities in the information available on transition effects data as well as in the methodologies applied across regions and sectors (Félez de Torres et al (2025)). As a result, estimating the impact of transition risk for the financial industry is usually a key challenge for central banks and supervisors alike (Jung et al (2025)).

In addition to the above gaps, important challenges relate to the actual modelling and analysis of physical risks (Box C). These challenges are visible when one tries to assess the combined effect of physical and transition risk over extended periods of time, a key element for developing comprehensive climate risk scenario analyses – for example to simulate short- and long-term impacts for banks (Schmieder et al (2025)).

Box C

Analysing physical risks: the need to go granular

The analysis of physical risks is evolving rapidly, leading to new data requirements at the aggregate and more granular levels. For example, a recent multi-country study examined economic losses from floods and tropical cyclones under alternative scenarios, suggesting a significant increase in damage rates by 2050, particularly in small island nations and vulnerable regions such as the Caribbean, Southeast Asia and East Africa. This underscores the necessity of having robust forward-looking indicators to anticipate the physical impact of climate risk and inform policies accordingly.

In particular, sufficiently granular data are needed to avoid **relying on aggregate calibrations that can be misleading**. Indeed, a recent analysis shows that neglecting granular asset-level data in the case of Mexico can lead to a significant underestimation of portfolio losses and the mispricing of tail risks, in turn undermining investment and policy decisions.

Granular data are also helpful to **support the identification of financial transmission channels of physical risk**. For instance, a study conducted in France found that micro-level information was key to pinpointing the precise localisation of physical assets exposed to floods and differentiating consequences for their owners and those occupying them. Such precise insights can be particularly valuable for countries lacking the capacity to develop sophisticated climate simulation exercises independently.

4. The role of central banks in national strategies for overcoming climate risk data gaps

Reflecting their important roles in today's economies, central banks are well placed to take stock and make sense of the growing climate-related data already available from different sources and in various formats. However, closing existing information gaps may also call for a more active role on their part, not least in the context of their oversight of the financial system. Lastly, central banks have been actively fostering coordinated data work on climate risk within national data ecosystems.

Making sense of the available information

What should the role of central banks be in national strategies to close information gaps related to climate risk? **One option is to leverage the wide range of available data and alternative indicators**, especially those to which they are exposed in conducting their various activities, so as to be able to develop a comprehensive perspective. The underlying reasoning is that the different data inputs at hand have their own strengths and limitations and can thus provide complementary insights. For example, absolute emissions metrics are directly relevant for assessing national carbon reduction plans and the cumulative climate impact. In contrast, emissions intensity indicators are useful indicators for analysing reduction efforts. Other meaningful metrics can shed light on a range of issues, such as climate adaptation strategies, supply chain characteristics, the impact of investors' decisions or related shifts in the portfolio composition of financial assets. In particular, the gathering of even anecdotal information can provide useful inputs on forward-looking capacity and capital expenditure plans.

The above suggests that **authorities such as central banks have a key role to play to facilitate the gathering of all existing information and the identification of the core set of complementary metrics** needed to overcome climate information gaps. In addition, they can set the direction for future enhancements in the global statistical infrastructure, in particular by emphasising the need for more data standardisation, the development of forward-looking metrics that are crucially lacking and the strengthening of scenario analyses.

A more direct role for central banks?

Closing existing information gaps also calls for developing new, more suitable data collection exercises needed to manage climate-related risks and support the transition to a sustainable economy. Though this can require substantial resources and time, **central banks may play a useful role and provide the necessary impetus for developing a more solid data foundation** to support evidence-based policies for tackling climate risks.

In particular, experience shows that central bank statisticians have been able to directly contribute to closing data gaps at the national and international levels, including by leveraging new models and innovative technologies and relying on a wide range of information sources (Jahangir-Abdoelrahman and Tissot (2023)). Apart from such compilation efforts, the focus has also been on dissemination, as central banks have been developing dashboards and repositories to facilitate public access to climate data and share their findings with a broader audience. They have in addition worked on addressing existing obstacles in data access and sharing.

Besides, central banks have an important role to play in boosting conceptual advancements, including by establishing reference information (metadata) and developing adequate methodologies. For instance, the development of new imputation methods and the clarification of interpretations have paved the way for a more accurate assessment of climate-related financial indicators in certain places. Efforts have also been made to include carbon accounting in the value chain (IFC (2024a)) and to provide reporting agents with more guidance on related methodologies and tools (BCBS (2024)).

Reflecting the above, **various central bank initiatives have been under way to actively bridge climate-related data gaps**, including in many emerging market economies (Box D). For instance, Bank Indonesia is fostering the establishment of a comprehensive data repository on the volume and type of green financial instruments. Such information can be essential for monitoring progress in the development of sustainable finance in the country and also to support the introduction of green incentive supervisory tools (eg the increase in loan-to-value ratios for green mortgages and the lowering of required down payments for electric vehicle loans). Similarly, a project led at the Central Bank of Malaysia simulates flooding scenarios and urban heat island effects, both very relevant climate-related risks, while initiatives in Saudi Arabia include the development of metrics to measure the transition to a low-carbon economy, supported by satellite data. Turning to Angola, the central bank has gradually been incorporating ESG sustainability information into its policies and processes.

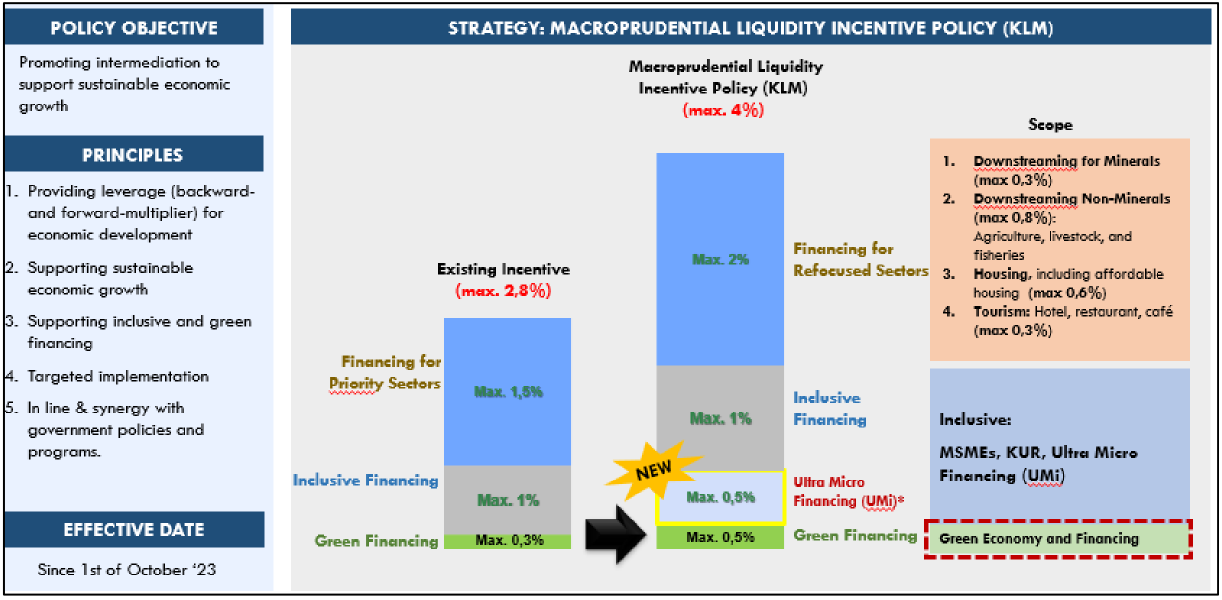
Box D

Central banks at the forefront of initiatives to close climate data gaps – an illustration

Many central banks throughout the world are leading national efforts to close climate data gaps, not least to support their policy decisions and spur sustainable finance. For instance, Bank Indonesia is collecting data on sustainable finance, including green mortgages, electric vehicle loans and sustainable bond holdings. A parallel project aims to identify green debt securities using novel methods (eg text mining, machine learning classification algorithms) and leveraging partnerships with data providers. In parallel, the Indonesian Financial Services Authority has initiated projects to report bank loans based on the Sustainable Finance Taxonomy and mandated banks to disclose scope 3 emissions. Authorities have also been focusing on the adoption of the Task Force on Climate-related Financial Disclosures (TCFD) framework and on expanding industry data partnerships to improve information transparency in sustainable finance. Lastly, better data will facilitate the monitoring of macroprudential liquidity policies that have been adjusted to accelerate sustainable financing and meet international climate agreements (Graph D1).

Climate data and national efforts to develop sustainable finance: the example of Indonesia's macroprudential liquidity policies

Graph D1



Source: Juhro et al (2025).

Malaysia, which is ranked fifth in the Asian region in terms of the economic impact of flooding, faces significant risks from rising temperatures and sea levels in the future. Projections suggest a significant increase in surface temperatures and a rise in sea levels of around 0.7 metres by 2100, impacting various sectors. In this context, the Central Bank of Malaysia launched a Joint Committee on Climate Change in 2022, co-chaired with the Securities Commission. A key project was the setting up of a platform integrating climate and environmental data within the existing financial sector information framework, allowing for the linking of flood scenarios and urban heat island effects to socio-economic risks.

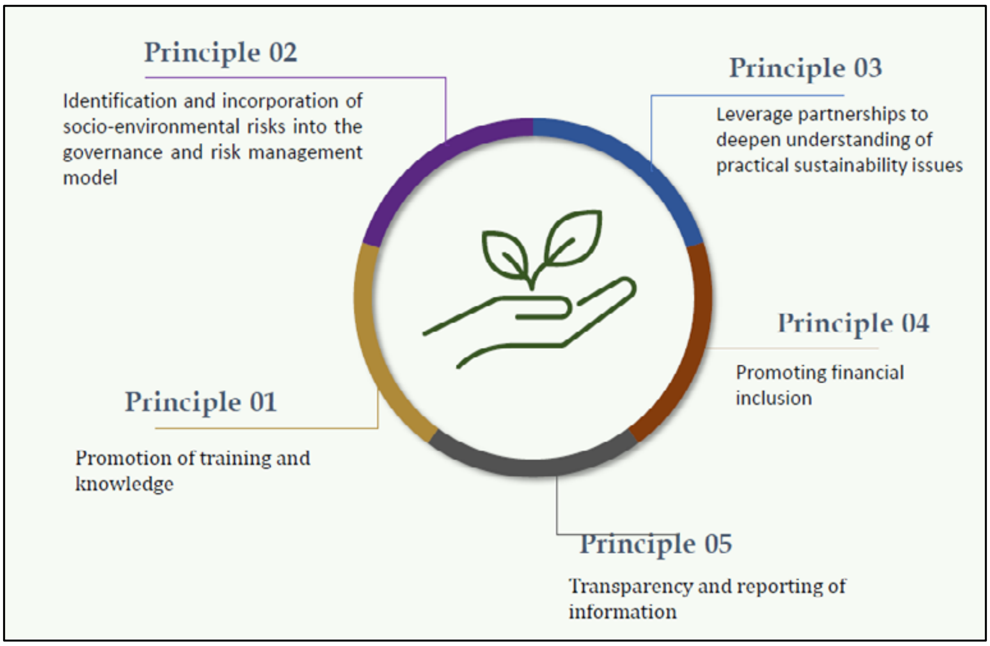
Turning to **the Arabian Peninsula**, the Gulf Cooperation Council (GCC) has developed a Circular Carbon Economy index to support its regional transition finance plan. This index helps policymakers assess and compare countries' performance and potential in achieving climate goals and is based on various indicators comparing oil and gas producers' progress in achieving the objective to *reduce, remove, recycle and reuse*. Other data initiatives include the use of satellite information for measuring greenhouse gas emissions.

A final example is related to the National Bank of **Angola**'s plan to incorporate the wide range of sustainability indicators into its policies and processes. Key challenges are related to capacity-building among internal staff, the creation of adequate databases and the conduct of climate stress tests to inform policies. The central bank also plays a key role in facilitating data cooperation between regulators, supervisors and market participants, and has established several principles in this context (Graph D2). A key driving factor was the recognition that the availability of relevant climate risk data is essential to support the following three main action points:

- The establishment of sustainability principles for the financial system in regulatory and supervisory policies, in line with international standards (eg Basel III, International Financial Reporting Standards (IFRS) and Financial Action Task Force (FATF) standards).
- The integration of climate risk into monetary and financial stability policies.
- The reduction of the central bank's carbon footprint and the incorporation of environmental, social and governance (ESG) factors in its operations.

Environmental, social and governance data for supporting the principles guiding the actions of the National Bank of Angola

Graph D2



Source: Monteiro (2025).

Supporting the data initiatives of other public stakeholders

Fortunately, central banks have been able to join forces to develop climate risk data with other relevant stakeholders in national data ecosystems. Various public administrations are important in this regard, reflecting the fact that a wide range of **government policies, including those on subsidies, research and development expenditures and technological incentives, can be mobilised to tackle the impact of climate change**. For example, authorities may support the production of relevant data underpinning national decarbonisation objectives in various ways, such as through fiscal incentives, regulatory disclosure requirements and the publication of climate-relevant information related to public spending.

In turn, the conduct of climate-related public policies can help to provide useful information for dealing with climate risk. For instance, a recent study shows that the implementation of national climate policies in various advanced and emerging economies has led to a better understanding of the complex relationships between fossil fuel subsidies, CO_2 emissions, the use of low-carbon technologies and the development of climate finance.[9] Central banks have a keen interest in supporting these initiatives that can contribute to the availability of better and more relevant data to address the consequences of climate change.

5. International initiatives to close climate risk data gaps

A key part of central banks' work to close climate risk-related data gaps has been undertaken under the umbrella of international initiatives. Those have been instrumental, in particular, for boosting the development of common methodologies and experimental indicators, including forward-looking ones.

Central banks' active involvement

Central banks have been actively supporting the global exchange of experiences to enhance statistical information related to climate risk, not least through the IFC, the Network for Greening the Financial System (NGFS), the various financial standard-setting bodies hosted by the BIS and the BIS Innovation Hub. For instance, the IFC has facilitated an exchange of experiences on the need for and availability of climate data to support central bank policies, while also contributing to arrangements set up to actually close the related data gaps, especially in the context of the G20 DGI (IFC (2022)). Turning to the NGFS, key initiatives include the development of climate data repositories and the establishment of benchmark scenarios. The various financial standard-setting bodies and the Financial Stability Board (FSB) have developed a regulatory and supervisory perspective to tackle climate risk, thereby helping to uncover data gaps and work on adequate methodologies and concepts to address them. Last but not least, important projects have been pursued by the BIS Innovation Hub to set up a number of state-of-the-art dashboards and innovative tools for collecting data and conducting climate risk analysis.

Apart from supporting these knowledge-sharing initiatives, **many central banks have also contributed directly to the various exercises initiated by international organisations in the area of climate risk statistics** (Graph 5). These exercises have been directed towards the creation of internationally harmonised statistical indicators for climate-related analysis, with the aim of providing a robust data foundation for more informed decision-making.

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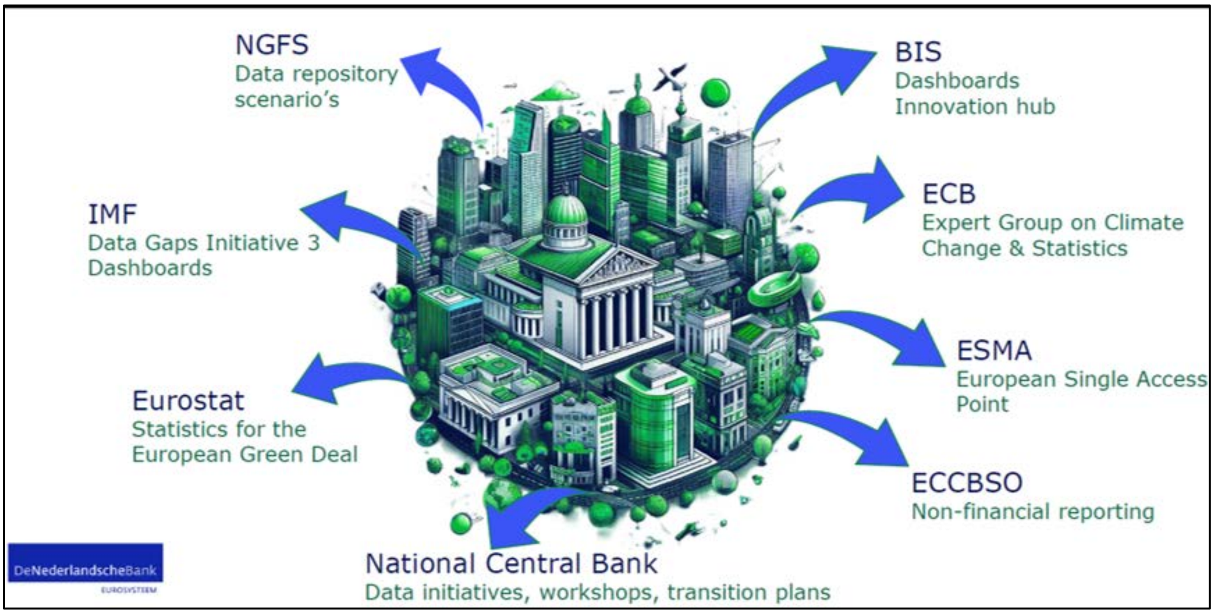
[9] The approach combined carbon intensity data (CO_2 emissions per GDP) to measure climate change with an analysis of government policies based on: (i) total fossil fuel support (% of tax revenue); (ii) environment-related research and development budget (% of total research and development budget); and (iii) development of environment-related technologies (% of all technologies).

Central banks' involvement in various international initiatives on climate risk data Graph 5



Source: Fortanier (2025).

They include in particular:

1. **The third phase of the DGI endorsed by the G20,** which covers seven climate risk-related recommendations addressing four topics: measuring carbon output; climate finance; forward-looking physical and transition risk indicators; and mitigation and adaptation measures (Graph 6; IMF et al (2023)). Efforts are ongoing to improve conceptual frameworks for these indicators, enhance data interoperability and comparability, and foster the global dissemination of the statistics compiled.

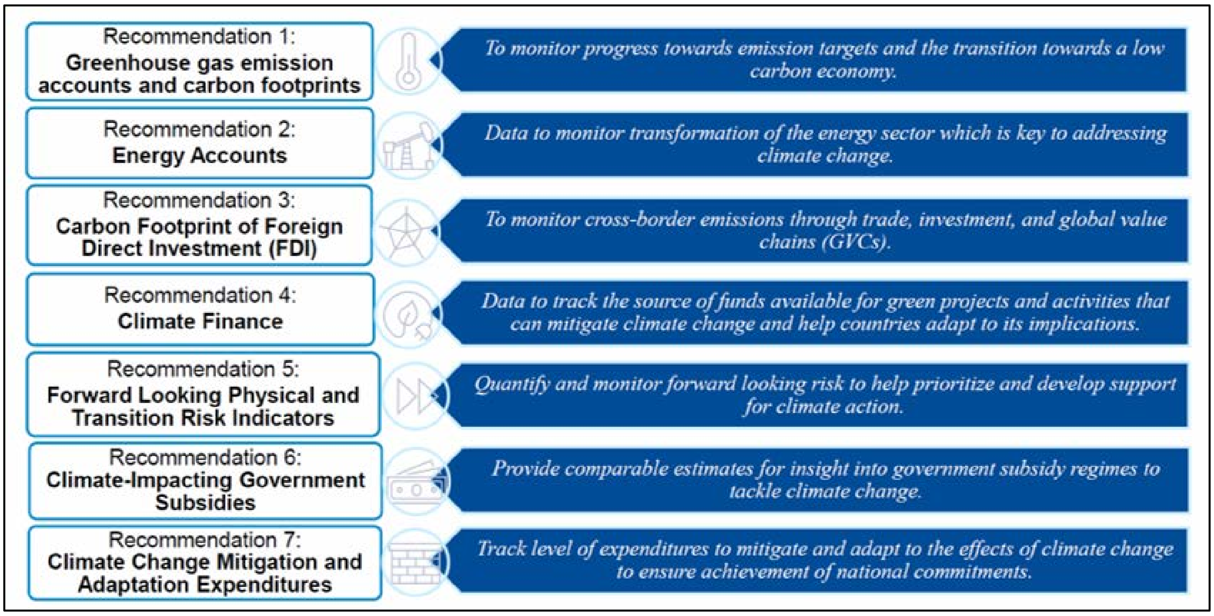
2. **Updates of international statistical standards:** the new 2025 version of the SNA includes environmental classifications for financial instruments and definitions for ESG and green financial instruments. Consistent with this, the revised Balance of Payments and International Investment Position Manual (BPM7) offers detailed breakdowns to better capture sustainable finance activities. Such efforts to harmonise compilation concepts are essential to build a global and comprehensive data ecosystem to tackle climate risk issues. For instance, the implementation of the new 2025 SNA will enhance data collections on natural capital, including non-renewable versus renewable energy stocks and their impact on economic growth.

3. **Work by the FSB to assess climate-related financial stability risks,** with a primary focus on enhancing the underlying concepts and dealing with associated data needs (FSB (2025)).

4. **The IFC review of the issues posed by carbon content measurement**, which has, in particular, highlighted the need for a comprehensive framework for establishing carbon content accounts consistent with emissions statistics (IFC (2024a)).

5. **Other international initiatives to collect and compile climate data,** including the International Monetary Fund (IMF) Climate Change Indicators Dashboard (CID)[10] and the NGFS data directory project developed together with the BIS Innovation Hub.

Overview of G20 DGI-3 recommendations related to climate risk Graph 6



Recommendation 1: **Greenhouse gas emission accounts and carbon footprints**	*To monitor progress towards emission targets and the transition towards a low carbon economy.*
Recommendation 2: **Energy Accounts**	*Data to monitor transformation of the energy sector which is key to addressing climate change.*
Recommendation 3: **Carbon Footprint of Foreign Direct Investment (FDI)**	*To monitor cross-border emissions through trade, investment, and global value chains (GVCs).*
Recommendation 4: **Climate Finance**	*Data to track the source of funds available for green projects and activities that can mitigate climate change and help countries adapt to its implications.*
Recommendation 5: **Forward Looking Physical and Transition Risk Indicators**	*Quantify and monitor forward looking risk to help prioritize and develop support for climate action.*
Recommendation 6: **Climate-Impacting Government Subsidies**	*Provide comparable estimates for insight into government subsidy regimes to tackle climate change.*
Recommendation 7: **Climate Change Mitigation and Adaptation Expenditures**	*Track level of expenditures to mitigate and adapt to the effects of climate change to ensure achievement of national commitments.*

Source: Harutyunyan et al (2025).

Lastly, **the central bank community has also been actively supporting specific data initiatives at regional levels.** A case in point relates to Europe, with the work led by the European System of Central Banks (ESCB) Expert Group on Climate Change and Statistics and related contributions of European national central banks in collaboration with other main stakeholders eg Eurostat, the European Securities and Markets Authority (ESMA) and the European Committee of Central Balance Sheet Data Offices (ECCBSO). The ESCB Statistics Committee has also developed harmonised indicators covering sustainable debt securities and financial sector portfolios across the euro area. Outside Europe, central banks have joined efforts in the context of training initiatives organised by the Center for Latin American Monetary Studies (CEMLA) and the South East Asian Central Banks (SEACEN) (Chadwick et al (2024)).

Fostering a comprehensive and coordinated international framework

In addition to their active involvement in international statistical initiatives, **central banks have played a key role in fostering the development of a comprehensive**

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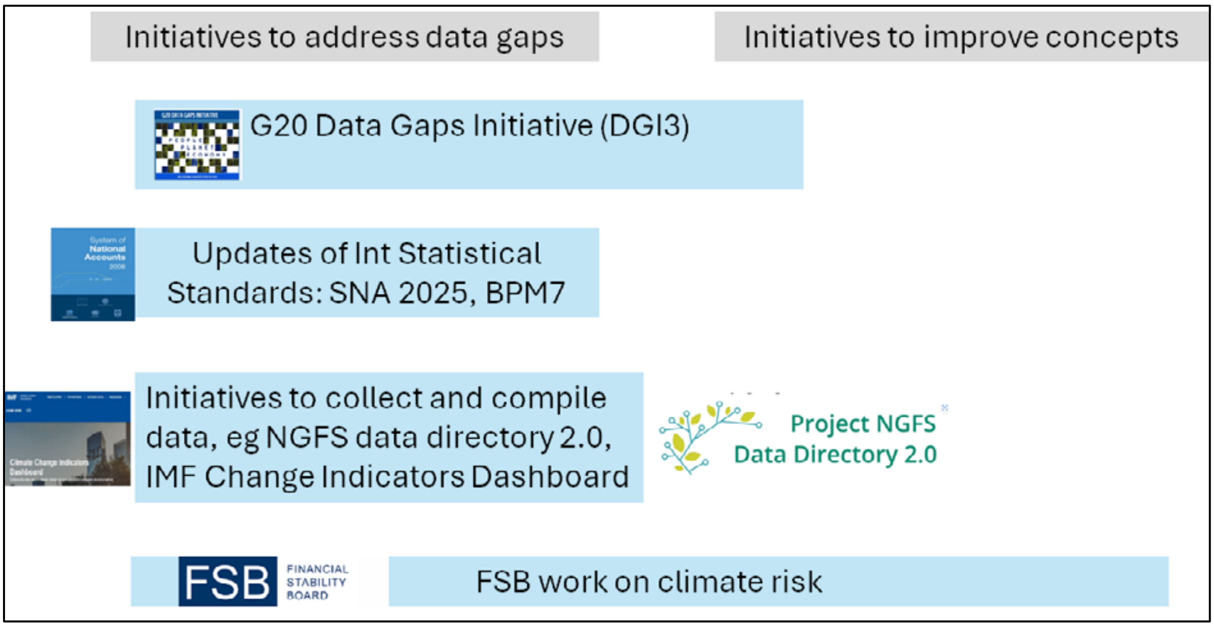
[10] This dashboard tracks various climate-related indicators to provide reliable data for policymakers and stakeholders in pursuing related macroeconomic and financial stability analyses.

and coordinated framework for closing climate-related data gaps. This, according to their own experience, requires a multi-faceted approach (Graph 7):

- The starting point is to ensure close collaboration through international organisations and networks, with a view to involving a wider range of stakeholders working with climate risk data (eg official statisticians, academics, regulators, policymakers, accountants and firms).
- Another focus area is to favour the convergence of the various data frameworks and practices developed across jurisdictions, especially through global methodological initiatives, especially in the context of the DGI-3 and the updates of the SNA/BPM (Barahona (2025)).
- The third point is to support the dissemination of reference data for the general public (eg through the various dashboards set up by the IMF and the Organisation for Economic Co-operation and Development (OECD)) as well as more restricted information-sharing exercises targeted at specific groups, for instance in the context of BIS central bank cooperative activities.
- Lastly, the active promotion of innovative concepts, estimation techniques, information technologies and data sources can facilitate the closing of climate risk data gaps by the various stakeholders involved.

Key climate data-related initiatives at the global level

Graph 7



Initiatives to address data gaps

Initiatives to improve concepts

G20 Data Gaps Initiative (DGI3)

Updates of Int Statistical Standards: SNA 2025, BPM7

Initiatives to collect and compile data, eg NGFS data directory 2.0, IMF Change Indicators Dashboard

FSB work on climate risk

Source: Harutyunyan et al (2025).

While central banks have not been alone in supporting the above actions, they have been instrumental in ensuring that they are understood within a comprehensive and coordinated framework. This reflects, in particular, the unique role they have as both providers of reference statistics and as users of trusted information to conduct evidence-based policies. The aim is to foster, in parallel and in a coordinated way, the improvement in definitions and taxonomies used, the development of new and relevant indicators, the dissemination of more accurate statistics and the adequate assessment of various risks associated with climate change.

An illustration: assessing the development of climate finance

One key illustration of the initiatives discussed above for enhancing climate risk information is related to sustainable finance. First, the update of international standards (SNA/BPM) has proved a key opportunity to develop comprehensive metrics for green financial instruments, covering bonds, loans, equities and investment funds. In particular, the SNA 2025 and BPM7 will incorporate principles and definitions for sustainable finance in, respectively, national accounts and balance of payments statistics (SNA (2024)). Second, improved data collection frameworks have been set up, especially in the context of the DGI-3 that is providing guidance for measuring and compiling climate finance statistics. Third, parallel efforts are being pursued to improve firm-level disclosure, especially with ISSB initiatives and the implementation of the European CSRD.

Yet a key challenge remains the lack of a single global taxonomy for sustainable finance, implying that views on what is "green" may greatly differ across jurisdictions. Moreover, the reliability of firms' disclosed information remains questionable in the **absence of comprehensive and consistent reporting practices**. For example, ESG instruments can be classified through various methods, such as self-labelling, second party opinions (SPOs) or external certification, and the results of these approaches may diverge markedly. This calls for further harmonisation work, which is likely to take time at the global level. In the meantime, a key focus should be on the transparency of the information collected, as issuers and holders of financial instruments should provide detailed metadata on the classification methods used for defining green instruments.

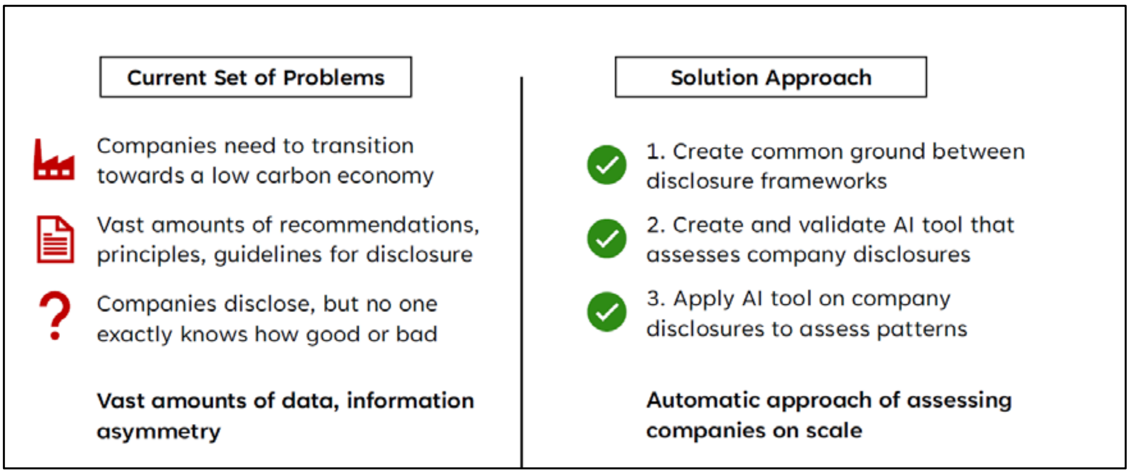
6. Leveraging innovation

Technical innovation (eg AI) offers promising solutions to overcome climate-related data gaps. **Central banks have indeed been playing an active role in making use of new data sources and tools in this area**, though their experience underscores the limitations of their traditional focus on economic and financial information and thus on the importance of ensuring collaboration with other stakeholders in the climate data ecosystem.

A first lesson is that new techniques can be effectively leveraged to better exploit existing but often non-conventional data sources. For example, text-mining techniques can extract relevant information from firms' climate disclosures to support the monitoring and analysis of sustainable finance developments.

Second, AI tools can help assess, in an automated way, the quality of the vast amount of information published by companies. For example, an AI-based solution has been developed to signal red flags in companies' published transition plans by identifying potential inconsistencies across the various indicators reported and assessing the completeness and quality of the information provided (Graph 8). This project revealed that companies' financial reports often emphasise climate target setting over concrete strategy implementation.

An AI-based approach to assessing the quality of firms' disclosed transition plans Graph 8



Current Set of Problems

- Companies need to transition towards a low carbon economy
- Vast amounts of recommendations, principles, guidelines for disclosure
- Companies disclose, but no one exactly knows how good or bad

Vast amounts of data, information asymmetry

Solution Approach

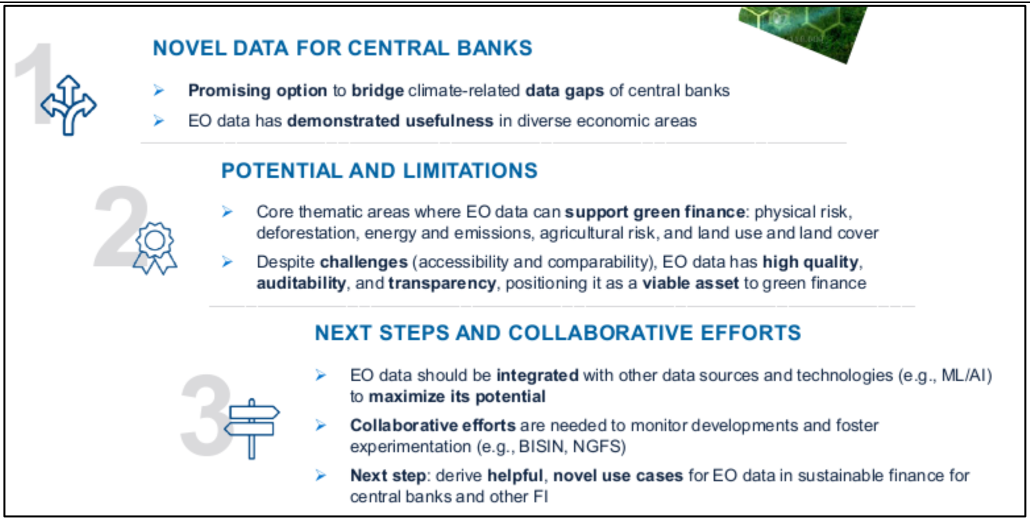
- ✓ 1. Create common ground between disclosure frameworks
- ✓ 2. Create and validate AI tool that assesses company disclosures
- ✓ 3. Apply AI tool on company disclosures to assess patterns

Automatic approach of assessing companies on scale

Source: Bingler et al (2025).

Third, innovation also brings the possibility of developing new, unstructured data sources. Earth observation satellite data are a case in point, as they can provide more granular insights to assess climate-relevant developments and address shortcomings and inconsistencies in existing (traditional) data. They can also reduce information asymmetries across scattered data sources, thereby limiting the potential for greenwashing practices (Graph 9).

Opportunities provided by new data sources: the case of Earth observation (EO) data Graph 9



1 NOVEL DATA FOR CENTRAL BANKS

- **Promising option** to **bridge** climate-related **data gaps** of central banks
- EO data has **demonstrated usefulness** in diverse economic areas

2 POTENTIAL AND LIMITATIONS

- Core thematic areas where EO data can **support green finance**: physical risk, deforestation, energy and emissions, agricultural risk, and land use and land cover
- Despite **challenges** (accessibility and comparability), EO data has **high quality**, **auditability**, and **transparency**, positioning it as a **viable asset** to green finance

3 NEXT STEPS AND COLLABORATIVE EFFORTS

- EO data should be **integrated** with other data sources and technologies (e.g., ML/AI) to **maximize its potential**
- **Collaborative efforts** are needed to monitor developments and foster experimentation (e.g., BISIN, NGFS)
- **Next step**: derive **helpful**, **novel use cases** for EO data in sustainable finance for central banks and other FI

Source: Alonso-Robisco et al (2025).

Fourth, innovation can boost both the accessibility to and analysis of climate-related data for supporting policies. For instance, the BIS Innovation Hub Singapore Centre has been able to develop three interrelated initiatives to enhance information on climate issues (Graph 10):

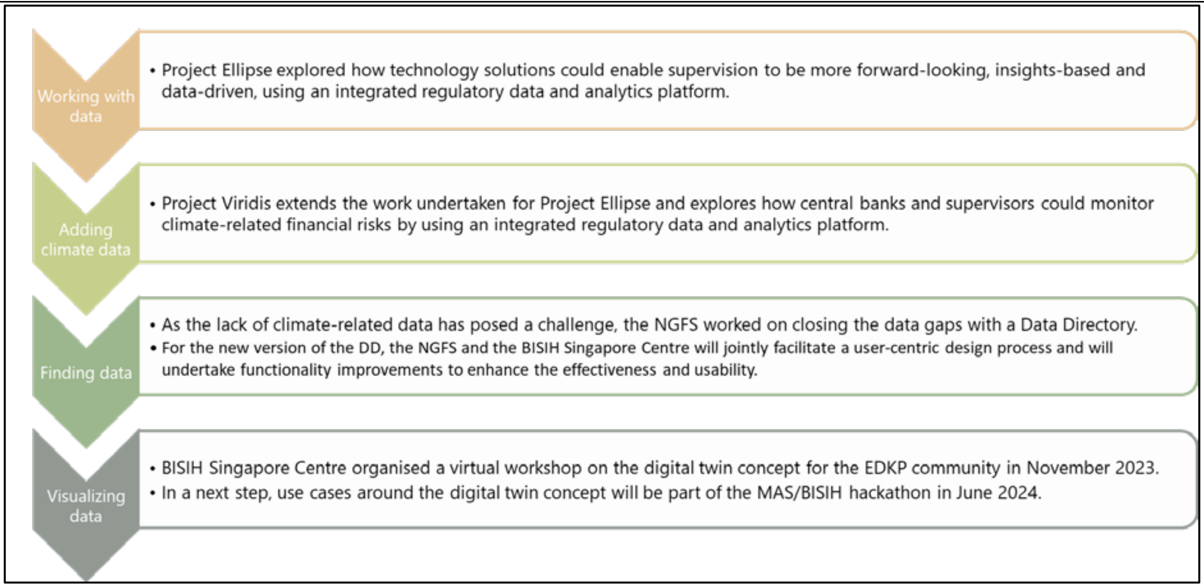
i. Building on Project Ellipse, Project Viridis provides a climate risk platform for financial authorities, allowing them to explore how integrating regulatory and climate data with advanced analytics can help identify key risk drivers potentially affecting financial stability.

ii. The NGFS Data Directory is a collaborative platform that allows crowdsourcing of climate-related information, including new data sources and adequate metrics. This directory offers, in particular, enhanced data search and analytical capabilities.

iii. The Ellipse Data Knowledge Platform (EDKP) Collaboration Community fosters dialogue on climate risk data and promotes collaboration.

Dealing with climate risk data: the BIS Innovation Hub Singapore Centre approach

Graph 10

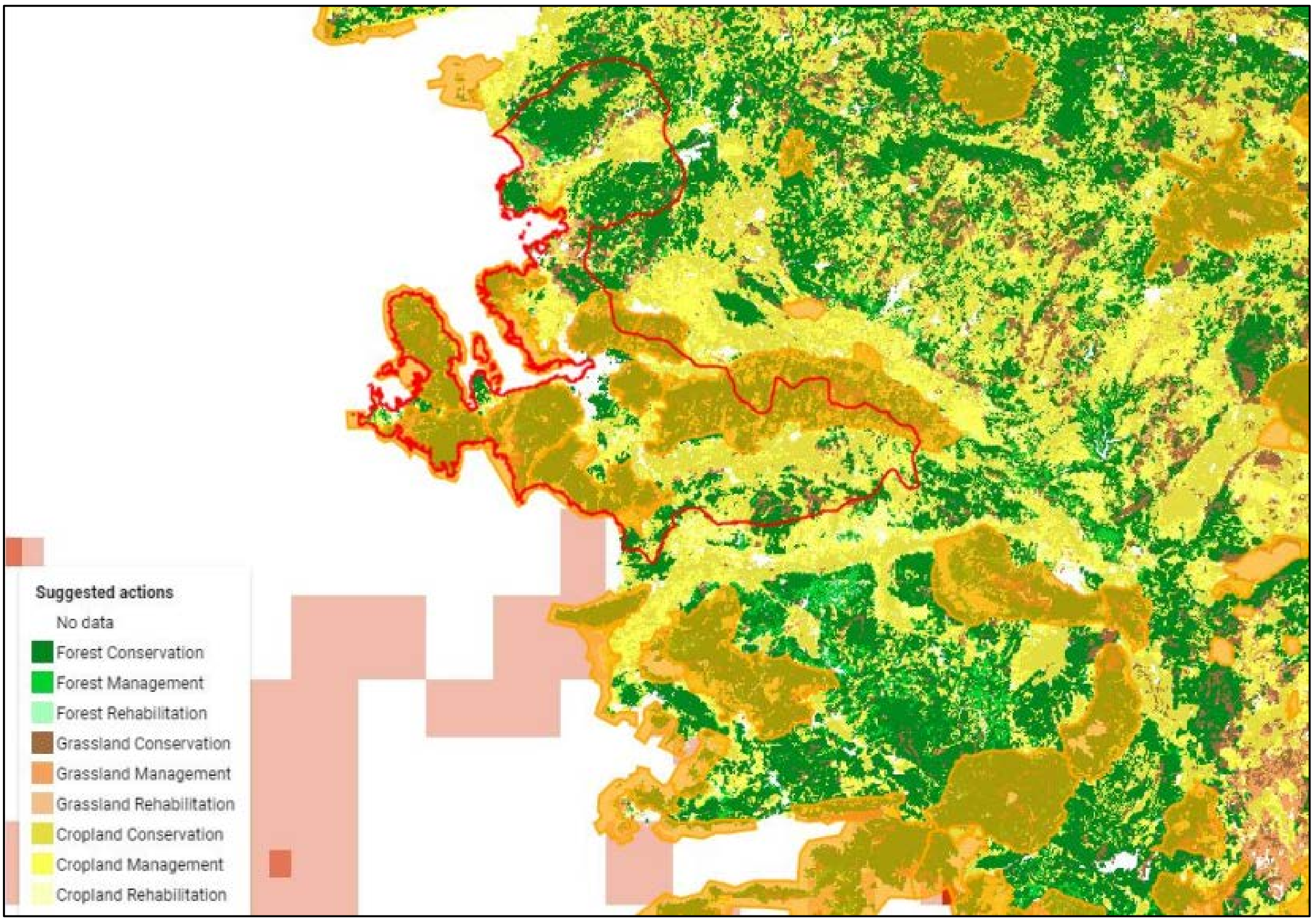


- Project Ellipse explored how technology solutions could enable supervision to be more forward-looking, insights-based and data-driven, using an integrated regulatory data and analytics platform.
- Project Viridis extends the work undertaken for Project Ellipse and explores how central banks and supervisors could monitor climate-related financial risks by using an integrated regulatory data and analytics platform.
- As the lack of climate-related data has posed a challenge, the NGFS worked on closing the data gaps with a Data Directory.
- For the new version of the DD, the NGFS and the BISIH Singapore Centre will jointly facilitate a user-centric design process and will undertake functionality improvements to enhance the effectiveness and usability.
- BISIH Singapore Centre organised a virtual workshop on the digital twin concept for the EDKP community in November 2023.
- In a next step, use cases around the digital twin concept will be part of the MAS/BISIH hackathon in June 2024.

Source: Hoffmann et al (2025).

Fifth, new techniques allow for combining different types of a priori unrelated data sources that can be instrumental for addressing the complex interactions of climate change. For instance, data from geographic information systems, remote sensing, and environmental and socioeconomic sources in Türkiye have been usefully combined to support more informed decisions on sustainable land use, the restoration of degraded soil and overall environmental conservation (Graph 11).

Combining various data sources for simulating sustainable land use: an application to the region of İzmir (Türkiye) Graph 11



Source: Seyhun and Yıldırak (2025).

Sixth, innovation allows for analysing alternative scenarios that are essential for dealing with the complex implications of climate change and potential non-linearities. A key example is the NGFS Scenarios Portal set up to assist central banks, supervisors and financial institutions in assessing both transition and physical risks based on sound evidence. The portal features two key components: the Scenario Explorer and the Climate Impact Explorer. The Scenario Explorer allows users to explore a range of climate scenarios, providing insights into potential future climate pathways and their economic and financial impacts. It offers detailed data and visualisations on variables such as temperature changes, carbon prices and economic indicators under different circumstances. The Climate Impact Explorer, on the other hand, focuses on physical risk. It provides users with access to data and models that illustrate the potential effects of climate change on various sectors and regions under different climate scenarios.

Lastly, and despite the promising use cases being explored, **a key lesson from central banks' experience is that adequately leveraging innovation can require considerable investment in information technology infrastructure, tools and skilled staff**, posing important challenges given existing resource constraints.

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IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

Central banks and climate risk data initiatives[1]

F Fortanier,
De Nederlandsche Bank

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

Central banks & climate risk data initiatives

Fabienne Fortanier

DeNederlandscheBank
EUROSYSTEEM

Central banks and climate change – why?

Impact on financial stability

What is the potential impact of climate change on the economy and the financial system?

How to ensure financial stability in the face of physical risks and transition risks?

Monetary policy

How should central banks adjust their monetary policy instruments to account for climate-related and environmental risks, including exposures of their own balance sheets?

Supporting Transition

What measures can central banks take to support an orderly transition to a carbon-neutral economy, and how can they balance short-term transition costs against long-term benefits

Economic analysis and policy advice

What are the economic implications of climate change and the transition to a carbon-neutral economy (incl mitigation policies, monetary policy transmission)

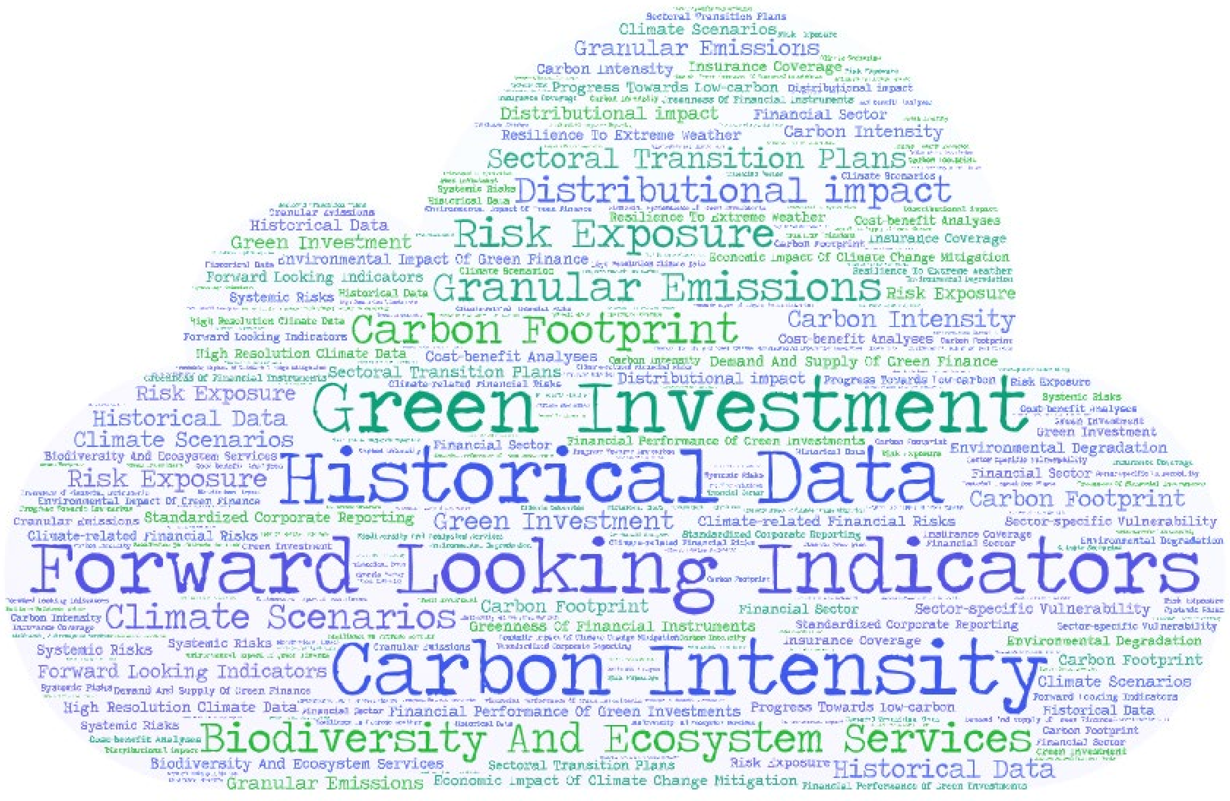
Supervision

What changes are needed in our regulatory frameworks to encourage financial institutions to adequately manage their climate-related risks

Green Finance

How can central banks promote green finance and the development of financial products that support sustainable economic activities

Central bank data needs



Central Bank climate data initiatives (examples)….

NGFS
Data repository
scenario’s

BIS
Dashboards
Innovation hub

IMF
Data Gaps Initiative 3
Dashboards

ECB
Expert Group on Climate Change & Statistics

ESMA
European Single Access Point

Eurostat
Statistics for the
European Green Deal

ECCBSO
Non-financial reporting

National Central Bank
Data initiatives, workshops, transition plans

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… in a wider context (regulatory, private, non-profit - examples)

IFRS Sustainability Disclosure Standards

CSRD Corporate Sustainability Reporting Directive

SASB Sustainability Accounting Standards Board

Greening Government initiatives

ESRS European Sustainability Reporting Standards

Climate Action 100+

PRI Principles for Responsible Investment

GHG Protocol

GRI Global Reporting Initiative

CDP Carbon Disclosure Project

IGCC Investor Group on Climate Change

NGFS
Data repository
scenario's

BIS
Dashboards
Innovation hub

IMF
Data Gaps Initiative 3
Dashboards

ECB
Expert Group on Climate
Change & Statistics

Eurostat
Statistics for the
European Green Deal

ECCBSO
non-financial reporting

National Central Bank
data initiatives, workshops, transition plans

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Data vs statistics: what about methodology?

WHAT TO DO IF...

... HUGE AMOUNTS OF DATA ARE STILL MISSING?

... DATA SOURCES ARE HIGHLY INCONSISTENT BETWEEN THEMSELVES?

... DATA SOURCES ARE COMMERCIAL - DIFFICULT TO ACCESS OR SHARE?

... COMPARABILITY ACROSS COUNTRIES, INSTITUTIONS OR SECTORS IS LACKING?

... THERE IS LIMITED TRANSPARENCY ABOUT DATA COLLECTION?

... INDICATORS NEED TO RELIABLY REFLECT TIME TRENDS?

Example: ESCB Expert Group on Climate Change and Statistics

- Following the **Governing Council (GC) action plan**, the ECB and national central banks have collaboratively developed **harmonised statistical indicators at the euro area level for climate-related analysis**
- First released in January 2023, updated **climate-related indicators** were released by **18 April** as outlined in the **Climate and nature plan 2024-2025**, accommodated by a **statistical paper** that explains the methodology.

	Sustainable finance	Carbon emissions	Physical risk
Released as:	**Experimental indicators**	**Analytical indicators**	
Indicators cover:	issuances and holdings of sustainable debt securities	financial sector loan and securities portfolios	

→ come with limitations and should be used and analysed with care
→ project is work in progress (feedback is very welcome!)

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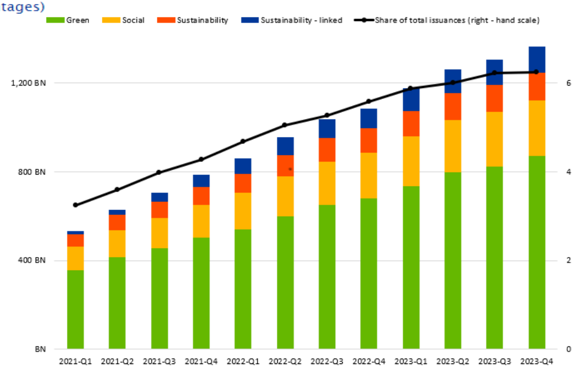
Issuances of sustainable debt securities in the euro area: including second party opinions

Chart 1 – Euro area issuances of sustainable debt securities – all levels of assurance

(Left-hand scale: EUR, outstanding amounts at face value; right-hand scale: percentages)

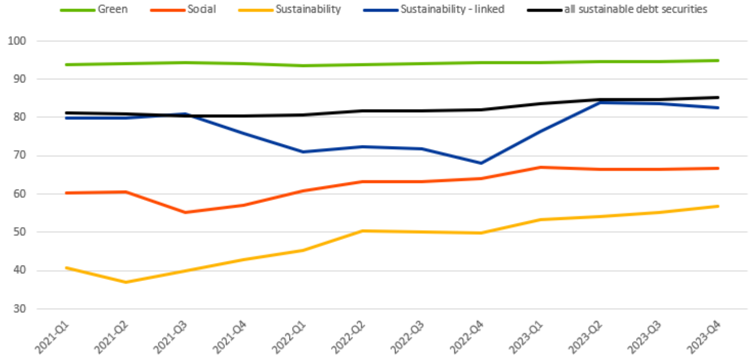


Source: Centralised Securities Database (CSDB).

Notes: "Share of total issuances" refers to the amount of all sustainable securities as a share of all debt securities issued in the euro area.

Chart 1b – Euro area issuances of sustainable debt securities – share of issuances with second party opinion

(Percentages)



Source: Centralised Securities Database (CSDB).

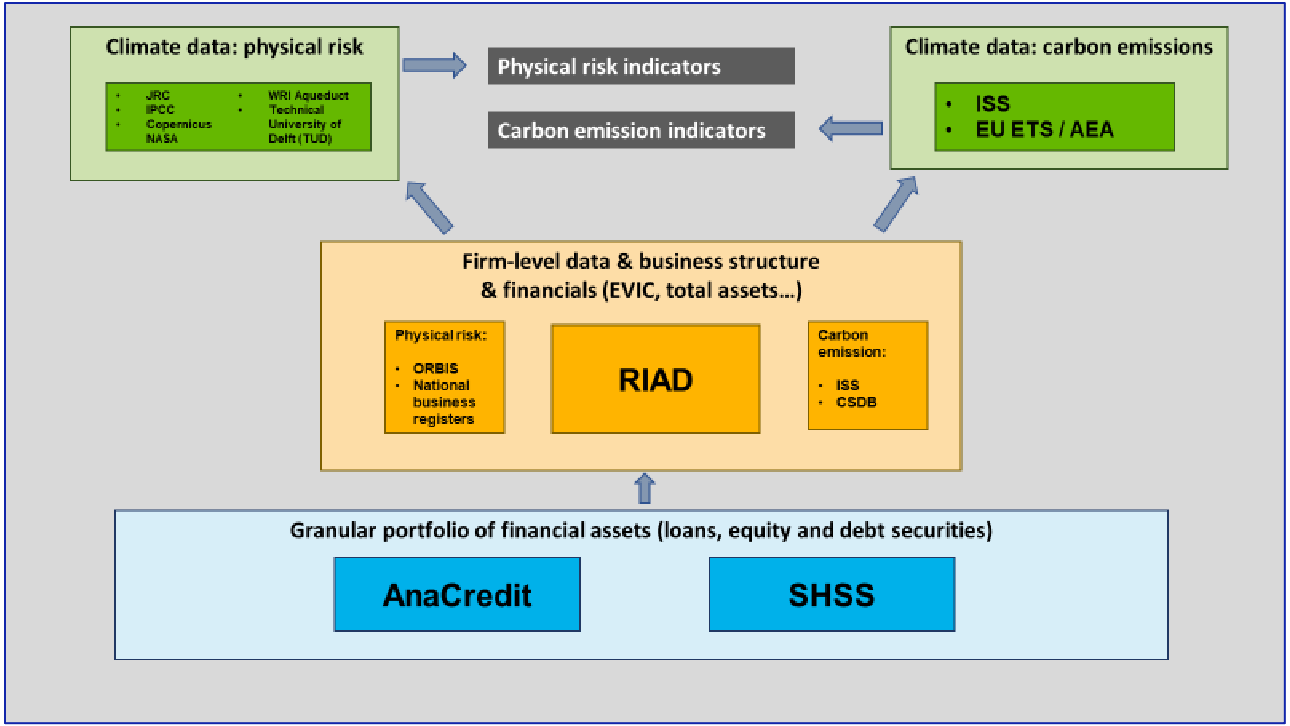
Notes: "Share of issuances with second party opinion" refers to sustainable debt securities with second party opinion as a share of all sustainable debt securities.

Key findings

- Outstanding amount of sustainable debt securities issued by EA has *almost tripled the last three years*
- Green and social bonds account for majority of the market
- Relevance of these instruments in the overall debt securities market remains minor, even when observing the looser level of assurance

- Overall, euro area issuers obtain external review of their sustainable bond issuances: around **85% of all sustainable debt in the EA has a SPO**
- Virtually all green debt securities issued in the euro area have obtained a second party opinion
- Social and sustainability instruments have slightly lower SPO assurance levels but in general above 55%

Emission and physical risk indicators are constructed bottom up using micro data



Climate data: physical risk

- JRC
- IPCC
- Copernicus NASA
- WRI Aqueduct
- Technical University of Delft (TUD)

Physical risk indicators

Carbon emission indicators

Climate data: carbon emissions

- ISS
- EU ETS / AEA

Firm-level data & business structure & financials (EVIC, total assets…)

Physical risk:

- ORBIS
- National business registers

RIAD

Carbon emission:

- ISS
- CSDB

Granular portfolio of financial assets (loans, equity and debt securities)

AnaCredit

SHSS

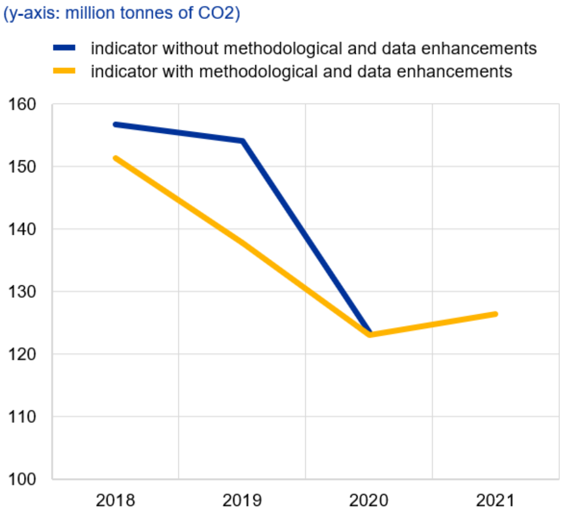
- **Carbon emission indicators** link financing and corporate emissions to describe the carbon emissions associated with the corporate securities and loan portfolios of financial institutions to assess the financial sector’s transition risks

- **Physical risk indicators** capture financial system exposures to companies located in areas susceptible to natural disasters (such as flooding, windstorms, wildfires or droughts) and chronic physical risks (heat and water stress).

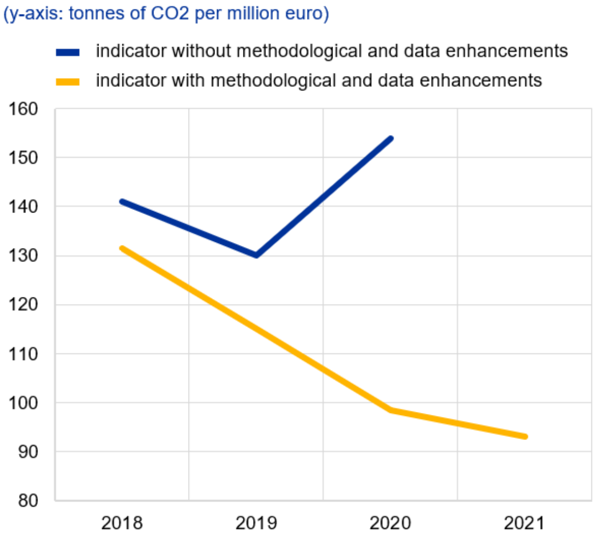
Notes: ISS is a commercial data provider offering carbon emission information at company level. EU ETS denotes the European Emission Trading System and AEA the Eurostat Air Emissions Accounts. JRC: Joint Research Centre. IPCC: Intergovernmental Panel on Climate Change. WRI: World Research Institute. RIAD: Register of Institutions and Affiliates Data.

Impact of methodological (e.g. outlier detection, price/volume change corrections) and data enhancements (imputations) on indicators

a) Financed emissions (FE), euro area aggregate, Scope 1, single entity-level loans



b) Weighted average carbon intensity (WACI), euro area aggregate, Scope 1, single entity-level loans



Financed emissions: Tons of GHG emissions financed by euro area financial institutions

Weighted average carbon intensity: tons of GHG emissions per million EUR of revenue → proxy for the exposure of a creditor to climate transition risks

Sources: ESCB calculations based on AnaCredit, Register of Institutions and Affiliates Database (RIAD), EU Emissions Trading System (EU ETS), and Eurostat Air Emissions Accounts (AEA).
Notes: The charts comprise only loans computed on single entity level for Scope 1 emissions. The WACI is adjusted for inflation and exchange rate effects.

Key findings

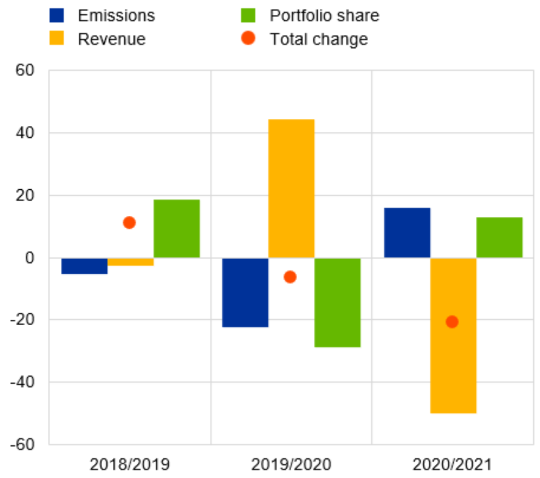
- **Downward trend** over the period → decarbonisation? Potentially reflecting diverse impacts of **COVID-19 pandemic**
- **Methodological and data enhancements** led to an overall **smoothing of the time series** (new imputation methods have largest impact) → statistically more robust time series analysis.

Towards actionable data: understanding WHY trends occur
Example: breaking down WACI-change over time

(a)

Decomposition of Weighted Average Carbon Intensity (WACI), corporate group level security portfolio, euro area aggregate

(y-axis: tonnes of CO2 per million euro)



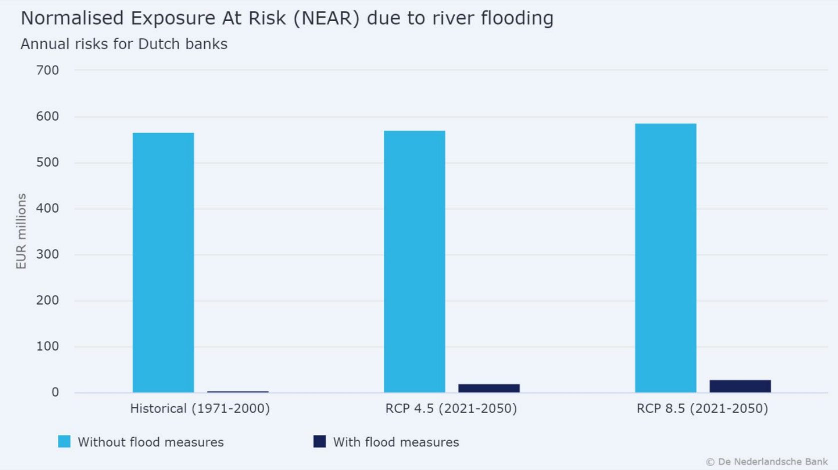
- **Decrease in emissions and revenue[1] from 2019 to 2020** (2019/2020) → could be due to disruptions of the economy from pandemic-related restrictions.
- **Emissions and revenue[1] increase from 2020 to 2021** (2020/2021) → could be due to economic recovery following pandemic-related restrictions.
- Time series breakdowns are also available for the **financed emissions** and **carbon footprint indicators**.
- The decomposition method underscores the **indicators' sensitivity** to changes in **financial components.**

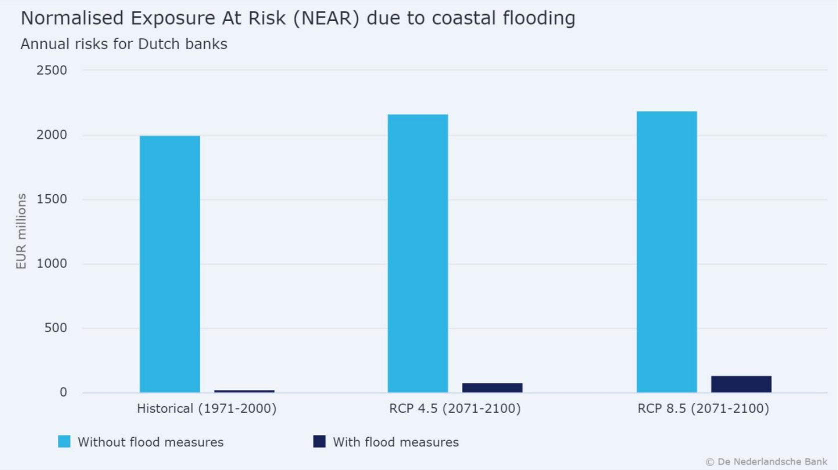
[1] Notably, a reduction in revenue from one year to the next corresponds to a positive revenue component in the WACI breakdown and vice versa. In other words, when revenue decreases, carbon intensity increases.

Sources: ESCB calculations based on data from AnaCredit, RIAD, CSDB, SHSS, Institutional Shareholder Services (ISS), EU ETS, Eurostat Air Emissions Accounts (AEA).
Notes: Securities include listed shares and debt securities of deposit taking cooperations (S122) and are computed at group level. Loans are computed at single entity level. The charts comprise only Scope 1 emissions.

Towards actionable data: interpreting the data

Flood risks (river and coastal) for Dutch banks: negligeable (EUR 30 mln/year), *if the dykes hold…*





Conclusion and next steps

- On climate change and addressing data gaps, **central banks have come a long way,** together with other actors, in a very short time
- More work remains necessary: **data challenges go beyond availability** but include quality, reliability, shareability, comparability, granularity…
- And even then, **methodology** and **interpretation** matters
- And new questions are arising:
  - Forward looking indicators (Paris alignment)
  - Accounting for compounding (physical) risks
  - new/wider physical risk categories including nature-related risks (biodiversity loss)…

Good we have this workshop!

Thank you

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IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

Going green in finance: bridging data gaps for enhanced financial risk and opportunities assessment[1]

F Fareed, A Harutyunyan, P Hurree-Gobin and M Kutlukaya,
International Monetary Fund

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

Going Green in Finance:

Bridging Data Gaps for Enhanced Financial Risk and Opportunities Assessment

Artak Harutyunyan, Padma Hurree-Gobin, Mahmut Kutlukaya,
and Fozan Fareed

2024
July

Going Green in Finance: Bridging Data Gaps for Enhanced Financial Risk and Opportunities Assessment

Prepared by Artak Harutyunyan, Padma Hurree-Gobin, Mahmut Kutlukaya, and Fozan Fareed*

July 2024

ABSTRACT: Addressing climate change is of paramount importance on a global scale, requiring immediate efforts in both adaptation and mitigation. To develop adequate policy measures to tackle climate change issues, policymakers need robust, comprehensive, and comparable data. Despite increasing awareness, a major obstacle is lack of relevant data, especially concerning climate finance data. The paper aims to lay the groundwork for an assessment of such data gaps and discuss ways to bridge them. It underscores the International Monetary Fund's (IMF's) endeavor to improve climate finance statistics to facilitate the collection of internationally comparable data. The paper highlights the IMF's different initiatives in this respect, namely the G20 Data Gaps Initiative 3 (DGI-3), including the recommendations aimed at addressing data gaps on climate finance and other climate related issues through the development of methodological guidance and reporting templates. Particular emphaiss is given to the current updates of the *2008 System of National Accounts (SNA)* and the *Balance of Payments and International Investment Position Manual, sixth* Edition (*BPM6*), and the upcoming update of the *Monetary and Financial Statistics Manual and Compilation Guide* (*MFSMCG*) which will consider climate finance and the growing need for statistical information. The paper also discusses experimental indicators developed on 'Climate finance' by the IMF, through its Climate Change Indicators Dashboard, leveraging on data (including private) already available, which emphasize the need for central banks, supervisors, and financial institutions to act to manage climate-related risks and mobilize funds for green investments.

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* All authors are from the Statistics Department of the International Monetary Fund. The views expressed in this paper are those of the authors and do not necessarily represent the views of the IMF, its Executive Board, or IMF management. The authors would like to thank participants of the IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution", Izmir, organized by the Central Bank of the Republic of Türkiye with the support of the Bank of France and the Deutsche Bundesbank during May 6-7, 2024, Ms. Sarah Barahona, Head of the National Accounts Division, Statistics and Data Directorate, OECD, for useful feedback and discussions.

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Introduction

Climate change is macro-critical, necessitating urgent action on adaptation, mitigation, and transition to a low carbon economy on a global scale. Addressing climate change brings along significant challenges. For instance, to cope with heightened climate-related physical risks, substantial investments are necessary for adaptation and resilience building. To combat climate change by means of achieving net zero, significant changes to tax regimes (i.e., carbon tax) and regulatory frameworks are needed, which create transition risks for the overall economy and financial institutions. To develop adequate policy measures to tackle climate change issues, policymakers need robust, comprehensive, and comparable data (NGFS, 2022; IMF, 2023a). Despite increasing awareness, a major obstacle is lack of relevant data, especially concerning forward-looking risk assessments and climate finance.

This paper aims to lay the groundwork for an assessment of climate finance related data gaps and discuss possible approaches to bridge them. The paper unfolds by addressing the macro-critical nature of climate change, its implications for the global economy, and the imminent need for additional climate finance to fund the necessary investments. It emphasizes the need for urgent and coordinated action, underlining the indispensable role of data in shaping effective policies. The paper details the challenges posed by the current lack of relevant data on climate finance and the IMF's ongoing efforts to address them, including by developing experimental indicators to close the most pressing data gaps. It also looks at the work to introduce climate finance measures into the *2025 System of National Accounts (SNA)* and the *Balance of Payments and International Investment Position Manual, seventh* Edition (*BPM7*); and into the upcoming update of the *Monetary and Financial Statistics Manual and Compilation Guide* (*MFSMCG*), emphasizing the importance of collecting internationally-comparable detailed climate (or sustainable) finance statistics using international statistical standards.

Substantial investments aimed at mitigating the impact of climate change are needed to reduce global greenhouse gas (GHG) emissions to net zero by 2050 (IMF, 2023a). IMF estimates that the private sector would need to play a vital role to respond to climate finance needs, particularly in the case of Emerging Market and Developing Economies (EMDEs) where private climate mitigation investment needs can range between 80 and 90 percent of the total investment needs (IMF, 2023b).[1] Strengthening the climate information architecture—data, disclosures, and alignment approaches (including taxonomies)—is an important part of the policy mix to attract private climate finance, which many EMDEs still lack (IMF, World Bank and OECD, 2023).

The paper is structured as follows: Section 2 delves into the experimental indicators related to climate finance that are featured on the IMF's Climate Change Indicators Dashboard (CID). This section further explores the G20 Data Gaps Initiative 3, which aims to establish statistical reporting and promote alignment approaches among countries on climate finance. Section 3 discusses the updates of the international statistical standards to incorporate climate finance. Section 4 concludes by highlighting potential areas for future work.

---

[1] EMDEs will need about $2 trillion annually by 2030 to reach that ambitious goal, according to the International Energy Agency, with the majority of that funding flowing into the energy industry. This is a fivefold increase from the current $400 billion of climate investments planned over the next seven years. See IMF (2023b) for a detailed discussion of investment needs. Moreover, it is also important to note that other financial flows, such as foreign direct investment (FDI) and public spending, are very critical for a successful transition.

Bridging Data Gaps

The IMF has stepped up its engagement with member countries in addressing climate change-related challenges through its surveillance, lending, and capacity development activities in recent years (IMF, 2021). The Fund's Article IV consultations now cover macro-critical issues triggered by climate change and the need to contain it. Financial Sector Assessment Programs include a climate component with increased attention to the risks posed by climate change for financial stability (Adrian et al., 2022). The Fund also provides support to countries vulnerable to climate change and natural disasters by expanding its capacity development programs. The Resilience and Sustainability Trust (RST) provides longer-term, affordable financing to low-income and vulnerable middle-income countries to help them address various challenges, including climate change and pandemic preparedness.

The IMF launched the Climate Change Indicators Dashboard (CID) in 2021 to disseminate macro-relevant climate change indicators. This initiative is aimed at addressing the growing need for environment and climate change related data in macroeconomic and financial stability analysis to support policies for climate change mitigation and adaptation. The CID presents two experimental indicators on climate finance:
i) Environment, Social and Governance (ESG) debt indicators, and ii) the carbon footprint of bank loans indicator. Pending internationally agreed statistical standards to ensure comparable data collection, the climate finance experimental indicators on the CID have relied on leveraging private commercial data sources and conducting one-off surveys. These efforts aim to address the most pressing data needs in this field.

The IMF in cooperation with the Inter-Agency Group and the Financial Stability Board coordinates the G20 Data Gaps Initiative 3 (DGI-3) to enhance the global statistical infrastructure in filling data gaps to support policy formulation. DGI-3 includes 14 recommendations addressing various statistical areas. Seven of the 14 recommendations are related to macro-relevant climate change statistics. Two of these seven recommendations, Recommendation 4 on Green Debt and Equity Financing and the Recommendation 5 on Forward-looking Physical and Transition Risk Indicators, are of particular importance for this paper given their focus on climate finance and transition risk implications for the financial sector.[2]

2.1. Climate Finance: An Overview of the IMF's CID Experimental Indicators

The financial sector is playing a crucial role in combating climate change by steering financial resources towards a path that favors low greenhouse gas emissions and fosters climate-resilient development. Green financial instruments, such as green bonds, are regarded as a means to shift investments towards "green" sectors. Green bonds are fixed-income instruments where the proceeds are allocated to support specific climate-related or environment friendly projects. There is existing body of literature on green bonds that presents an optimistic picture, highlighting their growing investor interest and market demand (Maltais and Nykvis, 2020; Bhutta et al., 2022; IMF 2023c). These studies underscore the capacity of green bonds to mobilize significant financial resources for environmentally friendly initiatives, while also offering competitive

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[2] The paper discusses the concepts of climate risk data and climate finance data. For clarification, it is important to note that climate risk data broadly pertains to the potential impacts of climate change on financial stability, whereas climate finance data focuses on the funding allocated to mitigate or adapt to climate change.

returns.[3] This dual benefit positions green bonds as a promising mechanism for achieving environmental and climate objectives.

Despite their growth over the last decade, green bonds issuances still represent a modest fraction of the total bond market, accounting for less than 5 percent of total issuances in 2023. Enhancing market depth and liquidity can be important for increasing the demand and supply of such instruments, thereby facilitating climate mitigation investments. The lack of transparency and standardized reporting on climate risks can often lead to these risks being inadequately priced into climate-focused securities (Krogstrup and Oman, 2019), having potential implications for liquidity and turnover rates. Initiatives and standards set by the International Capital Market Association (ICMA), the Climate Bonds Initiative (CBI), and the development of green taxonomies in regions like the EU[4] and ASEAN are playing a significant role in enhancing the sustainable securities market.[5]

To address the data gaps related to green bonds, the IMF has introduced indicators designed to capture the trends in Environmental, Social, and Governance (ESG) debt instruments, with a focus on green bonds, considering factors such as country-sector and currency aspects. The definition of ESG debt instruments is fundamental, as it is the foundation for any statistics derived from aggregated data on issuances. Several international and non-profit organizations are actively involved in developing guidelines and principles on Green Finance and, more generally, on ESG aspects of financial markets. Specifically for the case of green bonds, the ICMA and the CBI, among others, have made significant contributions to formalizing a set of voluntary guidelines and certification processes that issuers should follow when labeling securities as "*green*". The ICMA has published the Green Bonds Principles (ICMA, 2018), wherein it defines green bonds as "[…] any type of bond instrument where the proceeds will be exclusively applied to finance or re-finance, in part or in full, new and/or existing eligible Green Projects […] and which are aligned with the four core components of the GBP." In turn, the Green Bond Principles (GBP) are a set of voluntary guidelines that revolve around four core principles:

1. *Use of Proceeds* is the cornerstone of the definition of green bonds, which must be appropriately described in the legal documentation accompanying the security. All designated green projects must provide environmental benefits.[6]
2. *Process for Project Evaluation and Selection* comprises a set of processes by which the issuer communicates to investors what the environmental objectives are, the process by which these projects are evaluated, and the eligibility criteria.
3. *Management of Proceeds* principle requires the net proceeds of green bonds issuances to be credited to a sub-account and tracked.

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[3] Some studies find a relatively limited impact, especially with regards to the "greenium"—the premium often associated with green bonds due to their environmental benefits. This suggests that while the market for green bonds is growing, the financial incentives, specifically the added value of investing in environmentally beneficial projects, may not be as pronounced as anticipated. This nuanced perspective invites further examination into how green bonds are priced and the factors influencing their appeal to investors, shedding light on the complex dynamics between market demand and the tangible environmental impact of these investment vehicles.

[4] To read more about the sustainable finance initiatives, standards and legislations in the EU, see here.

[5] See IMF, World Bank and OECD (2023) for a detailed discussion on the benefits of taxonomies.

[6] Some categories of green projects are explicitly listed, including renewable energy, energy efficiency, pollution prevention and control, environmentally sustainable management of living natural resources and land use, terrestrial and aquatic biodiversity conservation, clean transportation, climate change adaptation, eco-efficient and/or circular economy adapted products, production technologies and processes, and green buildings.

4. *Reporting* principle necessitates issuers to voluntarily disclose information on the progress of financed Green Projects.

The CBI builds on the GBPs of ICMA to further lay out a certification process to validate the claims that investors make upon issuance of green bonds, described in the Climate Bonds Standard (CBI, 2019). In addition to satisfying consistency with the GBPs, the CBI requires that green bond issuers fully align with other green bond taxonomies, including their own Climate Bonds Taxonomy (CBI, 2021) and those proposed in the EU, ASEAN, India, and Japan. While the requirements to define a fixed-income security or other debt instrument as green bonds are aligned with those of ICMA, the certification process broadly consists of three distinct phases: pre-issuance certification, post-issuance certification. and ongoing certification.[7]

The Green Bonds indicator released on the IMF's CID, sourced from Refinitiv, a private commercial data provider, has been categorized under four broad segments, each corresponding to a different type of ESG debt instruments: green bonds, social bonds, sustainability bonds, and sustainability-linked bonds. This classification helps users and stakeholders to gain a better understanding of how each ESG instrument contributes to climate finance, allowing a structured approach to analyze their impact and effectiveness within the broader context of sustainable investments. For evaluating green, social and sustainability bonds, the key criteria are proceeds allocated to ESG related projects, issuer labelling, availability of dedicated ESG framework, and a second party opinion. For sustainability-linked bonds, the use of proceeds is not restricted to specific projects; instead, the main criteria are sustainable performance targets that the bond aims to achieve by certain target observation date and penalties for failing to meet these targets, issuer labelling, and documentation (framework, second party opinion).[8]

These data on ESG debt issuances on CID span the period from 1985 to 2023. The dataset encompasses issuances on annual basis for about 70 countries covering both Advanced Economies (AEs) and Emerging Markets and Developing Economies (EMDEs) as defined in the IMF's World Economic Outlook (WEO). The indicators on the CID can be divided into three broad categories:[9]

1. *Total ESG debt Issuances*: defined as the sum of all bonds' issuances, by instrument, taking place in a given calendar year. The instruments included in the climate finance statistics include green bonds, social bonds, sustainability bonds, and sustainability-linked bonds. These indicators are presented both as global aggregates and broken down by country-year. A further breakdown is available by type of issuer, sector, and currency of issuance.
2. *Cumulative Issuances*: defined as the cumulative sum of the value of all issuances from 1985 through 2023, in the entire sample of ESG bond issuances.

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[7] The CBI Taxonomy is presented in Annex I, and it generally is not fully aligned with the pre-approved categories of eligible Green Projects described above from the GBPs. The purpose of this taxonomy is to lay out a consistent set of criteria that issuers can use to quickly ascertain whether their proposed projects are indeed suitable for certification by the CBI. The taxonomy clarifies the definition of each category, determines whether it is aligned with the goals of the Paris Agreement, and, if applicable, lays out quantitative criteria which can be applied to verify that the project satisfies the requirements.

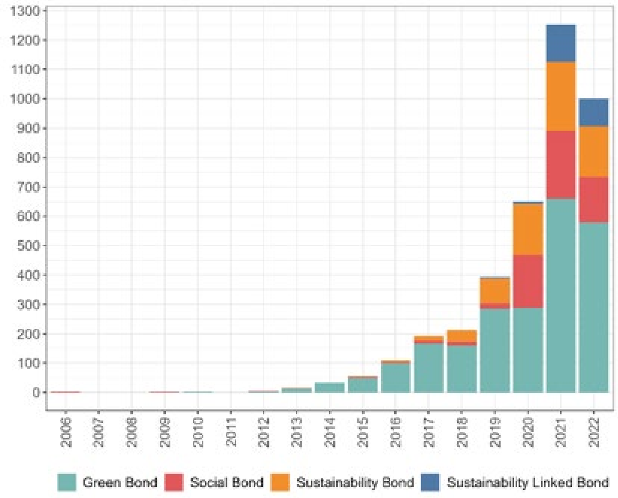
[8] Additional details are provided in Annex II.

[9] CID also provides information on variables such as the sectors, the use of proceeds, and the currency of issuance, which are relevant and important for analysis and are used for aggregation.

3. *Sovereign bonds Issuances:* defined as the sum of all government debt issuances in any year and country which are meant to fund public green projects. Importantly, this category only comprises central governments and central authorities and excludes local governments.[10]

The results in Figure 1 show that green bond and other ESG debt issuances continue to fall short of the financing needs, with 2022 witnessing slowdown in issuances amidst shifts in the global debt markets, which by some metrics continues for 2023 as well.[11] Despite an overall decrease in green bond issuances from 2021 to 2022, both banks and other financial corporations (OFCs) have sustained consistent levels of issuance (Figure 2). The euro and the U.S. dollar remain the predominant currencies of issuances, with the Chinese yuan following closely behind. Data also indicate that proceeds from green bonds are predominantly allocated to sectors such as clean transport, energy efficiency, and climate change adaptation.[12] These comprehensive data on breakdown of green bonds are accessible by country, issuer type, principal currency, and utilization of proceeds. This type of information provides policymakers with invaluable insights into the climate finance landscape, enabling them to identify any remaining gaps and make informed decisions.[13]

Figure 1. ESG Debt Issuance by Type of Instrument (In Billion USD)



Sources: Refinitiv; IMF Staff Calculations.

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[10] It is important to note that governments may use other budget allocations to fund environmentally friendly projects, so the level of green bond issuance should not be taken as a sole proxy measure for "fiscal greenness."

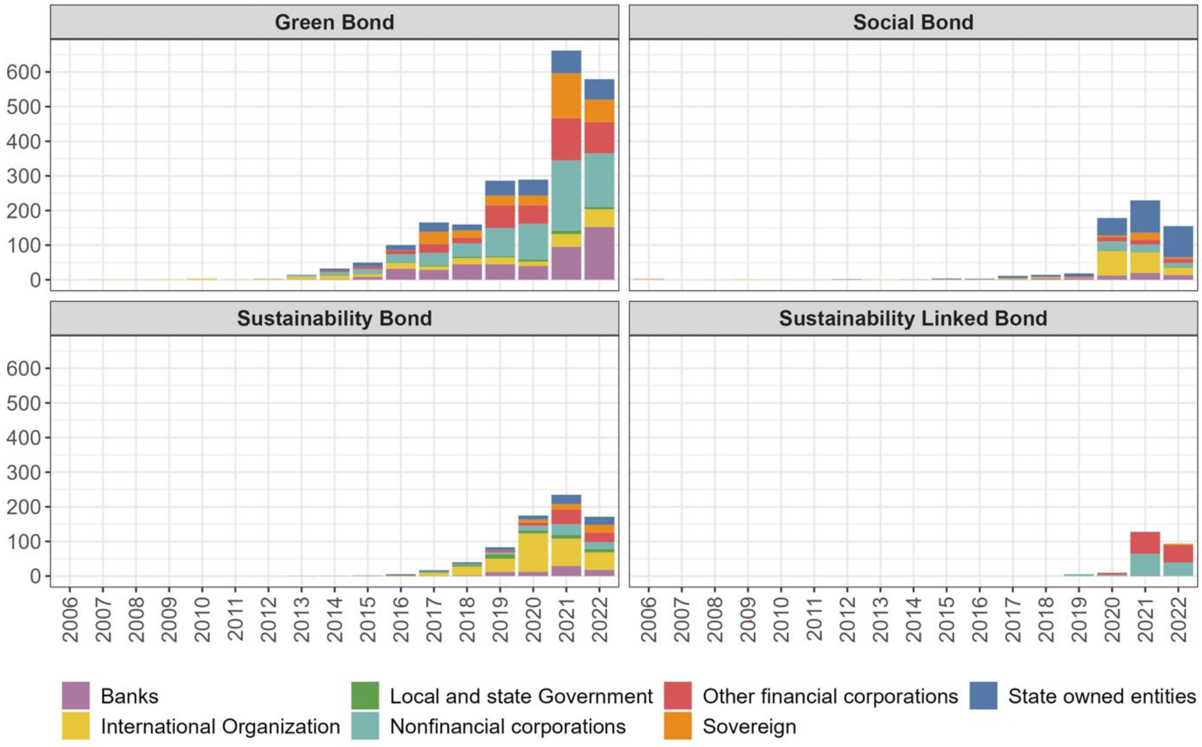
[11] Estimates of global investments required to achieve the Paris Agreement's temperature and adaptation goals range between US$3 to $6 trillion per year until 2050 (IMF, 2022).

[12] See Annex III for the charts on issuances by currency and by use of proceeds.

[13] See IMF (2023c) for a detailed discussion.

Figure 2. ESG Debt Issuance by Type of Issuer

(In Billion USD)



Sources: Refinitiv; IMF Staff Calculations.

As the need for funding to help facilitate a transition to a greener economy far exceeds the available supply, and securities financing may not be an option in various jurisdictions across the world, bank credit and capital market financing need to complement each other in terms of helping close the climate finance gap. The banking sector plays a vital role in providing finance to the real economy, and bank loans are key financial instruments used globally to facilitate this funding.

This paper also discusses the Carbon Footprint of Bank Loans (CFBL), another experimental indicator available on the CID. The CFBL aims to quantify the exposure of a country's banking sector to climate transition risks. It thus serves as a tool for policymakers and relevant stakeholders to measure the carbon intensity of bank loan portfolios—an experimental measure of the greenness of the domestic loan portfolio. The CFBL, based on aggregated sector level data, provides a data-lean way to appraise the exposure of the banking system to transition risk for a given country. The formulation makes it possible to calculate this indicator for a wide range of countries.[14] The methodology allows for cross-country comparisons, albeit with certain limitations.[15] Figure 3 suggests that banking systems of emerging markets tend to have higher carbon footprints compared to advanced economies, with wide regional heterogeneity, highlighting the potential transition risk exposures to these countries' loan portfolios.

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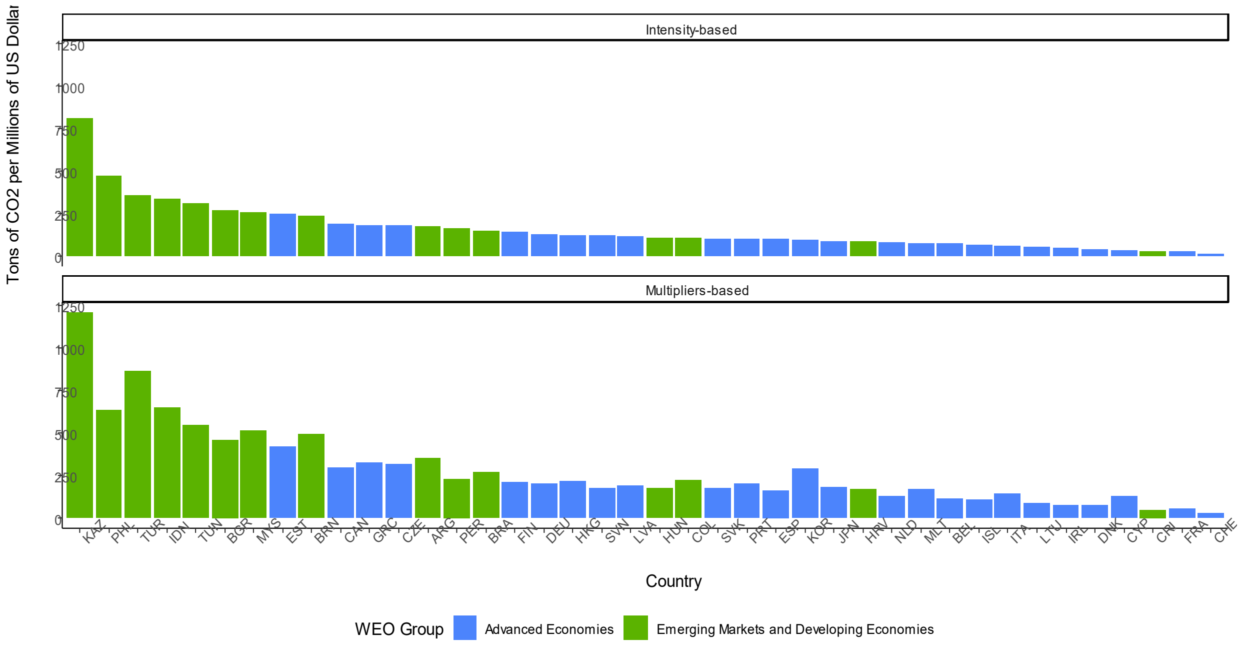
[14] The CFBL is currently available for 41 countries including EMDEs.

[15] See IMF (2023c) for a detailed discussion.

Figure 3. Carbon Footprint of Bank Loans (CFBL)



Source: IMF (2023c)

Recognizing the importance of statistical methodologies in tackling critical issues such as data gaps in green finance is essential. However, the challenge lies in developing and implementing these methodologies in a consistent manner across regions and countries, particularly when there are no established statistical standards and alignment approaches. The challenge is further compounded by the persistent issue of greenwashing.[16] Another significant limitation is the difficulty in defining climate finance, particularly with emerging new financial instruments like sustainability-linked bonds that lack the restrictions on the use of proceeds. While this flexibility broadens the scope for sustainable financing, it concurrently complicates efforts to precisely track the allocation of funds dedicated to fight climate change. Additionally, the constantly changing nature of climate finance instruments adds more complexity, necessitating a nuanced approach to address these multifaceted challenges. Similarly, the experimental CBFL indicators rely on a one-off survey on loans-by-industry, posing challenges in capturing the ongoing and most recent dynamics.

2.2. G20 Data Gaps Initiative 3 (DGI 3)

All these limitations outlined above necessitate improving data availability on climate change statistics at country level coupled with building on or further developing the established statistical infrastructure. These efforts, when carefully coordinated with existing international statistical workstreams, provide the necessary synergies, and gain more support. Additionally, statistical standards and alignment approaches are crucial for facilitating the collection of internationally comparable data, a prerequisite for informed decision-making.

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[16] The classification of instruments as 'green' may not necessarily align with their actual environmental impact, diverting funds intended for climate-related activities towards potentially 'brown' activities.

The IMF's commitment to this cause is exemplified through its leading role in the G20 Data Gaps Initiative (DGI).[17] In October 2022, the G20 FMCBGs endorsed the DGI-3 initiative and the related workplan drawing on collaborative efforts and collective expertise from the IMF, Financial Stability Board (FSB), and the Inter-Agency Group on Economic and Financial Statistics (IAG) to coordinate climate related work. DGI-3 addresses 14 recommendations, seven of which call for better climate data. The DGI-3 also draws on work undertaken by groups such as the Network for Greening the Financial System to develop a common understanding of climate-related financial instruments.

Efforts of the DGI-3 recommendations on climate change are focused on seven keys areas pertaining to developing greenhouse gas emissions by industry, energy accounts, carbon footprints, climate finance indicators, physical and transition risk indicators, climate impacting subsidies and climate-related expenditures. A vital aspect of this work involves developing internationally accepted concepts and statistical methods that ensure comparable and consistent measures across countries and over time.

One of the recommendations of DGI-3, Recommendation 5 'Forward-looking Physical and Transition Risk Indicators,[18] focuses on the need to monitor risks related to increasingly frequent and severe climate hazards (such as floods, drought, and fires) and the transition effect of climate policy on economic development and financial sector stability. Physical risk indicators plan to combine information on hazards, exposures, and vulnerability to help policymakers better understand the risk climate hazards pose to populations, the economy, including its buildings and structures, and financial markets. Similarly, transition risk indicators underscore the economic and financial challenges that arise from the global move towards a low-carbon future. Together, both these risks require careful management and foresight to safeguard financial stability and ensure a smooth transition to a sustainable economic model, and bridging data gaps is paramount in addressing these challenges.

Similarly, another recommendation of the DGI-3, Recommendation 4 '*Climate Finance,'*[19] focuses specifically on Green Debt and Equity Securities Financing. The objective of this recommendation is to address data gaps by developing (i) reporting templates to collect experimental data on issuances and holdings of green and sustainable debt securities and green listed shares consistent to the extent possible with the *Handbook on Securities Statistics* (HSS), and (ii) methodological guidance to ensure greater interoperability and comparability of data reported across economies in the future.

The DGI 3 Recommendation 4 data templates discussed and agreed at its Workshop on October 5–6, 2023 include a set of tables.[20] The collection covers statistics on issuances and holdings on a from-whom-to-whom basis for green bonds, sustainability bonds, sustainability-linked bonds, and green listed

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[17] An initiative launched in 2009 by the G20 Finance Ministers and Central Bank Governors (FMCBG) to close the policy-relevant data gaps identified following the global financial crisis to enhance the availability and quality of economic and financial data worldwide.

[18] For additional details, please see link.

[19] This recommendation is led jointly by the BIS and ECB (leads), with collaboration from the IMF, OECD, and FSB (user perspective). The work is also coordinated by the BIS-ECB-IMF Working Group on Securities Databases (WGSD).

[20] Available here: https://www.bis.org/ifc/events/231005_summary.pdf.

shares. The templates on the different types of green debt securities provide "of which" breakdowns corresponding to the established DGI-2 Recommendation 7 breakdowns.[21]

The data collection will rely on the existing DGI-2 Recommendation 7 current infrastructure for reporting, including frequency and timeliness, consistent with the HSS and using the Global Data Structure Definition (DSD) for Sector Accounts (NA_SEC) (See Annex IV for an illustrative reporting template). The reporting targets include a basic intermediate target for core data on green bonds by end-2025 and a final target for other data by end-2027.

The DGI 3 Recommendation 4 Task Team members and the coordinators of the sustainable finance workstreams for the *2025 SNA* and *BPM7* (see Section 3) through close collaboration have ensured that the approaches on both sides are aligned. The *2025 SNA* and *BPM7* principles and definitions have been informed by the work of the Recommendation 4 Task Team and the Recommendation 4 reporting templates will apply these same definitions.

Introducing climate finance in the international statistical standards

Progress in collecting internationally-comparable detailed climate finance statistics would remain limited unless the international statistical standards include measures of climate (or sustainable) finance, which is not the case currently. The work to update the standards and produce the new manuals—*Balance of Payments and International Investment Position Manual,* seventh edition (*BPM7*) and *2025 System of National Accounts* (*2025 SNA*)—has recognized the importance to provide expanded information on the interplay between the economy and the environment taking into account the evolving landscape of sustainable finance and the increasing demand for statistical information in this domain. Both the *2025 SNA* and *BPM7* will include, for the first time, lines for ESG and green financial instruments. The compilation of these ESG and green measures will be based on internationally agreed guidance to support the collection of statistics related to sustainable finance to quantify funding activities which actively contribute to green and climate outcomes.

3.1. *2025 System of National Accounts* and *Balance of Payments Manual 7*

From a user/policy perspective, the *SNA* update recommends that countries report the stocks and flows (holdings and issuances) of ESG and green financial instruments (debt securities, loans, and equity and investment fund shares) as 'of which' categories in the financial account and balance sheets. Although reporting mechanisms, classifications and regulations around sustainable finance are in their infancy in most countries, the update of the SNA acknowledges the importance of being forward-looking by introducing ESG and green breakdowns of all relevant financial instruments. Including these breakdowns in the financial account and balance sheets of the national accounts is important for tracking investment in the transition to a low carbon economy and informing decisions on monetary and fiscal incentives relating to it (OECD, 2020). The agreed

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[21] Under the DGI-2 Recommendation 7, the G20 economies provide on a quarterly frequency debt securities issuance data to the BIS consistent with the Handbook on Securities Statistics (HSS) covering sector, currency, type of interest rate, original maturity and, if feasible, market of issuance.

structure for ESG and green financial instruments and associated definitions[22] in the current juncture, as presented in the SNA update *Issues Note: Sustainable Finance in the 2025 SNA and BPM7*[23] are provided in Table 1 below with corresponding definitions in Table 2.

Table 1: ESG and green financial instruments in the *2025 SNA*

AF.1	Monetary gold and SDRs
AF.2	Currency and deposits
AF.3	Debt securities
	Of which: ESG debt securities
	Of which: Social debt securities
	Of which: Green debt securities
	Of which: Sustainability debt securities
	Of which: Sustainability-linked debt securities
	Of which: Other ESG debt securities
AF.4	Loans
	Of which: ESG loans
	Of which: Green loans
AF.5	Equity and investment fund shares
AF.51	Equity
	Of which: ESG equity
	Of which: Green equity
AF.52	*Investment fund shares*
	Of which: ESG investment fund shares
	Of which: Green investment fund shares
AF.6	Insurance, pension and standardized guarantee schemes
AF.7	Financial derivatives and employee stock options
AF.8	Other accounts payable/receivable

Source: SNA update Issues Note (2024), Table 3.

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[22] Definitions of ESG and "Green" instruments are evolving. The guidance note WS.12 Environmental Classifications notes that the *2025 SNA* adopts, in the interim, current definitions, which may change in the future and could therefore be re-examined closer to the publication date of the updated SNA, which will be accessible here.

[23] Final version (30 May 2024) incorporating the decisions of the joint meeting of the Advisory Expert Group on National Accounts (AEG) and IMF Committee on Balance of Payments Statistics (BOPCOM) of February 20, 2024.

Table 2: Definitions for ESG and green financial instruments

AF.3 Debt securities

- *Of which: ESG debt securities are debt securities where the use of proceeds is restricted to financing or refinancing activities or projects or where the issuer agrees to achieve performance objectives that improve the condition of the environment or society or governance practices. These include green debt securities, social debt securities, sustainability debt securities, sustainability-linked debt securities, and other ESG debt securities.*
    - *Of which: Social debt securities are debt securities where the use of proceeds is restricted to financing or refinancing activities or projects that improve the condition of society.*
    - *Of which: Green debt securities are debt securities where the use of proceeds is restricted to financing or refinancing activities or projects that improve the condition of the environment.*
    - *Of which: Sustainability debt securities are debt securities where the use of proceeds is restricted to financing or refinancing activities or projects that improve the condition of the environment and society.*
    - *Of which: Sustainability-linked debt securities are debt securities in which certain characteristics, such as the associated cash payments, are linked to achieving performance objectives that improve the condition of the environment or society*[24].
    - *Of which: Other ESG debt securities* are any ESG debt securities other than those identified as social debt securities, green debt securities, sustainability debt securities or sustainability-linked debt securities.

AF.4 Loans

- *Of which: ESG Loans* are funds lent by creditors to debtors in which 50% or more of the debtor's activities improve the condition of the environment or society or governance practices.
    - *Of which: Green Loans* are funds lent by creditors to debtors in which 50% or more of the debtor's activities improve the condition of the environment.

AF.5 Equity and investment fund shares

AF.51 Equity

- *Of which: ESG Equity are equity investments* by investors to institutional units in which 50% or more of the institutional unit's revenue comes from activities improve the condition of the environment or society or governance practices.
    - *Of which: Green equity* are equity investments by investors to institutional units in which 50% or more of the institutional unit's revenue comes from activities improve the condition of the environment.

AF.52 Investment fund shares

- Of which: ESG investment funds are funds investing in financial instruments, companies, projects or other funds that intend to achieve performance objectives that improve the condition of the environment or society or governance practices.
    - Of which: Green investment funds are funds investing in financial instruments, companies, projects or other funds that intend to achieve performance objectives that improve the condition of the environment.

Source: SNA update Issues Note (2024), Table 6.

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[24] This definition of sustainability-linked debt securities is essentially the same as that used by the DGI-3 Rec 4 Task Team: "sustainability-linked debt securities: debt securities whose characteristics (e.g. coupon payments) can vary depending on whether the issuer achieves predefined environmental or other sustainability objectives".

The proposal for the *BPM7* is to introduce an updatable appendix on measures and balance of payments/IIP indicators relevant for climate change-related financial risks. The IMF’s Committee on Balance of Payments Statistics (BOPCOM) has agreed to add supplementary ‘of which’ categories for ESG and green financial instruments in the balance of payments and international investment position (IIP) (SNA update Issues Note, 2024, Table 4). These are shown in Table 3.

Table 3: ESG and green financial instruments in the upcoming *BPM7* (IIP and BOP)

1	**Direct Investment**
1.1	Equity and investment fund shares
	Of which: ESG equity/investment fund shares
	Of which: Green equity/investment fund shares
1.2	Debt Instruments
	Of which: 1.2.0.1 Debt Securities
	Of which: ESG debt securities
	Of which: Social debt securities
	Of which: Green debt securities
	Of which: Sustainability debt securities
	Of which: Sustainability-linked debt securities
	Of which: Other ESG debt securities
2	**Portfolio Investment**
2.1	Equity and investment fund shares
	Of which: ESG equity/investment fund shares
	Of which: Green equity/investment fund shares
2.2	Debt Securities
	Of which: ESG debt securities
	Of which: Social debt securities
	Of which: Green debt securities
	Of which: Sustainability debt securities
	Of which: Sustainability-linked debt securities
	Of which: Other ESG debt securities
3	**Financial Derivatives**
4	**Other Investment**
4.1	Other equity
4.2	Currency and deposits
4.3	Loans
	Of which: ESG loans
	Of which: Green loans
4.4	Insurance, pension and standardized guarantee schemes
4.5	Trade credit and advances
4.6	Other accounts receivable/payable
4.7	SDRs
5	Reserve assets

In conjunction with the revised *2008 SNA* and *BPM6*, the forthcoming update of the *Monetary and Financial Statistics Manual and Compilation Guide* (*MFSMCG*) will introduce guidance on sustainable finance, including concepts and definitions for climate-related financial instruments. The updated manual will incorporate additional breakdowns to assist countries in better measuring climate finance and assess the impact of climate change on the financial sector.

3.2. Climate Finance Data Project for the Financial Sector

As much as climate issues are being integrated in the Fund's climate assessments and macro financial surveillance, a critical persistent obstacle has been limited and inconsistent data on climate finance.[25] To evaluate data availability as well as assess the possibility of collecting relevant granular climate-related financial details, the IMF will be launching a pilot project targeting approximately 50 economies.[26]

The project, underway, aims to collect climate-related components within the standardized report forms (SRFs) as part of the current Monetary and Financial Statistics (MFS) compilation structure (additional lines under main SRF templates—see Appendix V—and additional annex tables). The collection of the relevant data from these pilot countries will be undertaken while minimizing overlap with other initiatives. Initial focus is on improving data availability on green and brown assets of the banks, and sectoral/geographic distribution of exposures of banks and nonbank financial institutions. Cross-references at the aggregate level will be introduced, wherever possible, to achieve harmonization with the DGI-3 Recommendation 4 reporting templates and the international statistical standards.[27]

Participating economies in the pilot project will be requested to submit quarterly data, on a voluntary basis, with historical series covering a five-year period, whenever feasible. While the exercise will be used to test the underlying definitions of the *2025 SNA* and *BPM7*, countries may also report data based on their own definitions, should the latter not align with the proposed guidance. Metadata will therefore accompany the data reported in the pilot.

Results of this pilot exercise, including the metadata, will provide additional guidance for countries aiming to implement the new breakdowns in the *2025 SNA* and *BPM7*and benefit the discussion surrounding the forthcoming update of the *MFSMCG*. This comprehensive approach will also provide valuable insights into the sustainable finance intermediated by the financial sector and also the impact of climate change on the financial sector. If the pilot phase proves to be useful, it will transition into a regular exercise, with an expanded scope to include more countries. Based on the results, this initiative can either be integrated into the MFS data collection or established as a standalone database.

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[25] The absence of reliable data was explicitly mentioned in all 32 FSAPs conducted in 2021–23. About 20 percent of the 2023 staff reports acknowledged either the lack of climate data or the need to improve climate data.

[26] This will be a joint project between IMF's Statistics Department and Monetary and Capital Markets (MCM) Department.

[27] For example, aggregate green bond issuances by banks reported within the pilot collection would be cross-referenced and aligned with the reporting under DGI-3 Recommendation 4 templates – Table 1.2a. Given the absence of globally accepted criteria for brown assets, an option-based method is intended to gather data on national practices.

These data, with an expanded coverage beyond G20 countries, are expected to complement other ongoing work, such as the Financial Stability Board's SCAV Climate Vulnerabilities and Data (CVD) workstream[28] and the DGI-3 climate related work. This pilot project also aims to support data needs for the monitoring of RST countries' climate-related policy conditionalities. By contributing to the design and application of a robust climate information architecture, the pilot data collection, if proved successful and adopted as a regular collection, will provide invaluable service to national authorities, supervisors, and financial institutions in support for policy work on climate finance.

Concluding Remarks

Reliable and comparable climate finance data are crucial for assessing global efforts towards climate change mitigation and adaptation. Such data enable policymakers, researchers, international organizations, and stakeholders to track the flow of funds, and the alignment of financial flows on a low-carbon and resilient trajectory, evaluate the effectiveness of investments in climate change mitigation and adaptation, and ensure accountability in the use of resources (notably to mitigate greenwashing risks). Climate data are a key pillar of the climate information architecture (IMF, World Bank and OECD, 2023). Consistency in data reporting and analysis is essential in setting standardized benchmarks and facilitating international cooperation by highlighting areas in need for more support or intervention.

This paper has delineated the ongoing collaborative efforts of the IMF with other relevant stakeholders including member countries in addressing these challenges stemming from inadequate availability of relevant climate finance data and statistical guidelines in this field. These efforts encompass not only the development and dissemination of experimental indicators aimed at alleviating pressing data gaps but also the revision of the international statistical standards for the national accounts, external statistics and monetary and financial statistics. Updating these standards will foster a more equitable environment for climate finance statistics, thus facilitating informed decision-making and effective policy formulation in combating climate change. Ultimately, robust climate related data are vital for informing strategies that can effectively address the complex challenges of climate change on a global scale.

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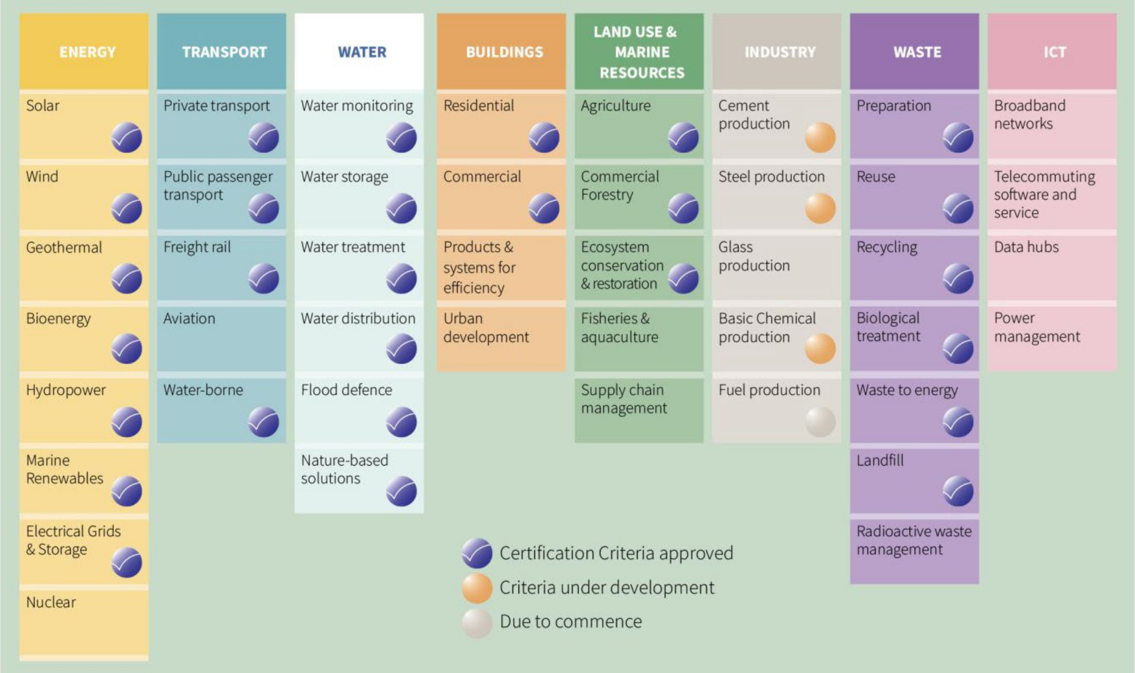
[28] The CVD's work aims at developing a monitoring framework to analyze the evolution of climate vulnerabilities and transmission or amplification channels in the global financial system, based on available metrics, which can be updated regularly and evolve over time as improved data and tools become available.

Annex I. Climate Bonds Initiative Taxonomy

The certification process broadly consists of three distinct phases:

1. *Pre-Issuance Certification: CBI certifies, through an Approved Verifier, that all GBPs are satisfied.*
2. *Post-Issuance Certification: CBI certifies that the green bond has been issued.*
3. *Ongoing Certification*: on an ongoing basis CBI certifies the disclosure and reporting requirements are fulfilled.

Figure: Climate Bonds Initiative Taxonomy



ENERGY	TRANSPORT	WATER	BUILDINGS	LAND USE & MARINE RESOURCES	INDUSTRY	WASTE	ICT
Solar ✓	Private transport ✓	Water monitoring ✓	Residential ✓	Agriculture ✓	Cement production ●	Preparation ✓	Broadband networks
Wind ✓	Public passenger transport ✓	Water storage ✓	Commercial ✓	Commercial Forestry ✓	Steel production ●	Reuse ✓	Telecommuting software and service
Geothermal ✓	Freight rail ✓	Water treatment ✓	Products & systems for efficiency	Ecosystem conservation & restoration ✓	Glass production	Recycling ✓	Data hubs
Bioenergy ✓	Aviation	Water distribution ✓	Urban development	Fisheries & aquaculture	Basic Chemical production ●	Biological treatment ✓	Power management
Hydropower ✓	Water-borne ✓	Flood defence ✓		Supply chain management	Fuel production ○	Waste to energy ✓	
Marine Renewables ✓		Nature-based solutions ✓				Landfill ✓	
Electrical Grids & Storage ✓						Radioactive waste management	
Nuclear							

✓ Certification Criteria approved
● Criteria under development
○ Due to commence

Source: Climate Bonds Initiative (CBI, 2021)

Annex II. Additional Details about ESG Debt

Here are some key definitions and concepts related to the ESG debt instruments published on CID based on data from Refinitiv.

- **CBI Aligned Green Bond—**Aligned to the Climate Bond Initiative (CBI) Climate Taxonomy and screened for eligible sector and use of proceeds.

- **CBI Certified Green Bond—**Certified by Climate Bond Initiative (CBI) to conform to the Climate Bond Standards and has a verifier appointed. More on CBI's certification: Certification under the Climate Bonds Standard | Climate Bonds Initiative .

- **Self-Labelled Green Bond—**Labelled by issuers to be a green bond and follows a green bond framework. Has use of proceeds dedicated to projects with environmental benefits. May eventually be changed to CBI certified or aligned, as assessment takes time.

- **Social Bond—**Labelled by issuers to be a social bond and follows a social bond framework. Have use of proceeds that are dedicated to projects with positive social outcomes.

- **Sustainability Bond—**Labelled by issuers to be a sustainability bond and follows a sustainability bond framework. Have a mix of green and social use of proceeds.

- **Sustainability-Linked Bond—**Labelled by the issuer to be sustainability linked bond (SLB), follows sustainability linked bond framework. Is non-use of proceeds bond unlike other ESG classification types. Proceeds can be spent on general purposes. Have specific KPIs and related targets that are connected to environment, social initiatives etc. If target is not met on the specified target observation date, there will be compensation paid to the bondholders which is usually in a form of coupon step-up or premium redemption. SLBs derive their ESG theme from the sustainable targets.

The IMF staff remapped the type of issuer variable from the underlying Refinitiv data to a custom classification scheme that is considered more aligned with statistical methodologies. This mapping is portrayed in the table below. Mapping was produced by joining two variables available from Refinitiv, that is, Type of Issuer (portrayed below in the table under the Refinitiv column) and the TRBC sector variable.

Table 4: Mapping of Type of Issuer Between Refinitiv and the CID

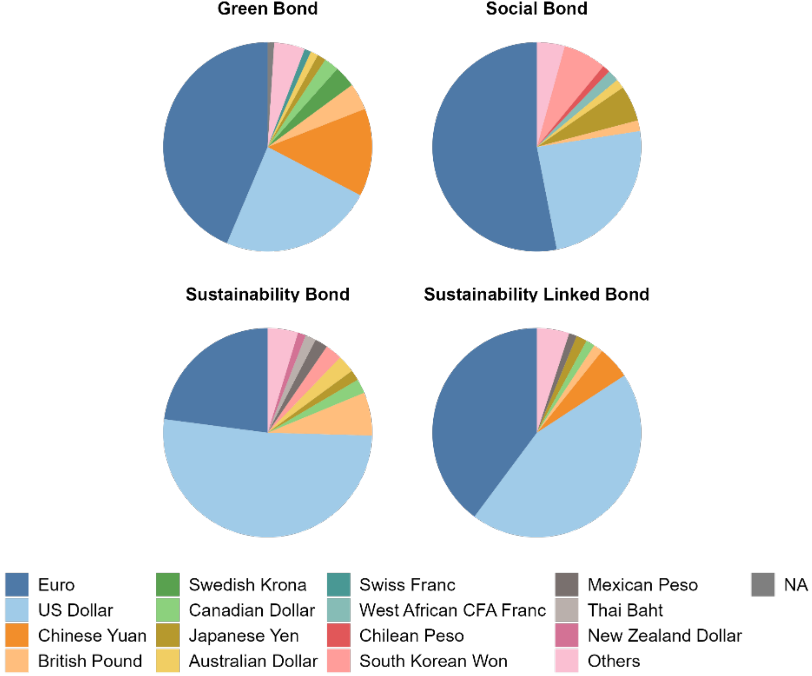
<table>
<tr><th>Refinitiv</th><th>CID</th></tr>
<tr><td>Agency</td><td>State-Owned entities, including:
▪ Public Banks
▪ Public OFC
▪ Non-Financial Public Corporations</td></tr>
<tr><td rowspan="3">Corporate</td><td>Banks</td></tr>
<tr><td>Other Financial Corporations</td></tr>
<tr><td>Non-Financial Corporations</td></tr>
<tr><td>Government / Central Banks</td><td>Sovereign</td></tr>
<tr><td>Non-US municipalities</td><td rowspan="2">State and Local Government</td></tr>
<tr><td rowspan="2">Other Government / Supranational</td></tr>
<tr><td>International Organizations</td></tr>
</table>

Source: Refinitiv, Thomson Reuters Business Classification, IMF Staff.

Annex III. Issuances by Type of Currency

Cummulative Global Sustainable Instrument Issuance by Type of Currency

(Cummulative, All Years)

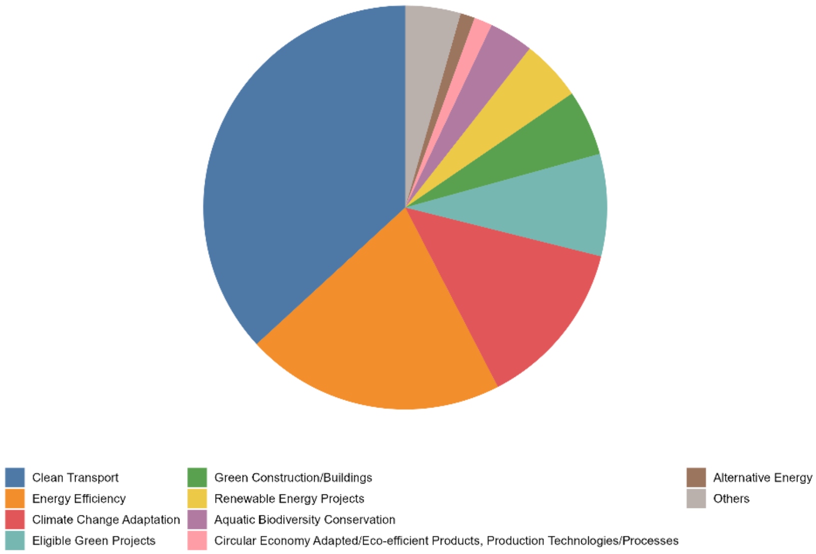


Note: Others = currencies with a share of less than 1%.

Sources: Refinitiv; IMF Staff Calculations.

Cummulative Green Bond Issuance by Use of Proceeds

(Cummulative, All Years)



Note: Others = proceeds with a share of less than 1%.

Sources: Refinitiv; IMF Staff Calculations.

Annex IV. Illustrative Reporting Template

The template below comes from the explanatory note on the recommendation 4 templates that can be accessed here.

Table 1.1a: Green Bonds Issues by Sector, Currency, Maturity, Interest Rate and Market of Issuance. Stocks at Nominal Value

🟧 **Orange cells: Core data to be transmitted by end-2025**

☐ **White cells: Advanced ambitions data to be transmitted by end-2027**

Issuer Currency Maturity Interest rate Market of issuance	Residents (S1)												All resident issuers (S1)
	Non-financial corporations (S11)	Financial corporations (S12)							General government (S13)		*Memo item:* public sector	Households and NPISH (S14+ S15)	
			Central bank (S121)	Other deposit-taking corporations (S122)	Money market funds* (S123)	Other financial corporations (S124 to S127)	*Of which:* Securitisation corporations (S125A)	Insurance corporations and pension funds (S128,S129)		*Of which:* Central government (S1311)			
Total	🟧	🟧		🟧	⬛	🟧			🟧	🟧		🟧	🟧
By domestic currency	🟧	🟧		🟧	⬛	🟧			🟧	🟧		🟧	🟧
By foreign currency	🟧	🟧		🟧	⬛	🟧			🟧	🟧		🟧	🟧
Short term at original maturity	🟧	🟧		🟧	⬛	🟧			🟧	🟧		🟧	🟧
Long term at original maturity	🟧	🟧		🟧	⬛	🟧			🟧	🟧		🟧	🟧
More than 1 year and up to and including 2 years					⬛								
More than 2 years and up to and including 5 years					⬛								
More than 5 years and up to and including 10 years					⬛								
More than ten years					⬛								
Of which: Long term at original maturity, with a remaining maturity up to and including 1 year					⬛								
Fixed interest rate					⬛								
Variable interest rate					⬛								
Inflation-linked					⬛								
Interest rate-linked					⬛								
Asset price-linked					⬛								
Domestic market					⬛								
International market					⬛								

*) Money market funds do not issue debt securities. 2008 SNA codes are used for sectors and subsectors.

Annex V. Illustrative Reporting Table

Table 5: Illustrative table to incorporate climate related data under SRFs – Other Depository Corporations - 2SR - Assets* (to be finalized)

Securities Other Nonfinancial Corporations NC*
Of which ESG debt securities
Of which: Social debt securities
Of which Green securities
Of which: Sustainability debt securities
Of which: Sustainability-linked debt securities
Of which: Other ESG debt securities
Of which Brown securities
Securities Other Nonfinancial Corporations FC*
Of which ESG debt securities
Of which: Social debt securities
Of which Green securities
Of which: Sustainability debt securities
Of which: Sustainability-linked debt securities
Of which: Other ESG debt securities
Of which Brown securities

*Nonfinancial corporations' sector is chosen for illustration purposes only. Similar data will be collected under the 1SR – Central Banks and 4SR – Other Financial Corporations report forms as well.

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Going Green in Finance: Bridging Data Gaps for Enhanced Financial Risk and Opportunities Assessment

CBRT-IFC WORKSHOP, İZMIR, TÜRKIYE

MAY 6-7, 2024

Artak Harutyunyan
Chief, Financial Institutions Division, Statistics Department

Outline of the Presentation

IMF and Climate Change

Role of IMF in Bridging Data Gaps on Green Finance

- Experimental Indicators on Climate Change Indicators Dashboard (CID)
- Data Gaps Initiative
- Updates to Statistical Methodology

The Way Forward

IMF and Climate Change

- Climate change is an **existential threat** to long-term growth and prosperity.
- The IMF is systematically covering climate-related issues through surveillance, lending, analytical, and capacity development work.

Source: F&D – December 2019

Risks

- Financial stability
- Economic stability

Transition Opportunities

- Job creation
- Growth
- Other externalities: improved biodiversity and air quality

Role of Climate Finance

Climate Finance

Achieving Paris Agreement objective and fighting the outcomes of climate change requires climate finance:

- Reduce reliance on carbon intensive means of production and thus emissions of greenhouse gases (GHG).
- Adaptation and resilience building

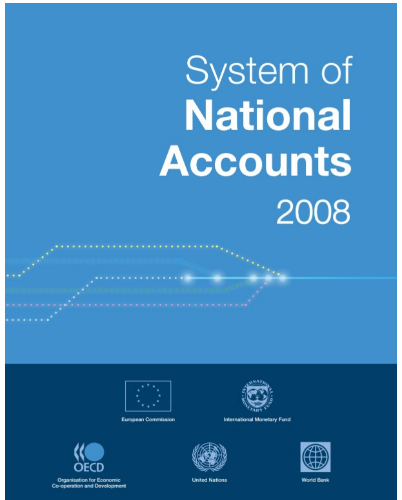
Finance gap

Estimates of global investments required to achieve the Paris Agreement's goals:

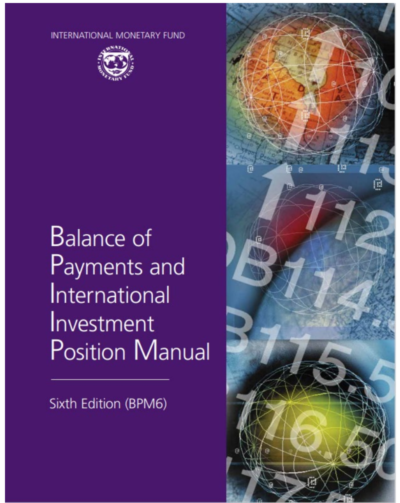
- US$3 to $6 trillion per year until 2050.
- Global climate finance currently adds to about US$630 billion annually. (IMF-2022)

Bridging Data Gaps: IMF's Statistics Department

- Climate Change Indicators Dashboard (CID)
- Data Gaps Initiative 3 (DGI-3)
- Introducing Climate Finance in Statistical Methodology
- Capacity Development


System of
National
Accounts
2008

European Commission
International Monetary Fund
OECD
United Nations
World Bank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Balance of
Payments and
International
Investment
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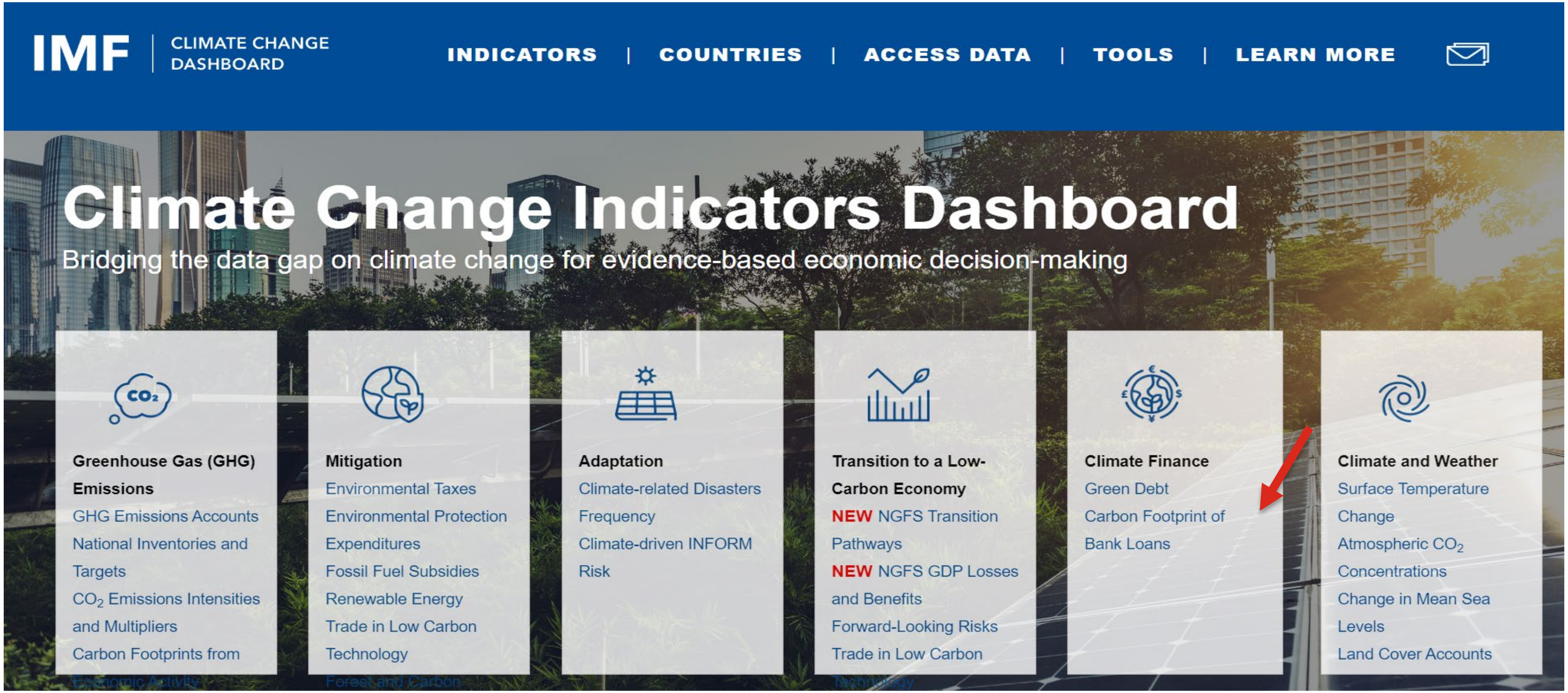
IMF's Climate Change Indicators Dashboard (CID)

- ✓ The CID addresses the growing need for climate-related data used in macroeconomic and financial stability analysis by identifying and developing a range of distinctive indicators, including experimental ones.



Climate Change Indicators Dashboard

Bridging the data gap on climate change for evidence-based economic decision-making

Greenhouse Gas (GHG) Emissions
- GHG Emissions Accounts
- National Inventories and Targets
- CO_2 Emissions Intensities and Multipliers
- Carbon Footprints from Economic Activity

Mitigation
- Environmental Taxes
- Environmental Protection Expenditures
- Fossil Fuel Subsidies
- Renewable Energy
- Trade in Low Carbon Technology
- Forest and Carbon

Adaptation
- Climate-related Disasters Frequency
- Climate-driven INFORM Risk

Transition to a Low-Carbon Economy
- NEW NGFS Transition Pathways
- NEW NGFS GDP Losses and Benefits
- Forward-Looking Risks
- Trade in Low Carbon Technology

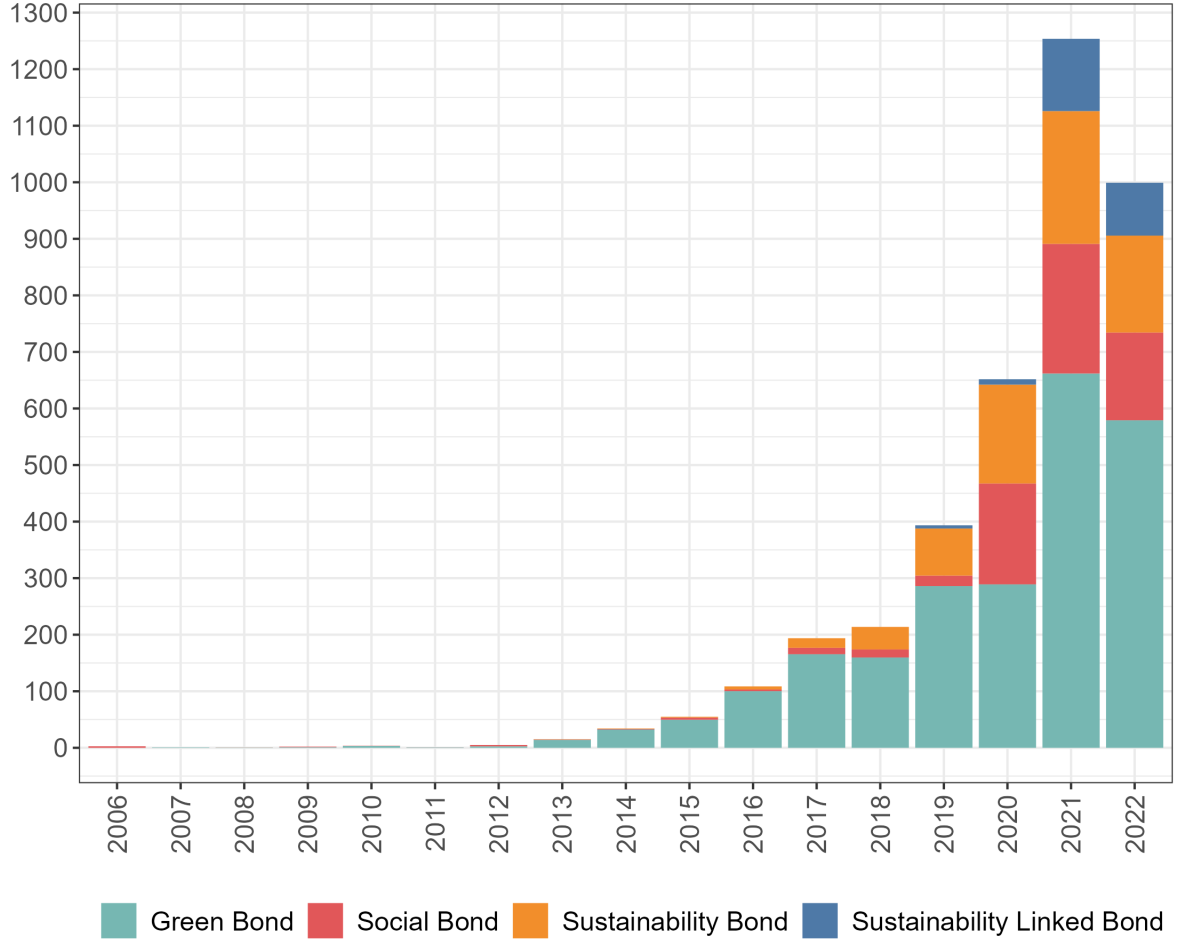
Climate Finance
- Green Debt
- Carbon Footprint of Bank Loans

Climate and Weather
- Surface Temperature Change
- Atmospheric CO_2 Concentrations
- Change in Mean Sea Levels
- Land Cover Accounts

ESG Debt Issuances Continue to Fall short of Meeting Financing Needs

Global Sustainable Instrument Issuance by Instrument

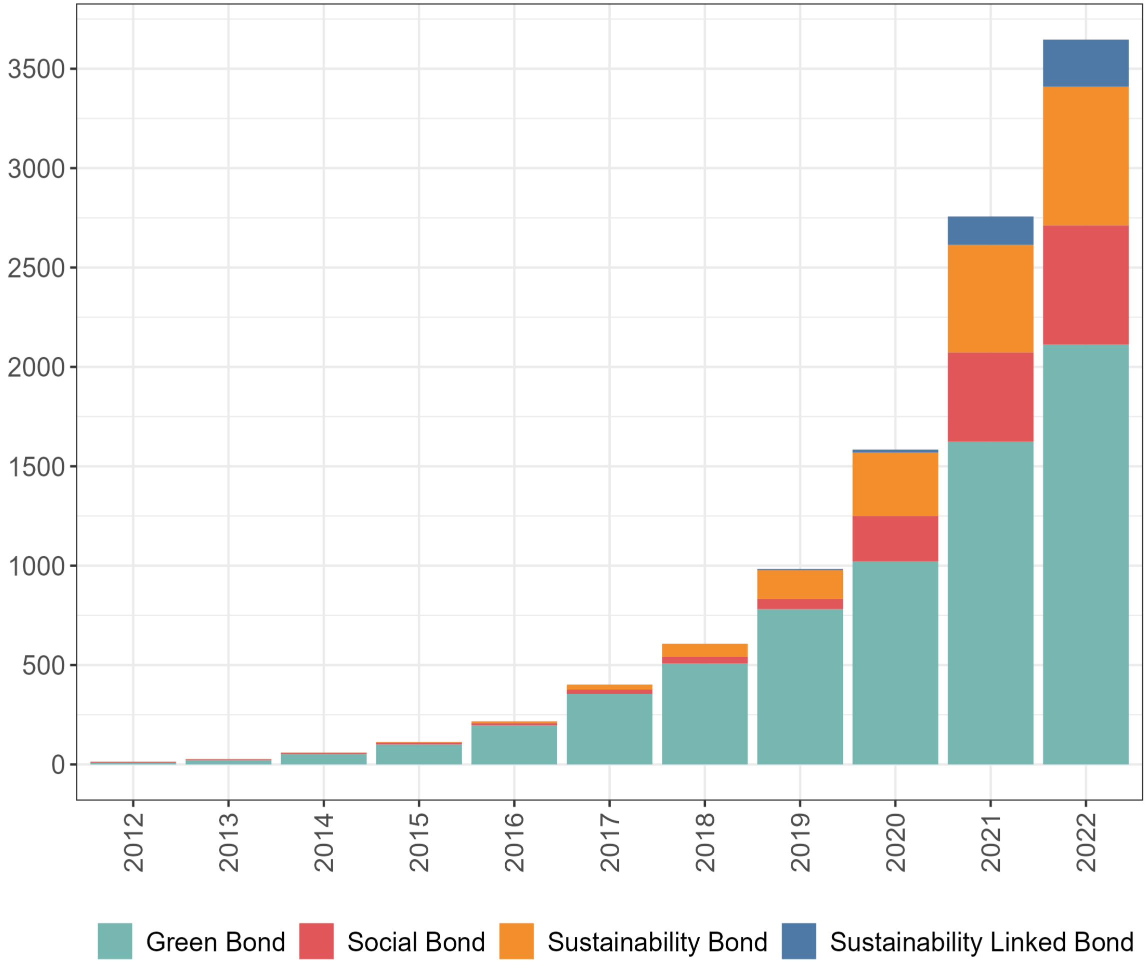
(Billions of U.S. dollars)



Sources: Refinitiv; IMF Staff Calculations.

Global Sustainable Instrument Amount Outstanding by Instrument

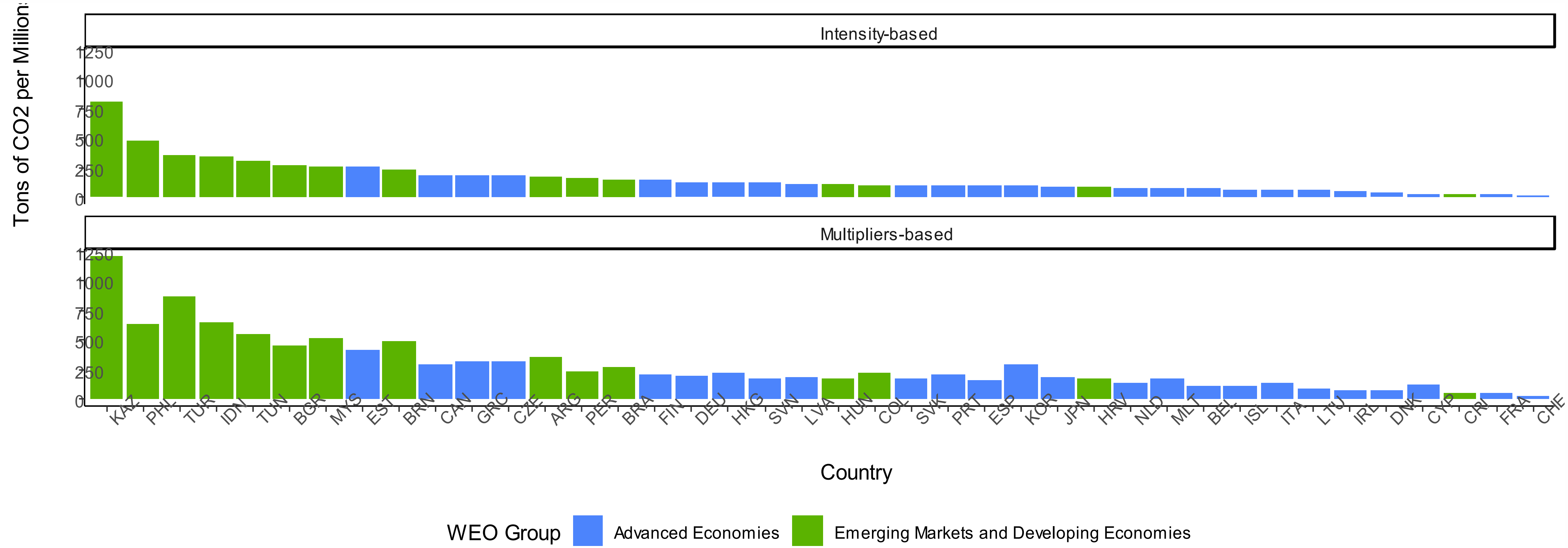
(Billions of U.S. dollars)



Sources: Refinitiv; IMF Staff Calculations.

Carbon Footprint of Bank Loans Indicator (CBFL)

- The CFBL indicator, a country-level indicator, constructed as the average of carbon dioxide (CO_2) **emission factors** from fuels used in each sector, weighted by the **sectoral share of outstanding loans** from deposit takers.
- EMDEs have higher metrics for both intensity-based and multipliers-based measures.



G20 – Data Gaps Initiative 3 - Recommendations

- The new DGI-3 endorsed by the G20 FMCBG will play an important role in addressing climate-related data gap.
- G20 Leaders asked the IMF to coordinate with the FSB, the IAG, and statistical authorities across the G20 to “begin work on filling these data gaps"
- DGI-3 Global Conference held in Washington D.C. in June 2023
- First Progress Report of DGI-3 was published in October 2023

- **Climate Change**
  - Greenhouse Gas Emissions Accounts, Energy Accounts and Carbon Footprint of FDI
  - Climate Finance
  - Forward Looking Physical and Transition Risk Indicators
  - Climate Subsidies and Mitigation and Adaptation Expenditures
- **Household distribution**
  - Distributions of Household Income, Consumption and Wealth
- **Fintech and Financial Inclusion**
  - FinTech Credit
  - Digital Money
  - Financial Inclusion
- **Access to Private and Administrative Data**
  - Data Sharing Agreements
  - Access to Private and Administrative Data

DGI 3 – Recommendations on Climate

Recommendation 1: **Greenhouse gas emission accounts and carbon footprints**	*To monitor progress towards emission targets and the transition towards a low carbon economy.*
Recommendation 2: **Energy Accounts**	*Data to monitor transformation of the energy sector which is key to addressing climate change.*
Recommendation 3: **Carbon Footprint of Foreign Direct Investment (FDI)**	*To monitor cross-border emissions through trade, investment, and global value chains (GVCs).*
Recommendation 4: **Climate Finance**	*Data to track the source of funds available for green projects and activities that can mitigate climate change and help countries adapt to its implications.*
Recommendation 5: **Forward Looking Physical and Transition Risk Indicators**	*Quantify and monitor forward looking risk to help prioritize and develop support for climate action.*
Recommendation 6: **Climate-Impacting Government Subsidies**	*Provide comparable estimates for insight into government subsidy regimes to tackle climate change.*
Recommendation 7: **Climate Change Mitigation and Adaptation Expenditures**	*Track level of expenditures to mitigate and adapt to the effects of climate change to ensure achievement of national commitments.*

DGI 3 – Recommendations 4 on “Climate Finance”

- **Policy Driver:** Incentivizing investments in green projects and activities that can contribute to climate change adaptation and mitigation.

- **Statistical Outputs**: Issuances and holdings of green debt securities and green listed shares.

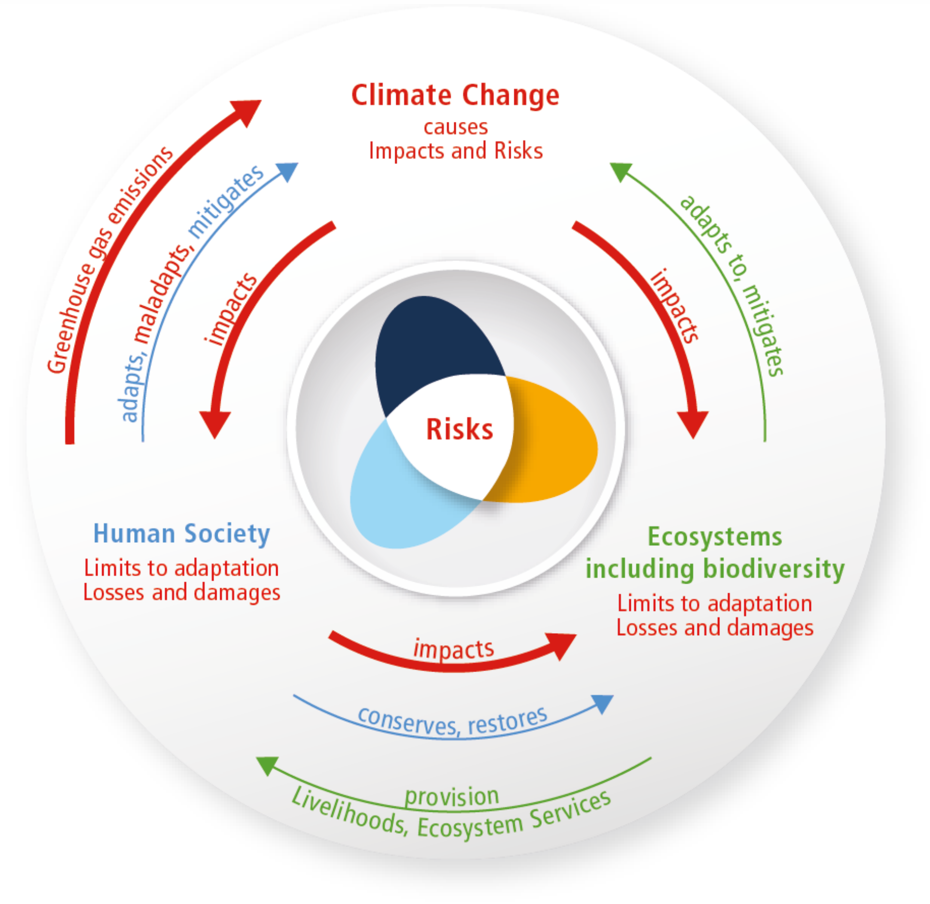
- Objective is to address data gaps by:
  1. Developing reporting templates for experimental data on issuances and holdings of green debt securities and listed shares securities consistent with the Handbook on Securities Statistics (HSS)
  2. Providing methodological guidance to enhance data interoperability and comparability

- BIS and ECB are leading this in collaboration with international organizations and G20 countries

- An in-person Workshop was held in Cape Town during October 5-6, 2023
  - Data templates were discussed and agreed upon
  - The collection covers statistics on issuances and holdings on a from-whom-to-whom basis for green bonds, sustainability bonds, sustainability-linked bonds, and green listed shares.

DGI 3 – Recommendations 5 on “Forward Looking Physical ad Transition Risk Indicators”

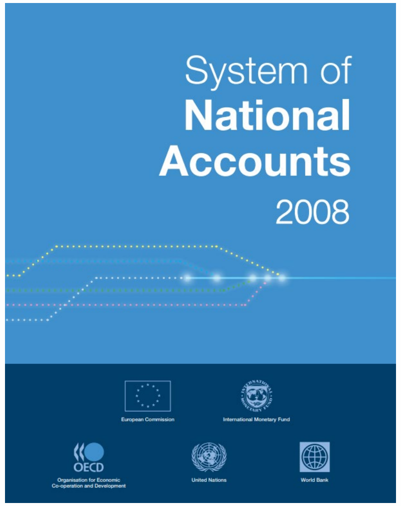
- **Policy Driver:** Quantify and monitor forward looking risk, physical as well as transition risks, to help prioritize and develop support for climate action.
- **Statistical Outputs:** Forward looking physical and transition risk indicators (risk to populations, economic growth, financial markets, firms etc.)
- **Methodological guidance** is being developed and a **concept note** has been presented and shared with G20 countries in a workshop in Q42023
- IMF is leading this work with other international organizations: BIS, FSB, ECB, OECD and World Bank.



Source: IPCC

Introducing Climate Finance in Statistical Methodology

- Update to the international statistical standards
  - The *SNA 2025* will include:
    - Additional environmental classes for bonds, loans, equity, and investment fund shares.
    - Definitions for ESG/Green Financial Instruments recognizing that these will be updated as they evolve over time.
  - Balance of Payments and International Investment Position Manual, *BPM7*– Annex (updatable) on Sustainable Finance
    - Some items from the BOP/IIP framework and possible additional breakdowns:
      - Direct investment in specific sectors; Direct Investment by counterparty country.
      - Supplementary "of which" category for transactions and positions in "green-labelled" bonds as well as for interest in the returns earned on them.
      - Supplementary data on international cooperation grants to low-income countries to finance climate change mitigation and adaptation.


System of
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Accounts
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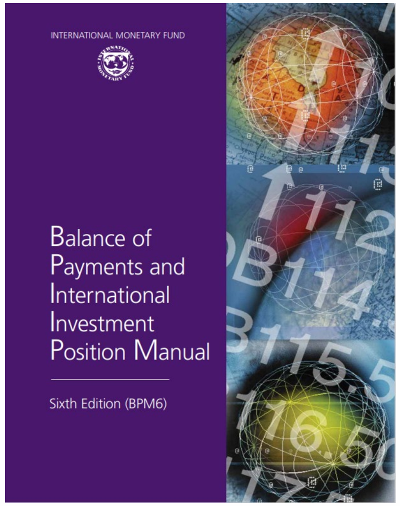
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Position Manual

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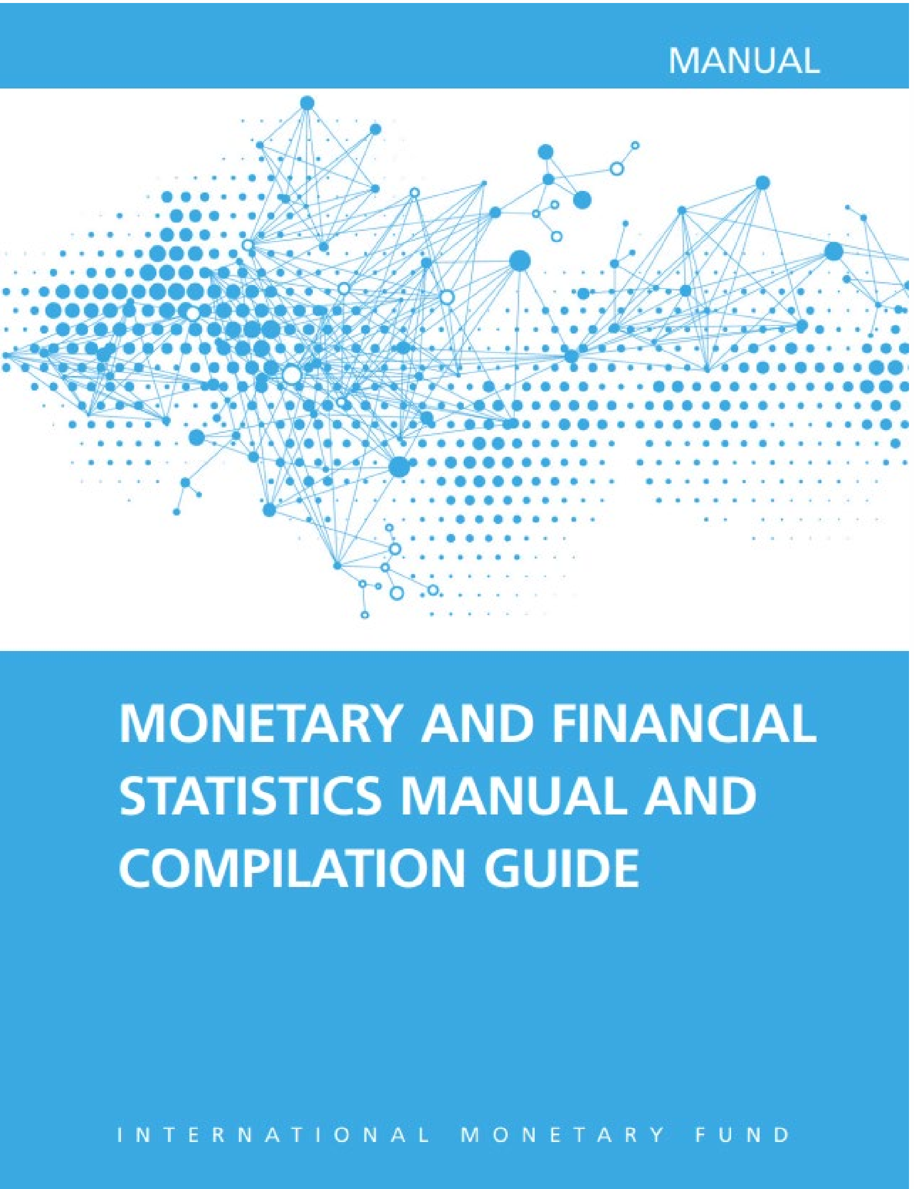
Climate Finance Data Project for the Financial Sector



MANUAL

MONETARY AND FINANCIAL STATISTICS MANUAL AND COMPILATION GUIDE

INTERNATIONAL MONETARY FUND

Main Objective:

Leverage IMF’s monetary statistics database to bridge climate-related data gaps for the financial sector

Conduct a pilot exercise

Evaluate data availability and assess the feasibility of collecting relevant granular climate-related details within the framework of the existing MFS database

Set of pilot countries will report data

→

Use of the metadata

Support the work on developing a harmonized compilation methodology

→

Dissemination of data and indicators

Separate set of supplementary tables to the MFS database or integrated

Complement other ongoing work (DGI 3.0, FSB Climate Vulnerabilities and Data WS)

Climate Finance Data Project for the Financial Sector

Objectives of the Project

- Project aims to integrate climate-related data into **standardized report forms** (SRFs) within the existing monetary statistics framework.
- Pilot results will also help **inform methodological guidance** for the SNA and BPM6 update.
- The project will aid the upcoming ***MFSMCG* update**.
- Based on pilot results, this can be integrated into the monetary statistics collection or as a standalone database, with **broader country coverage**.

Pilot Phase

- **Pilot** will be launched for **50 countries**
- Countries will be requested to **submit quarterly data**, on a **voluntary basis**, with historical series covering a five-year period, whenever feasible.
- Cross-references will be introduced at aggregate level, where feasible, to **align with Rec#4** reporting format.
- **Metadata** to be submitted, including definitions and variations.

Suggested Data Categories

Climate-related (low carbon / carbon intensive) assets/liabilities

- Data categories: Low carbon (green) / carbon intensive (brown) loans, debt securities, equity, financial derivatives.
- Potential Indicators: Share of low-carbon assets/liabilities in the balance sheet / loan portfolio / securities portfolio

Exposures by sectors

- Data categories: Loans and debt securities broken down by sector
- Potential Indicators: Carbon footprint of bank loans, carbon footprint of investments, share of exposures to high/low carbon intensity sectors

Geolocational distribution of exposures

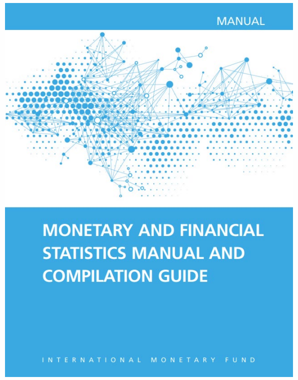
- Data categories: Geolocational distribution of loans
- Potential Indicators: Exposures of financial institutions to climate hazards (tropical cyclones, droughts, etc.)

Structure:

- Additional breakdowns under MFS reporting

LOANS
In National Currency
Loans Other Nonfinancial Corporations NC
- of which green
- of which carbon intensive
Loans Nonresidents NC
- of which green
- of which carbon intensive
In Foreign Currency
Loans Other Nonfinancial Corporations FC
- of which green
- of which carbon intensive
Loans Nonresidents FC
- of which green
- of which carbon intensive

- Supplementary tables



MANUAL

MONETARY AND FINANCIAL STATISTICS MANUAL AND COMPILATION GUIDE

INTERNATIONAL MONETARY FUND

Coordination with Other Ongoing Initiatives

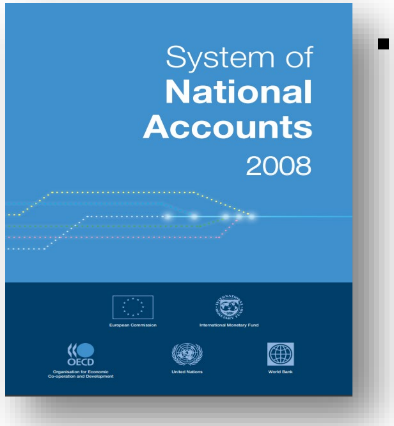
Strong links with ongoing statistical initiatives…

- Data collection beyond G-20 countries.
- Support the work on DGI
  - ➢ Rec 4 on Green Finance
  - ➢ Rec 5 on Forward Looking Physical and Transition Risk Indicators

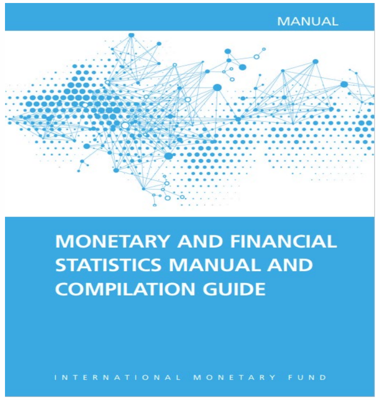
- New and updated indicators for the CID.
  - ➢ Climate finance indicators
  - ➢ Risk indicators

FSB FINANCIAL STABILITY BOARD

- Support CVD's work on the assessment of evolution of climate vulnerabilities.

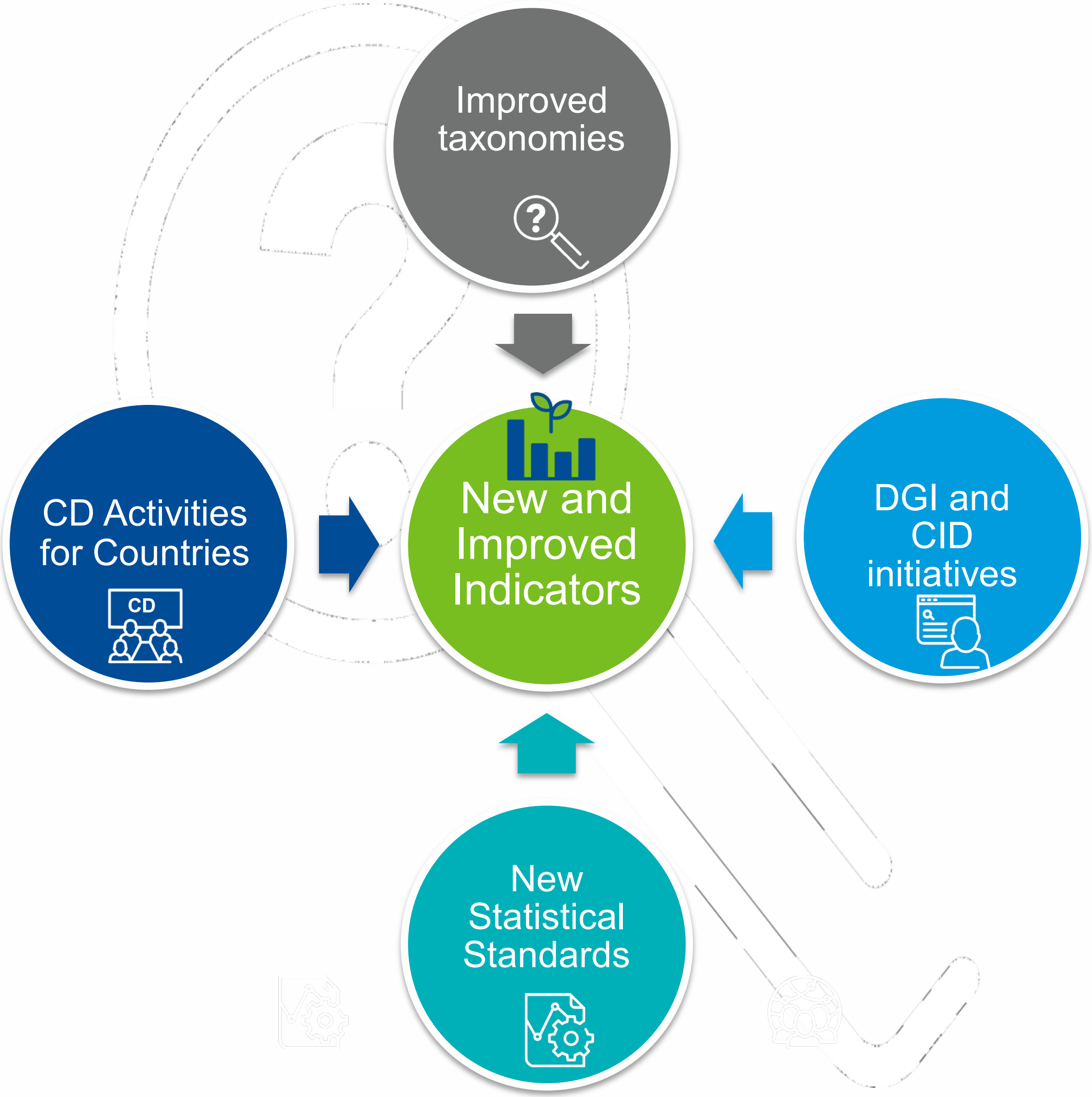


- Test the definitions (environmental classes) and provide feedback for SNA 2025 update.



- Important input for the MFSMCG update to harmonize compilation methodology.

Way Forward



Improved taxonomies

CD Activities for Countries

New and Improved Indicators

DGI and CID initiatives

New Statistical Standards

G20 DATA GAPS INITIATIVE

PEOPLE PLANET ECONOMY

DELIVERING INSIGHTS FOR ACTION

IMF | CLIMATE CHANGE DASHBOARD

Thank You!

Questions?

Proposed structure for ESG and green financial instruments for the 2025 SNA

Table 1: ESG and green financial instruments in the *2025 SNA*

AF.1	Monetary gold and SDRs
AF.2	Currency and deposits
AF.3	Debt securities
	Of which: ESG debt securities
	Of which: Social debt securities
	Of which: Green debt securities
	Of which: Sustainability debt securities
	Of which: Sustainability-linked debt securities
	Of which: Other ESG debt securities
AF.4	Loans
	Of which: ESG loans
	Of which: Green loans
AF.5	Equity and investment fund shares
AF.51	Equity
	Of which: ESG equity
	Of which: Green equity
AF.52	*Investment fund shares*
	Of which: ESG investment fund shares
	Of which: Green investment fund shares
AF.6	Insurance, pension and standardized guarantee schemes
AF.7	Financial derivatives and employee stock options
AF.8	Other accounts payable/receivable

Source: SNA update Issues Note (2024), Table 3.

Proposed table for ESG and green financial instruments for the BPM7 (IIP and BOP)

Table 3: ESG and green financial instruments in the upcoming *BPM7* (IIP and BOP)

1	**I. Direct Investment**
1.1	Equity and investment fund shares
	Of which: ESG equity/investment fund shares
	Of which: Green equity/investment fund shares
1.2	Debt Instruments
	Of which: 1.2.0.1 Debt Securities
	Of which: ESG debt securities
	Of which: Social debt securities
	Of which: Green debt securities
	Of which: Sustainability debt securities
	Of which: Sustainability-linked debt securities
	Of which: Other ESG debt securities
2	**II. Portfolio Investment**
2.1	Equity and investment fund shares
	Of which: ESG equity/investment fund shares
	Of which: Green equity/investment fund shares
2.2	Debt Securities
	Of which: ESG debt securities
	Of which: Social debt securities
	Of which: Green debt securities
	Of which: Sustainability debt securities
	Of which: Sustainability-linked debt securities
	Of which: Other ESG debt securities
3	**III. Financial Derivatives**
4	**IV. Other Investment**
4.1	Other equity
4.2	Currency and deposits
4.3	Loans
	Of which: ESG loans
	Of which: Green loans
4.4	V. Insurance, pension and standardized guarantee schemes
4.5	VI. Trade credit and advances
4.6	VII. Other accounts receivable/payable
4.7	VIII. SDRs
5	IX. Reserve assets

Illustrative reporting template: Recommendation 4

Table 1.1a: Green Bonds Issues by Sector, Currency, Maturity, Interest Rate and Market of Issuance. Stocks at Nominal Value

🟧 **Orange cells: Core data to be transmitted by end-2025**
White cells: Advanced ambitions data to be transmitted by end-2027

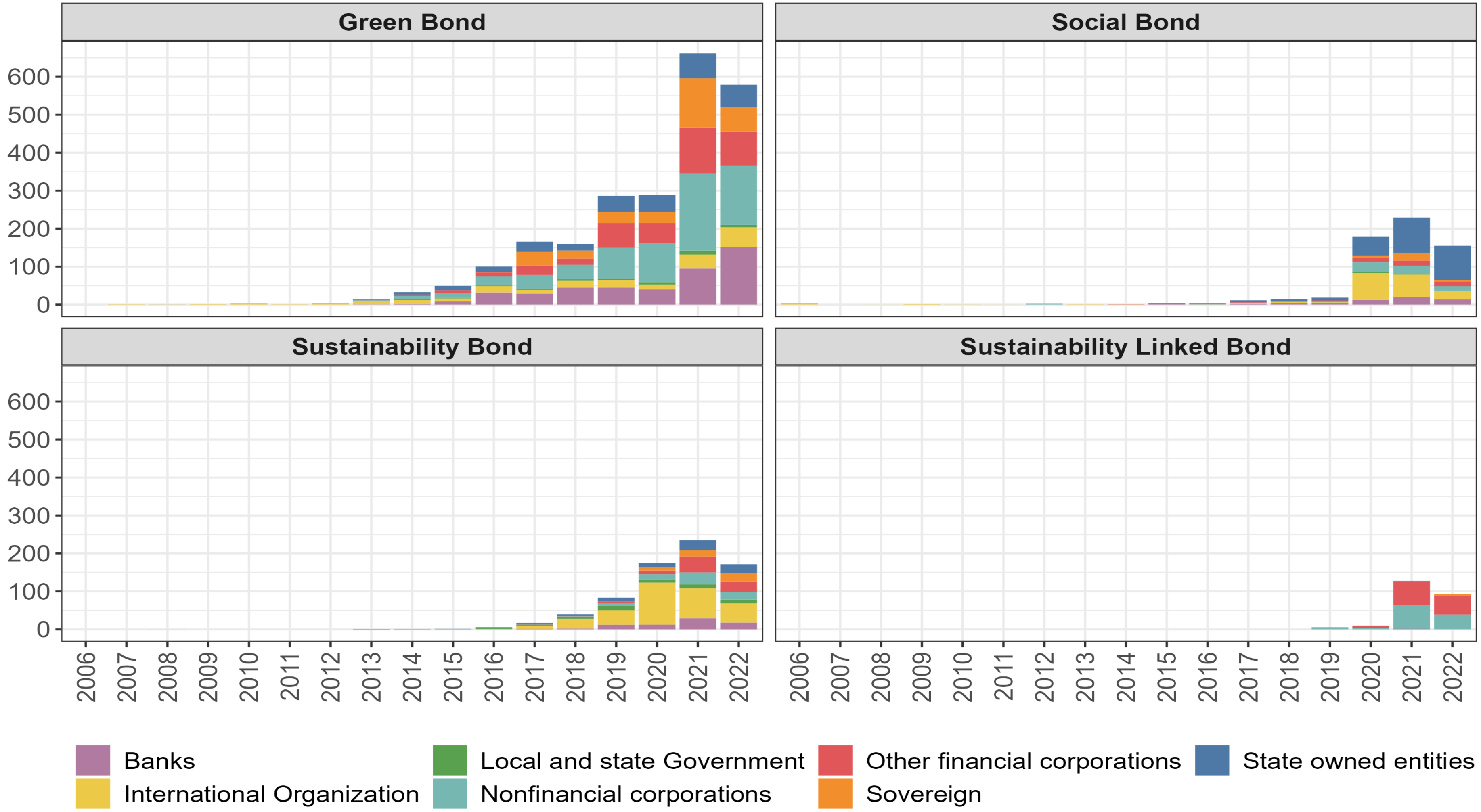
Issuer	Residents (S1)												All resident issuers (S1)
	Non-financial corporations (S11)	Financial corporations (S12)							General government (S13)		*Memo item:* public sector	Households and NPISH (S14+ S15)	
Currency Maturity Interest rate Market of issuance			Central bank (S121)	Other deposit-taking corporations (S122)	Money market funds* (S123)	Other financial corporations (S124 to S127)	*Of which:* Securitisation corporations (S125A)	Insurance corporations and pension funds (S128,S129)		*Of which:* Central government (S1311)			
Total	🟧	🟧		🟧	⬛	🟧			🟧	🟧		🟧	🟧
By domestic currency	🟧	🟧		🟧	⬛	🟧			🟧	🟧		🟧	🟧
By foreign currency	🟧	🟧		🟧	⬛	🟧			🟧	🟧		🟧	🟧
Short term at original maturity	🟧	🟧		🟧	⬛	🟧			🟧	🟧		🟧	🟧
Long term at original maturity	🟧	🟧		🟧	⬛	🟧			🟧	🟧		🟧	🟧
More than 1 year and up to and including 2 years					⬛								
More than 2 years and up to and including 5 years					⬛								
More than 5 years and up to and including 10 years					⬛								
More than ten years					⬛								
Of which: Long term at original maturity, with a remaining maturity up to and including 1 year					⬛								
Fixed interest rate					⬛								
Variable interest rate					⬛								
Inflation-linked					⬛								
Interest rate-linked					⬛								
Asset price-linked					⬛								
Domestic market					⬛								
International market					⬛								

*) Money market funds do not issue debt securities. 2008 SNA codes are used for sectors and subsectors.

Issuances by Type of Issuer

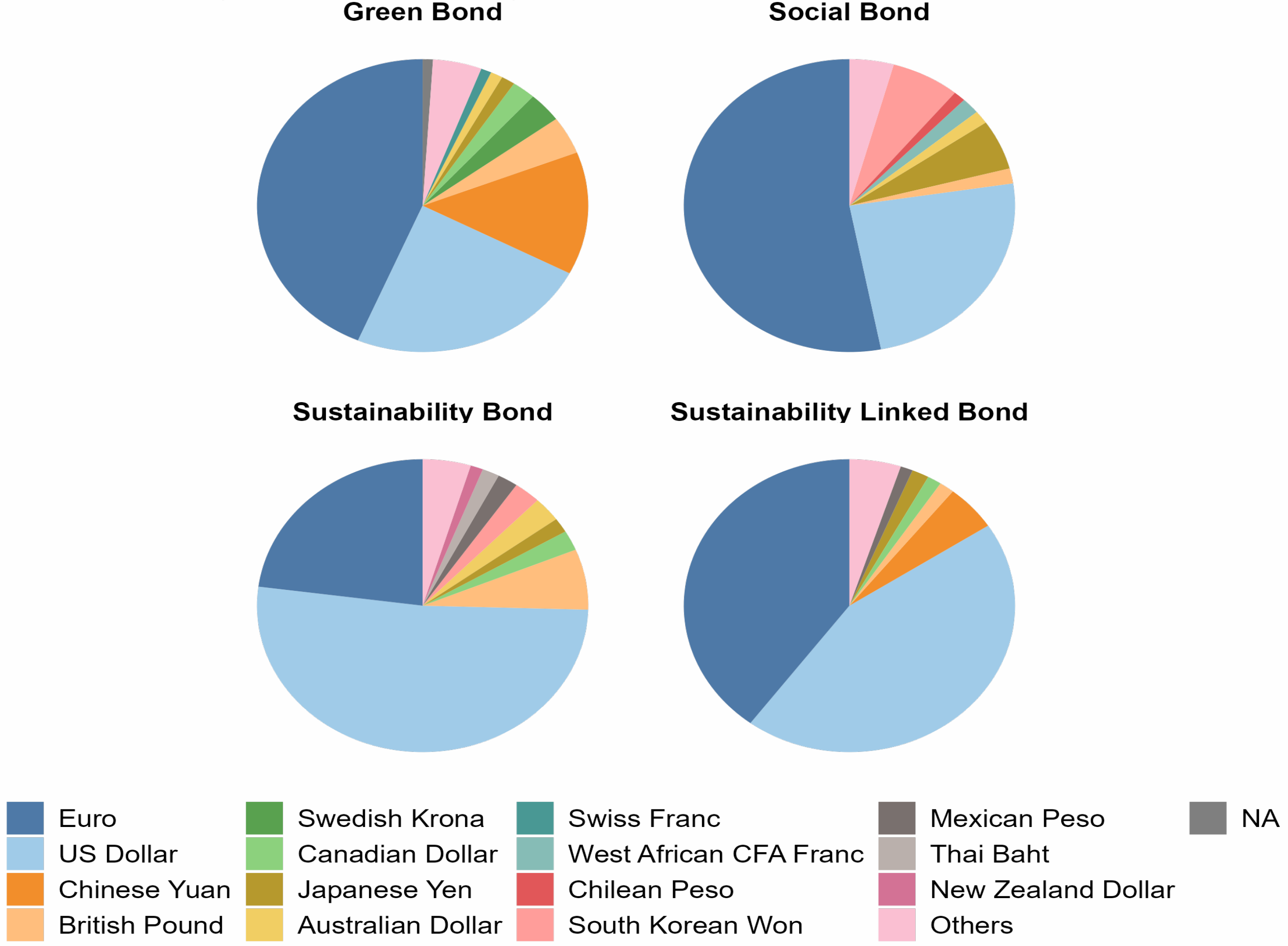
Global Sustainable Instrument Issuance by Type of Issuer

(Billions of U.S. dollars)



Sources: Refinitiv; IMF Staff Calculations.

The Euro and the Dollar emerge as the primary currencies for issuances, followed by Chinese Yuan



Cummulative Global Sustainable Instrument Issuance by Type of Currency

(Cummulative, All Years)

Note: Others = currencies with a share of less than 1%.

Sources: Refinitiv; IMF Staff Calculations.

IMF's Resilience and Sustainability Facility (RSF)

RSF

- ✓ Financing and policy reforms to reduce significant macro-critical risks associated with **long-term structural challenges: climate change** and **pandemic preparedness** at the outset.
- ✓ **Boost policy space** by building policy and financial buffers against such risks. Contributes to **longer-term *prospective* balance of payments stability**
- ✗ The RSF is **not aimed at project financing.**
- ✗ The RSF is **not aimed to address short- to medium-term BoP problems** (which is the focus of other Fund-supported programs).

IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

We aim to curb emissions – but how can we know where we stand?[1]

U von Kalckreuth,
Deutsche Bundesbank

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

We aim to curb emissions – but how can we know where we stand?

People and perspectives meet: an international workshop on carbon content measurement

Ulf von Kalckreuth, Deutsche Bundesbank

CBRT-IFC Workshop on Addressing Climate Change Data Needs: The Global Debate and Central Banks' contribution

Izmir, Türkye, 6-7 May 2024

Thanks to Alessandra Alfieri, Fabienne Fortanier, Robert Kirchner, Mike Mahoney, Stephan Moll, Karthik Ramanna, Christian Schmieder, and John Verrinder

Carbon content measurement for products, organisations and aggregates: creating a sound basis for decision making

International workshop organised by the IMF, the BIS/IFC, Eurostat, the Deutsche Bundesbank, the Banco Central de Chile and the University of Oxford Blavatnik School of Government

Link to conference website, incl presentations

"Only what gets measured, gets managed" (Bo Li)

Reliable and readily available measures of **carbon content** enable:

- **Companies** to align their production processes in a climate-friendly way,
- **Investors** to direct their capital towards climate-friendly investments if they wish,
- **Banks** to better assess the climate risks in their portfolios,
- **Governments and regulators** to intervene if necessary, and
- **Consumers** to better understand the consequences for the environment of their decision to purchase a particular product or service.

Carbon content information is a necessary condition for rational environmentally-oriented decision making.

"Only what gets measured, gets managed" (Bo Li)

Carbon content information is produced and needed on three levels:

• **Aggregate level -- country and sector**	**statistics**
• **Company level**	**non financial reporting**
• **Product level**	**carbon accounting**

As yet, measurements and measurement concepts are unrelated. There is **no joint framework, no cross-validation**, no way to use data from one level to **fill data gaps** in the other.

"Only what gets measured, gets managed" (Bo Li)

Carbon content information is produced and needed on three levels:

- **Aggregate level -- country and sector** **statistics**
  G 20 Data Gaps Initiative (DGI), ECB ESG climate indicators
- **Company level** **non financial reporting**
  ISSB Standards, EU Legislation, specifically CSRD and ESRS
- **Product level** **carbon accounting**
  industry initiatives (chemical industry, automobiles), accounting research

As yet, measurements and measurement concepts are unrelated. There is **no joint framework, no cross-validation**, no way to use data from one level to **fill data gaps** in the other.

The Hamburg workshop – design

=► At the workshop, **experts from different fields met** to inform each other on the status quo, the objectives, the way forward, and to discuss synergies.

=► Workshop **organised by leading questions**, formulated beforehand

=► Workshop was **designed for interactivity.**
No cfp, no pre-produced papers, many short presentations and discussions

=► **Two parallel modes:**
- morning and late afternoon: **in-presence // Chatham house rules**
- 1-3 pm **open hybrid panels** for maximum international interaction

The Hamburg workshop – topics

- Opening panel: Overarching questions in accounting and statistics of CO_2 emissions
- What do statisticians offer, what do they need from accounting and reporting standard setters?
- Direct and indirect emissions – company-level information management and input-output statistics. Accounting, recordkeeping, and auditing of emissions data in supply chains
- Direct measurement of primary emissions data
- Dissemination: Carbon data platforms
- Closing panel: Summarising results and ways forward

Link to full program

Some concepts

Special focus

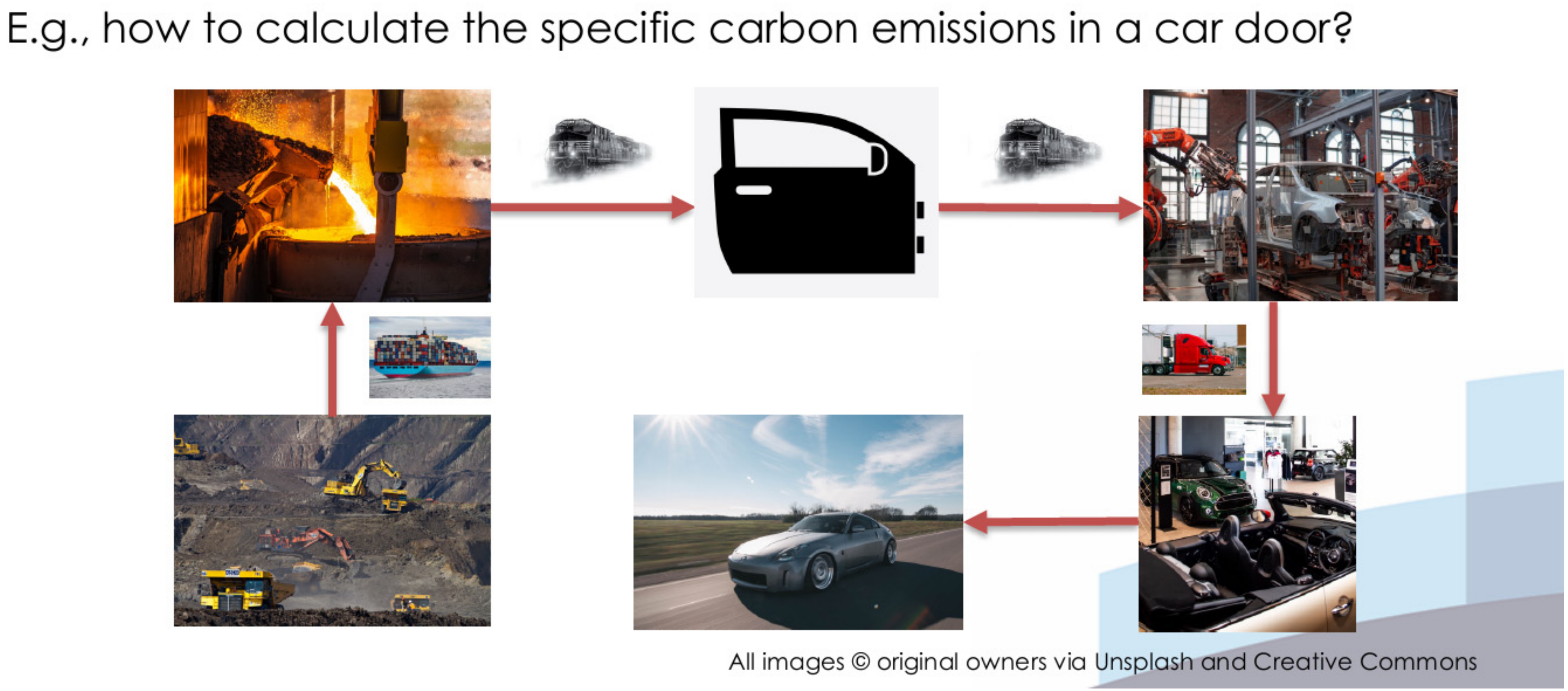
With emission data, we distinguish between

- **Direct emissions (Scope 1),** generated in production itself
- **Indirect emissions**, generated in the production of inputs,
  - Emissions due to the use of **energy** and **heat (Scope 2)**
  - **All other** indirect emissions **(Scope 3)**
- **Carbon content** – the sum of direct and upstream indirect emissions.
- Analogous to **total energy content of food.**

Direct measurement of direct emissions

Evaluating emissions associated with inputs

Some concepts



E.g., how to calculate the specific carbon emissions in a car door?

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Graph by courtesy of R. Kaplan and K. Ramanna, taken from session 1, levelling-up presentation

Indirect emissions and total carbon content

Consider the *bill of material* (BoM) of product *k*, with $a_{k,i}$ being the quantity of good *i* embodied in the production process:

$$\mathbf{a}_k = (a_{k1} \quad a_{k2} \quad \dots \quad a_{kK})'$$

Let d_k be the amount of GHG directly emitted and c_i be the carbon content of input *i*

direct emissions

indirect emissions

valuation structure of inputs

Then the carbon content of good *k* is given as the **sum of direct and indirect emissions**:

Carbon content vector

$$c_k = d_k + \mathbf{c}'\mathbf{a}_k = d_k + \sum_i c_i a_{ki} \qquad (1)$$

quantity structure of inputs

If the c_i are known, we can calculate the carbon content of product k directly.

The hen and the egg problem

What if we do not know the carbon content of our inputs?

Three types of answers:

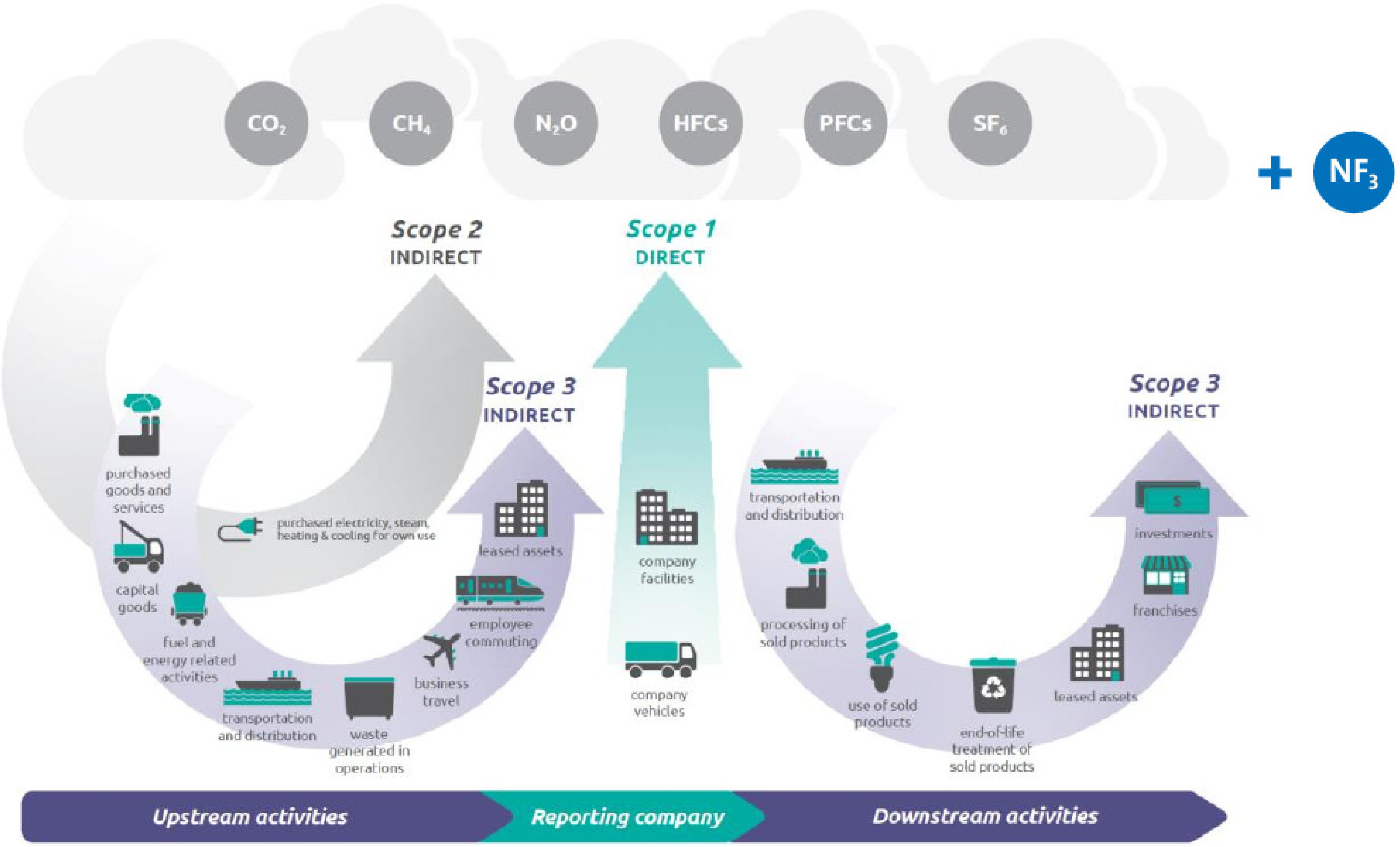
- Try to understand your value chain and quantify direct emissions on each stage, then sum up

  Drilling down the value chain: The tao of the GHG protocol
- From knowledge of input requirements, solve for carbon content of all products in the system

  Explicit knowledge: The tao of IO
- Make your input provider give you the required information

  Implicit knowledge: The tao of cumulative carbon accounting

The tao of GHG Protocol



Source: Greenhouse Gas Protocol (2011): *Corporate value chain (Scope 3) accounting and reporting standard.*

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The tao of IO

If the c_i are unknown, the equation is **recursive**. Equation (1) is an **IO model for production**. We can solve for the GHG value of all products simultaneously. Let

$$\mathbf{A} = (\mathbf{a}_1 \quad \mathbf{a}_2 \quad \dots \quad \mathbf{a}_K)$$

be the matrix of the BoMs for all produced goods. With **d** the vector of direct emissions for products 1,…, *K*, we may write:

$$\mathbf{c}' = \mathbf{d}' + \mathbf{c}'\mathbf{A}$$

and solving for **c** yields

$$\mathbf{c}' = \mathbf{d}'(\mathbf{I} - \mathbf{A})^{-1} \qquad (2)$$

Carbon contents of all goods

Direct emissions for all goods

Leontief inverse, reflecting production interlinkages

This is how actual IO works using industry level data from different countries.

It also shows how the carbon content of products is derived from direct emissions and interlinkages

Cumulative carbon accounting – the tao of E-Liability

E-liability is the most prominent version of cumulative carbon accounting. Proposed and developed by **R. Kaplan (Harvard) and K. Ramanna (Oxford)** since 2021.

E-liability works straight from the definition of carbon content:

$$c_k = d_k + \mathbf{c}'\mathbf{a}_k = d_k + \sum_i c_i a_{ki}$$

Carbon content is cumulative, like VAT, thus carbon content information is passed through the system, from input provider to producer and further down the supply chain, to the end-user.

To allocate emissions to output, all standard methodology of cost accounting is used! Direct and indirect emissions are treated as an **accounting liability**.

Direct information from providers or own measurement have highest priority. Data gaps filled using estimates, eg from statistics. If carbon contents provided by suppliers are used throughout the system, carbon contents will converge, even if starting values are bad (von Kalckreuth, 2022, 2024)

Common points emerging

The workshop was a testing ground for identifying joint views and shared issues to solve, among industry specialists, academics, standards-setters, central bankers, and statisticians.

Key message: carbon content information can be gathered and processed alongside financial information, using the same concepts and the same infrastructure:

- Balance sheets
- Finacial and cost accounting

This is a **vision** and a **challenge**

Essential role of carbon content – direct plus upstream indirect emissions -- for cumulative carbon accounting

Common points emerging

The workshop was a testing ground for identifying joint views and shared issues to solve, among industry specialists, academics, standards-setters, central bankers, and statisticians.

- Crucial role of **reliable and relevant carbon content data** at both macro and micro levels
- We need to move fast, therefore the need to **leverage on what exists**
- Need for a global approach -- **compatible standards**
- The importance of **process efficiency**, minimising burdens on entities
- The application of latest **digital technologies** for compilation, reporting and data flow
- The role of **incentivisation** techniques
- The benefits of **inter-disciplinary cooperation** (industry specialists, academics, standards-setters, central bankers, statisticians…)

The statistical angle

- Macro statistics are the predominant form of public data available now
- But they are:
  - **Highly based on assumptions** >> can be improved with data from industry
  - **Not granular** >> need to work on more detailed industry/product breakdowns
  - **Patchy in coverage** across countries >> role of Data Gaps Initiative
  - Role of statistics to help filling gaps and support convergence in microdata
- Importance of efficient **statistical access to emerging microdata**, **sharing of classifications and definitions** where possible

Disclosure or accounting – or both?

- Establishing a **distinction** between them…
- Many current initiatives based on **disclosure**
  - But unlikely they will organically develop into accounting
  - **Engagement with standard setters** on future direction
- The underlying principle of “passing on” carbon content (e.g. on invoices) can be applied in both disclosure and accounting approaches
- E-liabilities based on double entry accounting.
- Ordinary cost accounting does not need audits, as the information it generates is for internal use only. This is different with carbon accounting.
- Need to identify who could actually create carbon accounting standards.

Direct measurement

- Situation is **unsatisfactory.** Estimates and rules of thumb predominate. No clear view of total emissions

- Workshop saw many innovative approaches…
- Increasing role of **satellite imagery** –> in this conference an entire session
  - – Certainly at macro level
  - – Surprising advances at micro level
- Combining / contrasting direct measurement data – they can build on each other
- How can developing expertise at industry and scientific levels be pooled?

Sectoral aspects

- Need for a **unified system for carbon content measurement**
- Some sectors are:
  - – **more relevant** than others (fossil fuels, cement, chemicals, cars, steel…)
  - – **already working in a collaborative way** within their specific situations
- **Small entities** need a simple way to contribute ‘bottom-up’, leveraging on statistical data
  - – E.g. work of Carbones sur Factures, IDG security
- Consider **government entities**…
  - – as reporters …
  - – as major procurers

Making information available

- Challenge to present carbon content data alongside financials
  - – **At macro level** for policy purposes
  - – **At entity level**, alongside financial statements
  - – **On products** in an informative and standardised way
- How to bring data together?
  - – **Commercial initiatives**
  - – **The ECCBSO / CMFB** initiative: collecting CSRD company level data for statistics
  - – Possible proliferation of data bases

In sum – what is needed

The workshop concluded that at the level of products, companies, industries, and countries we need carbon content information that is ***accurate, interoperable***, ***trustworthy,*** and ***available.***

Accuracy needs **high quality internal reporting of direct emissions and input structures,** with standard cost accounting procedures providing a robust framework. Where carbon content data on inputs is lacking, suitable proxies need to be used.

Consistent and interoperable indicators require **common standards**, defining inputs, allocation processes, and the treatment of carbon content over time. As a standard input for carbon accounting, direct and upstream indirect carbon content is of vital importance

Trustworthiness and the value of the data in external transactions hinge on **verification and auditing**, reinforcing the integration of carbon accounting within financial and cost accounting.

Communication devices, such as carbon content on bills and data exchange platforms, are necessary for promoting ***availability*****.**

In sum – what is needed

- **Bo Li** demands ***‘collaboration*** *and* ***innovation’*** on our way towards a functioning system of information on carbon contents.

  – Setting the required standards and promoting them needs ***international collaboration*.**

  – Making useful data available on all levels needs ***innovation*,** also from statisticians.
    - Direct mesurement
    - Processing, storage and passing on of information

  – ***Timely and consistent information on country and industry totals*** are an important backbone in the emerging system of carbon content information.

IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

Assessing the climate consistency of finance: taking stock of methodologies and their links to climate mitigation policy objectives[1]

J Noel and R Jachnik,
Organisation for Economic Co-operation and Development

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

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Assessing the climate consistency of finance: Taking stock of methodologies and their links to climate mitigation policy objectives

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Assessing the climate consistency of finance: Taking stock of methodologies and their links to climate mitigation policy objectives

Environment Working Paper No. 200

By Jolien Noels and Raphaël Jachnik (1)

(1) OECD Environment Directorate.

Authorised for publication by Jo Tyndall, Director, Environment Directorate.

Keywords: Investment, finance, climate alignment assessment methodologies, greenhouse gas emissions, climate change mitigation scenarios.

JEL Classification: G23, G24, Q54, Q56.

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Abstract

This paper analyses existing methodologies developed by commercial services providers, research institutes or civil society organisations for investors and financial institutions, to assess the alignment of their assets and portfolios with the Paris Agreement temperature goal. The analysis is based on four main analytical dimensions: coverage of financial asset classes, choice of greenhouse gas (GHG) performance metrics, selection of climate change mitigation scenarios, and approach for aggregating alignment assessment for a given asset class and at portfolio level. Within these dimensions, the analysis highlights that a range of different and complex methodological choices, as well as current scope and data limitations, impact the environmental integrity and policy relevance of alignment or misalignment results. The paper provides suggestions for improved and more comprehensive financial sector alignment assessment. These include the development of different complementary methodologies to cover a broader range of financial asset classes than the current main focus on listed corporate equity, the development of more tailored mitigation scenarios by climate policy and science communities, better communication of uncertainties by all stakeholders, and the need for a series of indicators to assess progress and impacts that include but are not limited to GHG-based alignment assessments.

Keywords: Investment, finance, climate alignment assessment methodologies, greenhouse gas emissions, climate change mitigation scenarios.

JEL Codes: G23, G24, Q54, Q56.

Résumé

Ce document analyse les méthodologies existantes développées par des fournisseurs de services commerciaux, des instituts de recherche ou des organisations de la société civile et pour les investisseurs et institutions financières, afin d'évaluer l'alignement de leurs actifs et portefeuilles avec l'objectif de température de l'Accord de Paris. L'analyse repose sur quatre dimensions analytiques principales: la couverture des classes d'actifs financiers, le choix des mesures de performance en terme de gaz à effet de serre (GES), la sélection des scénarios d'atténuation du changement climatique, et l'approche pour agréger l'évaluation de l'alignement par classe d’actif financier et au niveau du portefeuille. Au sein de ces dimensions, l'analyse met en évidence qu'une série de choix méthodologiques différents et complexes, ainsi que les limites actuelles en termes de couverture et de données, ont un impact sur l'intégrité environnementale et la pertinence politique des résultats d’alignement ou de non-alignement. Le document fournit des suggestions pour une évaluation améliorée et plus complète de l'alignement du secteur financier. Elles incluent notamment le développement de méthodologies différentes et complémentaires pour couvrir un plus large éventail de classes d'actifs financiers par rapport à l'accent principal mis actuellement sur les l’actionnariat d’entreprises cotées en bourse, le développement de scénarios d’atténuation plus adaptés par les communautés politiques et scientifiques du climat, une meilleure communication des incertitudes par toutes les parties prenantes, et la nécessité de disposer d’une série d'indicateurs permettant d’évaluer les progrès et les impacts comprenant, mais sans s'y limiter, les évaluations d'alignement fondées sur les GES.

Mots-clés: Investissement, financement, méthodes d'évaluation de l'alignement climatique, émissions de gaz à effet de serre, scénarios d'atténuation du changement climatique.

Codes JEL: G23, G24, Q54, Q56.

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This analysis is also a contribution to the body of work of the Research Collaborative on Tracking Finance for Climate Action, an OECD-led technical research platform to advance and share knowledge for improving the tracking of climate-relevant finance, including to inform finance-related discussions under the United Nations Framework Convention on Climate Change (UNFCCC).

More specifically, the present paper provides evidence of relevance to assessing progress towards Article 2.1c of the Paris Agreement, which calls for "Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development." By taking stock of and analysing methodologies used by the financial sector to assess alignment from a climate mitigation perspective, the paper complements earlier country-sector pilot studies by the Research Collaborative, that tested options for measuring the such alignment from the perspective of real economy investments.[1]

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---

[1] See (Jachnik and Dobrinevski, 2021[141]), (Dobrinevski and Jachnik, 2020[138]) and (Dobrinevski and Jachnik, 2020[139]).

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Executive summary

This paper takes stock of and analyses existing methodologies for the financial sector to assess the alignment of its assets and portfolios with the Paris Agreement (PA) temperature goal. Article 2.1c of the Paris Agreement calls for "*making finance flows consistent with a pathway towards low greenhouse gas* (GHG) *emissions and climate-resilient development*". This formulation contributed to the development of the concept of "climate alignment" of investments and financing. Methodologies to assess progress towards such alignment need to be robust, policy relevant and transparent, as they set incentives for investment decisions and influence the degree to which such decisions have an actual impact on GHG emissions or not. While Article 2.1c refers to both mitigation and resilience, the focus of the present analysis is on mitigation. Parallel efforts to define and assess resilience-aligned finance remain at an early stage.

There is growing landscape of coalitions, frameworks and methodologies promoting the alignment of finance with the temperature goal of the PA. Classifying initiatives according to these three categories helps clarify their purpose and role. However, initiatives may perform multiple and evolving roles over time. In this context, coalitions and frameworks promoting climate-transition and -alignment in the financial sector can build on and be informed by existing international frameworks, such as the OECD's Responsible Business Conduct Due Diligence Guidance.

This study develops an approach to analyse climate-alignment assessment methodologies for the financial sector to help clarify their relevance for assessing progress towards Article 2.1c. The analytical dimensions are: (1) asset class coverage, (2) choice of GHG performance metrics (including targets), (3) climate change mitigation scenario(s) used to assess alignment, and (4) approach to assess alignment at the financial portfolio level. Within these dimensions, the analysis identifies common practices and opportunities for improved and more comprehensive financial sector alignment assessments.

Overall, the absence of agreed approaches to disaggregate the global PA temperature goal and downscale GHG emissions scenarios is a core source of uncertainty and variation when assessing the alignment of financial assets. In practice, different countries, sectors and corporates can and will decarbonise at different rates. Current climate change mitigation scenarios often do not match the sectoral and geographical specificity needed to assess individual assets. In terms of sectors, this notably poses challenges in matching scenarios to economic and financial sectoral classifications. In terms of geography, this may result in methodologies not addressing equity considerations. The climate policy and science community could contribute to improved alignment assessment methodologies by providing more relevant scenarios and reference points for use in the corporate and financial sector.

Gaps in asset class coverage could undermine the environmental integrity of climate-alignment assessments. This paper is the first to analyse climate-alignment assessment methodologies across asset classes beyond listed corporate equity. It finds that several large asset classes, such as private equity, real estate, and infrastructure are underrepresented in such methodologies. This is also the case for sovereign bonds, although individual investors typically have lower ability to directly engage with and influence investees (countries) than for aforelisted asset classes. Limited availability of climate-alignment assessments for these categories of financial assets may result in not capturing a range of underlying economic actors, activities and physical assets responsible for significant portions of GHG emissions.

Different perspectives on climate alignment translates into methodology providers choosing different metrics and temporalities to measure climate performance. This leads to different results that are difficult to reconcile. In particular, absolute versus intensity-based metrics may find different alignment results for a given asset. The temporal coverage of the methodology is also a strong driver of alignment results and variation. Notably, alignment tends to be assessed more frequently as being achieved using methodologies that only look at a unique point-in-time in 2050. However, such results may allow for delayed action and fail to capture the cumulative emissions that drive temperature outcomes.

The results of climate-alignment assessments are influenced by the coverage of GHG emissions (type and scope) as well as by the treatment of offsets. While the former is mainly constrained by data availability and quality (notably for scope 3 GHG emissions), there remains much opacity about the use of offsets by economic and financial sector actors, which in turn results in a lack of clarity in alignment assessment methodologies. This poses risks to the environmental integrity of alignment assessments, especially given the uncertain additionality of offsets. Those methodologies that explicitly aim to exclude offsets tend to find less alignment in corporate-related financial assets.

New illustrative analysis finds that regardless of the methodology used, listed corporate equity, for which results are available, tends to be mostly not aligned with the PA temperature goal. For those corporate-related financial assets assessed as aligned, such results depend heavily on the different perspectives taken by providers and their assumptions across the dimensions. Further, data availability and consistency remain a challenge even for listed corporate equity.

Aggregate-level assessments of financial portfolios add another layer of complexity and can hide individual activities that may be misaligned. There is no agreed approach to aggregate and allocate alignment results for a given financial asset class, and even less so across different asset classes as these need to follow different alignment assessment methodologies. Several methodologies calculate an "Implied Temperature Rise" metric, but many other methodologies do not yet have a portfolio metric. While portfolio-level metrics and aggregation approaches need to be developed further, such approaches raise environmental integrity concerns, notably by obscuring asset-level performance and methodological differences across asset classes, and thus require careful consideration and methodological transparency.

A dashboard of indicators that includes but is not limited to GHG-based climate-alignment results, can provide a more nuanced and comprehensive view of the contribution of finance to reaching climate policy goals. Climate-alignment assessment is a policy-relevant but complex metric. It relies on many methodological choices and comes with uncertainties and variations in results. A clearer communication of uncertainties by methodology providers is warranted. Improved environmental integrity could be achieved through the development of complementary methodologies to cover a broader range of financial asset classes, and of more tailored scenarios by climate policy and science communities. Complementary indicators of progress, such as measures of the presence and characteristics of concrete plans (including to upscale climate solutions), can further help put GHG-based alignment assessment results in perspective and provide a more holistic view. Further work is needed to design a representative dashboard, complemented with clear communication on underlying assumptions, methodologies and data limitations. This in turn can inform aggregate-level assessments of progress, including under the UNFCCC (Global Stocktake and Biennial Assessment and Overview of Climate Finance Flows).

Further research and analyses can contribute to improved assessments in a number of areas. First, climate-alignment processes in finance can benefit from greater interoperability with other emerging concepts (e.g. transition finance, taxonomies) as well as existing frameworks (e.g. responsible business conduct due diligence). Second, uncertainties and assumptions of climate change mitigation scenarios relied on by climate-alignment assessment methodologies are not well understood. Further research on this could inform the climate integrity of assessments. Third, methodological and indicator development for asset classes other than listed corporate equity are required to ensure assessments do not hide emissions elsewhere, e.g. further work on corporate loans, private equity, mortgages and sovereign bonds, would be beneficial. Finally, efforts to define and assess finance alignment with adaptation and resilience goals need to be explored, including in terms of interrelation with mitigation-related assessments.

1. Introduction

Article 2.1c of the Paris Agreement (PA) calls for "making finance flows consistent with a pathway towards low greenhouse gas (GHG) emissions and climate-resilient development" (UNFCCC, 2015[1]). This formulation contributed to the development of the concept of "climate alignment"[2] or "misalignment" of investments and financing activities by the financial sector (banks, institutional investors), enterprises, and public institutions (e.g. treasuries managing national budgets, development banks).

Investors and financial institutions are increasingly putting forward climate mitigation-related commitments and targets, such as under the Glasgow Financial Alliance for Net Zero (GFANZ), launched in the run up to COP26. However, there is increasing evidence that some climate mitigation-related targets and commitments raise questions of integrity (CPI, 2021[2]; Rogelj et al., 2021[3]), as well as analyses indicating that they may not translate in action and impact on the ground with, for instance, continued financing and investment in fossil fuel combined with limited phase out plans (ShareAction, 2022[4]; BankTrack, 2022[5]; Carbon Tracker, 2022[6]).

Against this backdrop, this paper provides a stocktake and comparison of the increasing number of methodologies developed by research institutes, civil society actors and commercial services providers to assess the degree of alignment or misalignment of the financial sector and financial markets with the PA temperature goal. In doing so, it notably analyses if and how such methodologies directly refer to and relate to the achievement of international and national climate mitigation policy goals.

Based on a tailored analytical approach, this paper draws conclusions on the current state of existing climate-alignment assessment methodologies used in the financial sector. It does so by analysing their assumptions, coverage and gaps, as well as how they may contribute to assessing progress towards climate mitigation policy objectives set by the public sector, most notably the overarching PA temperature goal. New illustrative data further strengthen the findings. Finally, this paper identifies where climate policy makers can prioritise efforts and provides suggestions for improved and more comprehensive and policy-relevant financial sector alignment assessments. This is essential to track progress towards making finance consistent with the PA temperature goals, as highlighted by the UNFCCC Standing Committee on Finance's most recent Biennial Assessment and Overview of Climate Finance Flows (UNFCCC SCF, 2021[7]).

1.1. Context

GHG emission pathways with over 50% chances to limit warming to 1.5°C with no or limited overshoot and those with over 67% chances to limit warming to 2°C require global GHG emissions to peak between 2020 and 2025 (IPCC, 2022[8]). In both cases, rapid and deep GHG emission reductions need to follow throughout 2030, 2040 and 2050, including in non-CO_2 emissions (methane, nitrous oxide, fluorinated gases). Global net zero CO_2 emissions will need to be reached in the early 2050s in modelled pathways that limit warming to 1.5°C (>50%) with no or limited overshoot, and around the early 2070s in modelled pathways that limit warming to 2°C (>67%). Beyond these points in time, many of these pathways would

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[2] Some market participants may also refer to climate alignment as Paris alignment.

require net negative CO_2 emissions, which in turn rely on the widespread availability and use of CO_2 removal technologies. Even with the availability of such technologies, deep early reductions in GHG emissions are required in any 1.5°C pathway (Holz et al., 2018[9]).

In turn, at a conceptual level, financial flows and stocks could be considered aligned or misaligned with the PA temperature goal if they contribute to economic systems that are consistent (or inconsistent) with such GHG pathways. In practice, the notions of climate mitigation alignment and consistency not only relate to scaling up finance for activities already aligned with the PA temperature goal, but also to financing activities and economic sectors that need to undergo and implement changes to transition towards net-zero emissions, especially in high-emitting and hard-to-abate sectors.[3] However, there is no agreed or unique way of downscaling the PA's global temperature goal to the level of individual financial assets and underlying economic sectors, actors, or countries, all of which can and will decarbonise at different rates over time. As a result, and as further discussed in this paper, any assessment of the degree of alignment or misalignment of financial assets and portfolios is dependent on a range of different assumptions and methodological choices.

In this context, a number of commercial services providers as well as industry and civil society initiatives have been developing different types of methodologies to assess the climate alignment of financial sector holdings and new investments (PAT, 2020[10]; Institut Louis Bachelier et al., 2020[11]; Schwegler et al., 2022[12]). These methodologies are typically tailored to the profile and needs of different investors and financial intermediaries such as banks, asset managers, and asset owners.[4] The methodologies rely on assumptions about how the GHG emission reductions needed to reach the PA temperature goal are shared and attributed between countries, sectors, as well as business and financial value chains. This is a major source of uncertainty with such assessments.

Despite such limitations, the results derived from climate finance alignment assessment methodologies can help to improve understanding of the interlinkages between the climate performance of the financial sector and climate action on the ground, as well as contribute to influencing investors' decisions. Such decisions, in turn, can influence the real economy and the effective achievement, or not, of the PA temperature goal.

Indeed, the climate consistency and alignment perspective considers the impact of the activities of economic actors, including companies and the financial sector, on climate mitigation and resilience policy goals, i.e. so-called *environmental materiality*[5]. In contrast, the financial and corporate sectors typically look at climate-related information from the perspective of what is financially material to the business, notably in terms of risks, i.e. *financial materiality*. In this context, the Task Force on Climate-related Financial Disclosures (TCFD) categorised climate-related financial risks as transition risks or physical risks (TCFD, 2017[13]; TCFD, 2021[14]) (see Box 1.1). As illustrated in Figure 1.2, the alignment of finance with climate policy goals (environmental materiality perspective) and the management of climate-related financial risks (financial materiality perspective) are interrelated but stem from different starting points and aims, and are also, at least partly, different in scope.

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[3] The OECD is has conducted complementary work to develop a guidance on transition finance to support the assessment by investors and financiers of the credibility of corporate climate transition plans and to support corporates in developing such plans (OECD, 2022[24]).

[4] Asset owners include pension funds, endowments, foundations and individual investors.

[5] Environmental materiality refers to the material impact of a company on the environment (Boissinot et al., 2022[18]).

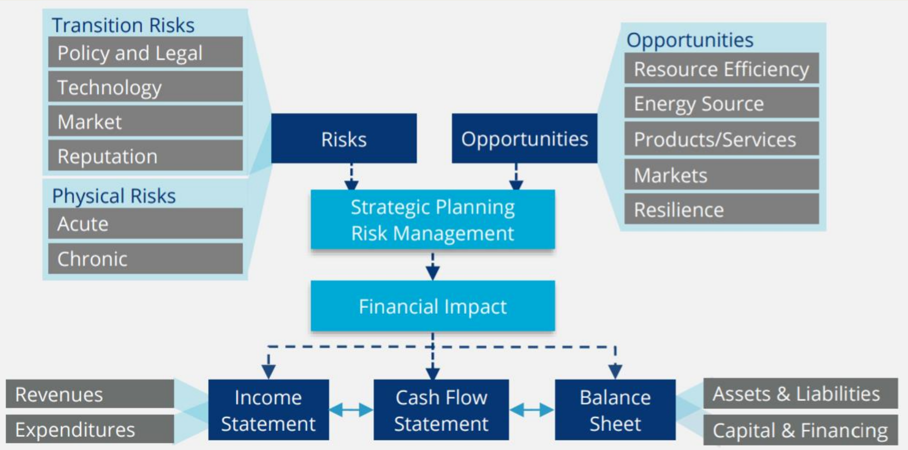
Box 1.1. ESG investing and climate-related financial risks

In the financial sector, Environmental, Social, and Governance (ESG) investing can be defined as an investment approach that seeks to incorporate these three considerations into asset allocation and risk decisions with the aim to generate and preserve financial returns (Boffo and Patalano, 2020[15]). Financial services providers are developing an increasing number of products and practices in this area, including instruments for issuers, third party ratings, principles and guidance. Such products and services primarily aim at informing efficient market functioning, notably in terms of management and pricing of risks and opportunities, in light of wider societal objectives.

Under the Environmental component of ESG analyses, financial market participants, notably the Task Force on Climate-Related Financial Disclosures (TCFD) (TCFD, 2017[13]; TCFD, 2021[14]), have categorised climate-related risks to economic actors (Figure 1.1) as:

- *Transition risks* that arise from changes in public policy, legal, technological, demand and market in order to mitigate climate change. They may be costly due to stranded assets, defaults, and collapse in stock market value (Campiglio and van der Ploeg, 2021[16]).
- *Physical risks* related to the physical impacts of climate change. They become costly to organisations due to direct damage to assets or indirect impacts from supply chain disruption due to extreme events or longer-term changes in climate patterns.

Figure 1.1. TCFD climate-related risks and materiality framework

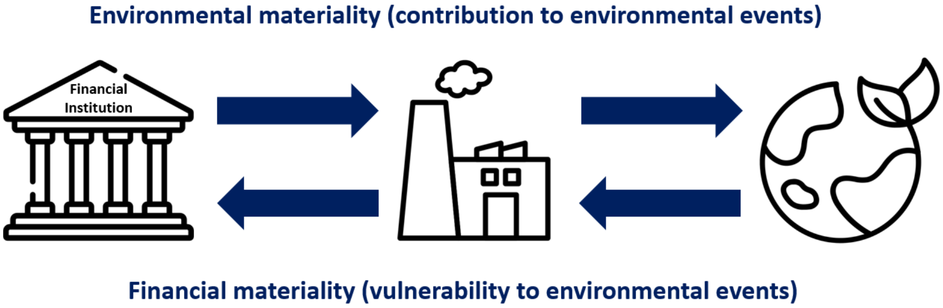


Source: (TCFD, 2017[13]).

In some cases, specific climate-related risk categories are further separated out, such as *liability risks* arising from litigation and other legal action and claims from parties that could seek to recover climate-related losses from others who they believe may have been responsible (Setzer and Higham, 2021[17]).

Concepts used by financial market stakeholders and the climate community are inherently linked. Based on concerns of potential misinformation being provided to the markets due to potential “greenwashing”, the environmental ‘E’ pillar under ESG is for instance increasingly scrutinised from the perspective of its ability to support the PA goal of aligning financial flows with climate change mitigation policy goals. This entails looking at data and metrics similar to those used as input by the alignment assessment methodologies analysed in the present paper.

Figure 1.2. Relating environmental and financial materiality



Source: (Boissinot et al., 2022[18]).

The reliability and acceptability of methodologies for assessing progress towards the PA goal remains subject to the testing and disclosure of underlying assumptions. Such transparency is key to address risks of greenwashing from climate-related metrics more generally. This issue is also faced by environmental, social and governance (ESG) metrics and ratings, designed to contribute to informing financial materiality assessments, Indeed, previous research investigating metrics that underpin the climate mitigation-related rating of ESG assessments identified that a higher rating is not always consistent with an effective contribution to GHG reduction (Boffo and Patalano, 2020[15]; NGFS, 2022[19]; Heeb, Kellers and Kölbel, 2022[20]; OECD, 2022[21]).

1.2. Objective and scope

Climate-alignment assessments of finance require analyses of real economy investments and financing (notably tangible fixed assets[6]) as well as of the financial system (financial markets and financial sector). While both are inherently linked, their respective assessment entails different types of data and analyses. For example, the nature and lifespan of tangible fixed assets has a direct link to GHG emissions (emitted or avoided by the asset), from which most financing transactions and assets under management on financial markets are at least one step upstream.

OECD country-sector pilot studies conducted between 2019 and 2021 under the Research Collaborative on Tracking Finance for Climate Action, explored data and reference points to assess the consistency of real economy investments with climate mitigation policy objectives.[7] By taking stock and analysing the characteristics (in terms of coverage and assumptions) of existing alignment assessment methodologies developed for and by the financial market and sector, the present analysis takes a complementary view. In doing so, the aim is to draw conclusions on the relevance of such methodologies for tracking progress towards the climate mitigation-related part of Article 2.1c of the PA, as well as identify gaps, limitations and possible action points to address them.

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[6] Tangible fixed assets typically are physical assets such as infrastructure, land, buildings and equipment.

[7] The pilots covered the building sector in the United Kingdom (Jachnik and Dobrinevski, 2021[141]), the transport sector in Latvia (Dobrinevski and Jachnik, 2020[138]), and the manufacturing sector in Norway (Dobrinevski and Jachnik, 2020[139]). The focus was on gross primary investment flows in new infrastructure or equipment and the refurbishment of such assets, and its underlying sources of finance (in the form of grants, debt-, equity- and guarantee-related instruments). Such focus was motivated by an initial scoping paper (Jachnik, Mirabile and Dobrinevski, 2019[137]) and corresponds to the scope addressed by a range of other country-level analyses (e.g. (Hainaut and Cochran, 2018[144])) and international-level pilot assessments (e.g. (Micale et al., 2020[143]).

Two main approaches can be used to assess the climate alignment of finance with climate mitigation policy goals:

- Outcome-based approaches, which typically compare actual or projected GHG emissions of entities or activities to GHG emissions scenario pathways (or GHG intensity thresholds derived on that basis) as a benchmark. This approach can also be based on other type of information provided by climate mitigation scenarios, such as forecasted technology usage or production capacity.
- Principles-based approaches, which typically classify activities into climate aligned or not (sometimes with an intermediate category), and may address activities that don't result in much direct GHG emissions but can enable or hinder climate mitigation, e.g. road and rail infrastructure.

The majority if not all of the existing climate-alignment assessment methodologies, as reviewed in this paper, are outcome-based. The principle-based approach is, on the other hand, more often used in the context of regulatory processes. For example, the climate mitigation-related technical screening criteria developed under the EU Taxonomy combine both outcome- and principle-based criteria (EU Platform on Sustainable Finance, 2021[22]).

Methodologies that are considered have been developed by commercial services providers, research institutes, civil society or other financial market stakeholders. The methodologies may cover all types of finance and any financial asset class(es), and may assess alignment or misalignment with both international (PA) or national climate mitigation policy goals.

While Article 2.1c of the PA refers to both mitigation and resilience in making finance flows consistent with climate goals (UNFCCC, 2015[1]), the focus in the present analysis is placed on mitigation. The alignment assessment of finance from a climate-resilience perspective faces different challenges and requires different data and assessment methodologies. These are being explored in complementary OECD analytical efforts (Mullan and Ranger, 2022[23]).

Beyond climate mitigation and resilience, it is important that finance also aligns with other environmental policy goals (e.g. biodiversity, water) as well as contributes to a just transition for workers and communities affected by climate impacts. These considerations are outside the specific scope of the present analysis but the findings presented here can eventually be combined and feed into broader analyses, e.g. in the context of OECD Responsible Business Conduct standards under the OECD Guidelines for Multinational Enterprises (see Section 2.2), which specifies the relevance of these standards for climate change), as well as when assessing alignment in relation multiple Sustainable Development Goals (SDGs). This is consistent with Article 2 of the PA, which sets out the three interlinked goals of climate mitigation, climate resilience and making finance consistent with the former two, in the context of sustainable development and efforts to eradicate poverty (see (UNFCCC SCF, 2021[7]) and (UNFCCC, 2015[1])).

The remainder of this paper is structured as follows:

- Chapter 2 outlines the analytical approach that help structure the analysis presented in this report. In order to provide further context, the chapter first introduces the different steps of the climate alignment process, then provides an overview of finance-related climate alignment coalitions, frameworks and methodologies, before putting forward the dimension used in the remainder of the paper to run an in-depth analysis of climate-alignment assessment methodologies specifically.
- Chapter 3 presents the results of the analysis of methodologies to assess the climate alignment of finance. These results are presented according to the following main analytical dimensions: financial asset class coverage, choice of GHG performance metrics, selection of climate change mitigation scenario(s) to assess alignment, approach for assessing and aggregating alignment at the financial portfolio level.
- Chapter 4 provides illustration of actual results from climate-alignment assessment methodologies for a sample of corporate-related assets, sovereign bonds, as well as of existing attempts to conduct portfolio-level assessments, i.e. aggregating results from individual financial assets.
- Chapter 5 summarises conclusions in terms of common practices and areas for further developments by providers of climate-alignment assessment methodologies, possibilities for climate policy makers to support improved and policy-relevant assessments, as well as implications for international-level assessment of progress towards Article 2.1c of the PA.

2. Analytical approach and dimensions

This chapter introduces the approach that underpins the analysis then presented in Chapter 3. To contextualise the analysis, the chapter first briefly takes stock of the wide-ranging initiatives addressing climate alignment of finance, then positions the climate-alignment process in the context of the existing international framework for Responsible Business Conduct, before detailing the specific dimensions that form the basis for analysing climate-alignment assessment methodologies.

2.1. A dynamic landscape of finance-related initiatives supporting climate alignment

There is a range and growing number of civil society- and business-driven initiatives relevant to or directly supporting climate alignment in the financial and corporate sectors (Table 2.1). Some initiatives to measure and report GHG emissions have been established for a decade or longer, such as the GHG Protocol and the Carbon Disclosure Project (CDP). Further initiatives launched in 2015, the year of the adoption of the PA, have become important anchor points of corporate and investor practices in relation to climate, including the TCFD, the Science Based Targets initiative (SBTi) and the Partnership for Carbon Accounting Financials (PCAF). While the initiatives mentioned in this paper support climate-aligned finance, some of them may also specifically support companies in setting their transition targets or developing a transition plan, for which the OECD has developed guidance (OECD, 2022[24]).

The development of initiatives specifically aimed at assessing the alignment of finance with the PA has been progressive since the adoption of the agreement. It is worth noting that close to all such initiatives originated in "developed" countries, in part as a reflection of the concentration of where the majority of capital and liquidities are available from (IPCC, 2022[8]). In this context, a range of jurisdictions and regulatory bodies are developing their own official climate-related approaches and taxonomies, including in emerging economies (Natixis, 2021[25]; OECD, 2020[26]). As stated above in the Introduction, these are not considered as part of the present analysis. Their development can, however, be informed by civil society- and business-driven initiatives.

Climate alignment-related initiatives can take the form of coalitions, frameworks or methodologies:

- A **coalition** is a collaboration or group of organisations or initiatives with a common goal. The main purpose is typically to convene, engage and mobilise peers or private sector to create leverage and contribute to steer the debate. Coalitions sometimes put forward a pledge of some sort.
- A **framework** is a broad guidance that indicates a general direction and includes a set of principles for achieving certain goals. It, however, typically leaves way to interpretation, for instance by allowing the use of several possible implementation tools and methodologies.
- A **methodology** is a set of practical guidance including precise metrics, rules and reference points to address one or more of the practical steps needed to achieve certain standards and goals or targets. More specifically, climate-alignment assessment methodologies provide a detailed approach for calculating the degree of alignment or misalignment for a given type of asset or actor, sometimes detailed by sector.

Table 2.1. Development timeline of selected initiatives relevant to climate-alignment assessment

Starting year	Examples of initiatives	Coalition	Framework	Methodology
Prior to 2015	GHG Protocol			■
	Carbon Disclosure Project		■	
	Institutional Investor Group on Climate Change	■		
2015	Task Force on Climate-Related Financial Disclosures	■	■	
	Science Based Targets			■
	Partnership for Carbon Accounting Financials			■
2016	right. based on science XDC model			■
2017	Transition Pathway Initiative			■
	Climate Action 100+	■	■	
	Network for Greening the Financial System	■	■	
2018	Carbon Risk Real Estate Monitor			■
	FTSE x Beyond Ratings' method			■
	Paris Agreement Capital Transition Assessment			■
2019	Climate Safe Lending Network	■	■	
	Net-Zero Asset Owner Alliance (Inaugural 2025 Target Setting Protocol)	■	■	
	IIGCC Paris Aligned Investment Initiative (Net Zero investment framework)	■	■	
2020	Carbone 4 2-infra			■
	CDP-WWF temperature rating			■
	S&P Sustianble1 (formerly Trucost) Paris Alignment			■
2021	Glasgow Financial Alliance for Net Zero (Financial institution net-zero transition plan framework)	■	■	
	MSCI Implied Temperature Rise			■
2022	SBTi Financial Institutions Net Zero Expert Advisory Group	■		

Note: Last updated in September 2022. This table does not provide a comprehensive overview but only aims to illustrate the growing number and range of initiatives. Further, the categorisation of initiatives as coalitions, frameworks and methods will rapidly become outdated based on further developments and collaboration between initiatives.
Source: Authors.

Coalitions of financial or corporate organisations may support multiple frameworks, or gradually develop their own frameworks. Sometimes, frameworks progressively dive into further technical details, thereby turning into methodologies. Alternatively, some frameworks and methodologies are developed in close co-operation with one another such as the Climate Action 100+ Net-Zero Benchmark and the Transition Pathway Initiative (TPI). Further, methodologies developed independently by expert institutions may then be referenced by frameworks as possible or recommended implementation tools. As a result, there are many dynamic interlinkages between the initiatives, both:

- Within a category: For instance, the GFANZ coalition launched in the context of UNFCCC COP27, combines pre-existing coalitions: Net Zero Asset Managers initiative (NZAM), the Net Zero Asset Owner Alliance (NZAOA), the Net-Zero Banking Alliance (NZBA), the Net-Zero Insurance Alliance (NZIA), Net Zero Investment Consultants Initiative (NZICI) and the Net Zero Financial Service Providers Alliance (NZFSPA).
- Across the three categories: As an example, the NZAOA indicates that it collaborates with different frameworks and methodologies, including SBTi, the Partnership for Carbon Accounting Financials (PCAF), Institutional Investors Group on Climate Change (IIGCC), TPI, Climate Action 100+ and Paris Agreement Capital Transition Assessment (PACTA).

Some initiatives belong to more than one of the categories and their categorisation can often change over time. As an example, the NZAOA was initially launched as a coalition but then also developed a framework for asset owners to calculate, allocate and set targets to reduce the greenhouse gases associated with their portfolios (NZAOA, 2021[27]). Likewise, the IIGCC was launched as a coalition two decades ago and more recently developed a framework providing a set of recommended actions, metrics and methodologies, through which investors can maximise their contribution to achieving global net zero global emissions by 2050 or sooner (PAII, 2021[28]). Similarly, GFANZ states that one of its work streams supports the further development of work on portfolio alignment metrics for financial institutions (GFANZ, 2021, p. 14[29]). It also developed a '*financial institution net-zero transition plan framework*' in 2022 (GFANZ, 2022[30]).

The above examples make it clear that the ecosystem of initiatives supporting climate alignment in the financial sector is a developing and rapidly changing field. As climate-alignment frameworks remain work in progress, such developments can build on and be informed by relevant existing international standards, which can strengthen the coherence and interoperability of approaches. Such standards notably include those developed under the OECD Centre for on Responsible Business Conduct (RBC).

2.2. The relevance of Responsible Business Conduct standards

The OECD RBC's Guidelines for Multinational Enterprises (MNE Guidelines), consist of government-backed recommendations to multinational enterprises operating in or from adhering countries. The MNE Guidelines currently are the only authoritative, consensus-based, government instrument on RBC operating at the international level. The recommendations cover all areas of business responsibility: disclosure, human rights, employment and industrial relations, consumer interests, science and technology, and the environment, including climate change (OECD, 2011[31]).

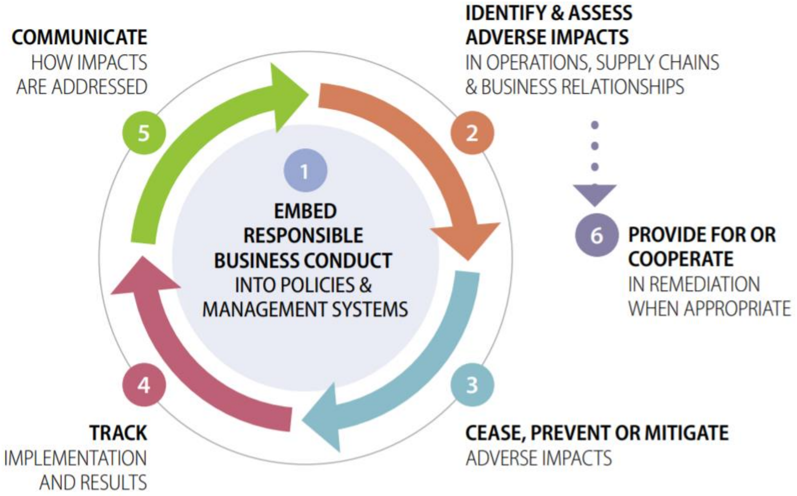
The MNE Guidelines provide non-binding principles and standards for responsible business conduct in a global context consistent with applicable laws and internationally recognised standards. The Guidelines notably set out the expectation for business, including investors and financial institutions, to:

- identify, prevent and mitigate actual and potential adverse impacts of business' operation, supply chains and relationships (including investments) on people, the environment and society
- contribute to economic, environmental and social progress with a view to achieving sustainable development.

To support business (including financial institutions and investors) in implementing the Guidelines, the OECD developed the Due Diligence Guidance, a framework and management system to help businesses assess and address their actual and potential adverse impacts (OECD, 2018[32]). The sectoral applications of the RBC due diligence extends to the financial sector, i.e. institutional investors (OECD, 2017[33]) and banks (OECD, 2019[34]), as well as project and asset finance transactions (forthcoming OECD RBC guidance).

The OECD Due Diligence Guidance lays out six steps in the due diligence process to assess 'RBC alignment' (Figure 2.1), which can be adapted to businesses' specific circumstances: (1) embed RBC into the businesses' policies and management systems; (2) identify and assess actual or potential adverse impacts of a business' own activities as well as those in its supply chains and business relationships, which includes GHG emissions (3) cease, prevent or mitigate such actual or potential adverse impacts, (4) track implementation and results, (5) communicate how impacts are addressed; (6) enable remediation of adverse impacts when appropriate.

Figure 2.1. Due diligence process and supporting measures



Source: (OECD, 2018[32]).

The principles laid out by the Guidelines and the steps of the Due Diligence Guidance make it clear that RBC is an outward-facing approach. This implies that it differs from traditional business risk management systems, which focus on risks to the enterprise, e.g. financial risk, market risk, operational risk, reputational risk (also see Box 1.1 on climate-related risks).

RBC's outward-facing approach, combined with its backing from governments, makes it pertinent in the context of assessing and managing business contributions to the achievement of public policy goals, including climate policy goals. The RBC Due Diligence Guidance can be particularly relevant for businesses seeking to address and reduce GHG emissions across their supply chains in addition to their own operations, i.e. thereby covering GHG emission scopes 1, 2 and 3 as discussed in Section 3.2.3. Such relevance extends to financial institutions and investors, in the context of undertaking due diligence across their investees[8].

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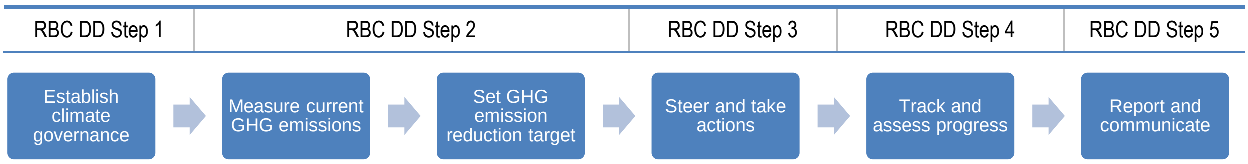
[8] The OECD is developing a paper on "Managing Climate Risks and Impacts through Responsible Business Conduct: A tool for institutional investors" to clarify how the due diligence process recommended by the OECD MNE Guidelines can be applied by investors to prevent and mitigate adverse climate impacts associated with their investee companies.

The climate-specific frameworks identified in Table 2.1. above among the examples of climate alignment initiatives provide guidance towards achieving climate alignment (The Coalition of Finance Ministers for Climate Action, 2021[35]; Katowice Banks & 2DII, 2020[36]; PAII, 2021[28]; PCAF, 2021[37]). These frameworks differ in terms of choice, sequence and naming of steps to be followed, but typically include some or all of the following elements:

- establish climate governance, which involves integrating climate considerations in management practices and policies
- measure current GHG emissions (backward looking)
- set GHG emission reduction target (forward looking)
- steer and take action, which for investors can take the form of, e.g. engagement to facilitate climate transition, managed divestment, or of investment in climate solutions
- track and assess progress, which can involve both backward- and forward-looking perspectives
- report and communicate on results achieved to date.

While not an exact match, these elements are similar in nature to those captured by the RBC Due Diligence process, as per the matching presented in Figure 2.2.

Figure 2.2. Climate-alignment process matched to Responsible Business Conduct Due Diligence steps



Note: RBC DD stands for Responsible Business Conduct Due Diligence, see (OECD, 2018[32]).
Source: Authors informed by (The Coalition of Finance Ministers for Climate Action, 2021[35]; Katowice Banks & 2DII, 2020[36]; PAII, 2021[28]; PCAF, 2020[38]).

Climate-alignment assessment methodologies, which the remainder of the paper focuses on, typically address the *tracking and assessment of progress* step. Most of these methodologies, however, also use as input the measurement of current GHG emissions and the setting of reduction targets, as well as deliver assessment results of relevance to inform reporting and communication.

Prominent methodologies outlining how entities should account for emissions include: the GHG Protocol for non-financial corporates, PCAF's Global GHG Accounting and Reporting standard for financial corporates and UNFCCC National Inventory Submissions (NIR) methodology for countries (relevant for the sovereign bond financial asset class). The SBTi is unique in that it is the only initiative that defines a methodology on how companies in different sectors should set emissions reduction targets (SBTi, 2020[39]). Moreover, the SBTi is in the process of developing a methodology for science-based net-zero targets in the financial sector, supported by its Financial Institutions Net Zero Expert Advisory Group (SBTi, n.d.[40]; SBTi, 2022[41]). There is currently no such equivalent for countries, which define their own targets in the context of their NDCs.

The forthcoming paper also provides an initial overview of how the due diligence process relates to and can draw on other frameworks and tools for assessing, managing or disclosing climate impacts associated with investments.

2.3. Dimensions to analyse climate-alignment assessment methodologies

Methodologies built for the purpose of tracking progress towards climate-alignment of finance were initially mainly developed by research institutes and independent financial analysis entities. More recently, mainstream financial players have developed and commercialised their own methodologies or acquired existing methodologies.

Although no common analytical approach exists to analyse such methodologies, some reviews of existing ones have been conducted, notably:

- In 2020, the TCFD-affiliated Portfolio Alignment Team (PAT) reviewed seven methodologies for portfolio warming metrics (PAT, 2020[10]). The review identified three steps in these methodologies, namely translating carbon budgets into scenarios, assessing company-level alignment, and assessing portfolio-level alignment.
- Similarly, the French research institute Louis Bachelier reviewed existing methodologies available to investors as of 2020 to measure the climate alignment of their assets. The institute finds four general steps, namely (1) assessing the climate performance of the portfolio, (2) selecting appropriate scenarios and reference trajectories, (3) building micro-level temperature benchmarks and (4) assessing alignment and temperature (Institut Louis Bachelier et al., 2020[11]).
- Other stock-taking exercises have been conducted focusing on methodologies to assess climate-related transition risk (Bingler, Colesanti Senni and Monnin, 2021[42]; Bingler and Colesanti Senni, 2022[43]; UNEP FI, 2021[44]). Unless they also explicitly aim to assess alignment, such methodologies are not considered here.

Common dimensions analysed in such previous research include: the type of metric, scope of emissions, sources of current and forward-looking company data, sources of scenarios, scenario granularity, whether the assessment is static or dynamic, how the metric is expressed and how the aggregation to portfolio level is done (Institut Louis Bachelier et al., 2020[11]; PAT, 2020[10]). Institut Louis Bachelier (2020[11]) also considers whether avoided and removed emissions are included, and how to allocate the scenario to companies and portfolios. PAT (2020[10]) further considers how the metric is expressed, e.g. as carbon budget overshoot or implied temperature rise (PAT, 2021[45]).

Compared to these existing studies, the present analysis further integrates the perspective of climate policymakers, by bringing in references from the climate policy literature. Moreover, the analysis also expands other asset classes beyond corporates by also looking at methodologies to assess the climate alignment of sovereign bonds issued by countries, as well as of investments and financing relating to real estate and infrastructure (see Table 3.1 in Section 3.1).

As introduced above, climate-alignment assessment methodologies address the tracking and assessment of progress step of the broader alignment process (Figure 2.2), but also use as input the measurement of current GHG emissions as well as the setting of reduction targets, and feed into reporting. With this in mind, and in order to analyse the characteristics of such methodologies, the present analysis considers the following four overarching analytical dimensions. These dimensions (and sub-dimensions within each) build on the aforementioned previous research as well as aim to reflect issues critical to analysing the relevance of methodologies from a climate policy perspective:

- **Type of financial asset class covered**, such as corporate equity and debt (with a distinction between listed and private companies), sovereign bonds, infrastructure- as well as real estate-related investment and financing (notably mortgages), noting, however, that there is no definitive or comprehensive classification.
- **Choice of GHG performance metrics** (including targets), based on the following sub-dimensions:
  - type of GHG performance metric, e.g. absolute or intensity

  - temporal perspective and coverage of metrics, e.g. backward- or forward-looking, short-/medium-/long-term periods, cumulative or one point in time
  - types and scopes of GHGs considered
  - treatment of carbon offsets and avoided emissions
- **Selection of climate change mitigation scenario(s) to assess alignment**, based on the following sub-dimensions:
  - data and information sources
  - temperature outcomes and uncertainty based on scenario(s) used
  - sectoral scope and specificity
  - geographic scope and specificity
  - techniques to allocate scenarios to entities
- **Approach of assessing alignment at the financial portfolio level**, considering the following sub-dimensions:
  - metric at portfolio level
  - aggregation approach, including across asset classes
  - assessment and avoidance of double counting.

Figure 2.3. Dimensions for analysing climate-alignment assessment methodologies

Financial asset class coverage	Choice of GHG performance metrics	Selection of CC mitigation scenario(s)	Alignment at the financial portfolio level
Listed equity Private equity Corporate debt Sovereign bonds Real estate Infrastructure Other	Type of GHG performance metric Temporal perspective Types and scopes of GHGs in metric Treatment of carbon offsets and avoided emissions	Data and information sources Temperature outcomes and uncertainty Sectoral scope and specificity Geographic scope and specificity Techniques to allocate scenarios to entities	Metric at portfolio level Aggregation approach Double counting

Note: GHG refers to greenhouse gas, CC to climate change.
Source: Authors.

3. Deep-dive on climate-alignment assessment methodologies in finance

Methodologies to assess alignment of financial assets and portfolios with the PA temperature goal are increasingly being developed on a voluntary basis. As mentioned in Section 2.2, these methodologies build on the measurement of current GHG emissions and on the setting of GHG emission reduction targets. They deliver assessment results of relevance to inform reporting and communication. While this overall remains an evolving area, some initiatives have been established for over five years (Table 2.1). Therefore, now is a good time to take a closer look at the characteristics of these methodologies, notably in terms of how they relate to climate policy goals.

To this end, this chapter analyses a selection of methodologies[9] developed by 16 commercial services providers, research institutions or civil society organisations on the basis of the four analytical dimensions introduced in Section 2.3: coverage of financial asset class (Section 3.1), choice of GHG performance metrics (3.2), climate change mitigation scenarios used to assess alignment (3.3), and approach for aggregating alignment assessment at financial portfolio level (3.4).

The analysis presented in this chapter is the result of a combination of desktop research and consultation with methodology providers. Such consultations (see Acknowledgements) took place to gather further information, insights and views as well as, in some cases to access sample data. In all cases, the presentation of results anonymises individual providers. The rationale for doing so is that the analysis was not intended to evaluate or rank individual existing methodologies, but rather to draw general conclusions on the current and potential relevance of such methodologies to contribute to measuring progress towards the achievement of international and national climate mitigation policy goals.

3.1. Financial asset class coverage

Climate-alignment assessment methodologies are typically developed for specific types of financial assets or asset classes. Such assets can be grouped at different levels and based on different categories, in part due to the fact that the composition of the portfolio of investors and financial institutions differs greatly depending on their type, mandate and strategy. In the present analysis, financial assets, for which existing alignment assessment methodologies could be identified and analysed include: listed equity, private equity, corporate bonds, sovereign bonds, real estate, and infrastructure (noting that investments in real estate and infrastructure typically take the form of equity, bonds or other debt-related instruments). At this stage, no methodology could be identified for other asset types commonly referred to, such as (but not limited to) derivatives, commodities and cash.

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[9] Note that one provider can have multiple methodologies for different asset classes.

A complete coverage of financial asset classes in climate-alignment assessment methodologies is desirable for two main reasons:

- To provide a comprehensive picture of the financial sector's holdings and investments. This is increasingly relevant as investors and financial institutions, including government pension funds, possibly central banks as well governments, may start using such methodologies to disclose progress (GFANZ, 2022[46]).
- Such methodologies set incentives for investment strategies and decisions. In this context, it should be noted that the degree of influence from investors on the investee depends on the asset class. While active engagement strategies are often used for corporate-related assets (Flammer, Toffel and Viswanathan, 2021[47]), individual investors have less ability to influence sovereign investees. Nonetheless, passive and active investors may consider the possibility of rebalancing their portfolio towards relatively more climate-aligned sovereign bonds (Cheng, Jondeau and Mojon, 2022[48]).

A single climate-alignment assessment methodology is unlikely to be applicable across all asset classes. Differences in characteristics of financial asset classes contribute to explaining why different financial asset classes may require tailored different decarbonisation mechanisms and, as a result, tailored alignment assessment methodologies. Differences in risk-return profiles may influence the asset composition of different financial institutions and investors, depending on their risk appetite, and under different macroeconomic conditions. For instance, sovereign bonds may be preferred for those seeking stable returns and during periods of recession and/or deflation (as was in part the case during the COVID-19 crisis), while other asset classes may be prioritised during periods of high economic growth (e.g. listed and private equity) or high inflation (e.g. commodities and real estate).

The vast majority of existing climate-alignment assessment methodologies in the financial sector have been developed for listed corporate equity (Table 3.1). In principle, these methodologies can be used for other types of corporate-related financial assets, such as private equity and corporate bonds and loans. In practice however, they are almost exclusively applied to publicly-traded corporate shares, for which data is more widely available. Even when a methodology for listed equity is applied to corporate bonds, there may be limited coverage (TPI, 2021[49]).

The lack of explicit coverage of corporate bonds may be explained by the perspective of the most common users of climate-alignment assessment methodologies, i.e. asset owners or managers aiming to reallocate their investments towards climate-aligned assets. However, non-financial corporates more commonly seek financing for their climate transition via debt rather than equity instruments (OECD, 2022[24]). In this context, corporates may also aim to raise cash for climate-aligned activities through ring-fenced bonds, which may, however, not necessarily imply that the issuer is fully aligned beyond the specific activities financed by the bond. Hence, more methodological development efforts are needed.

In some cases, methodology providers may have customised their methodologies slightly for specific projects or case studies covering other asset classes. For example, private equities and real estate (including mortgages, see (2DII, 2020[50])) can be considered within the PACTA methodology. However, those are not currently covered by the free online tool due to data constraints. Moreover, PACTA for banks has sought to facilitate banks´ access to software and data to analyse the alignment of their loan portfolios. Further, S&P has covered private equity and private debt universes on request by clients. MSCI is also building an alignment methodology for private equity and debt in collaboration with Burgiss Data (MSCI, n.d.[51]). However, the methodologies for asset classes for some methodology providers indicated as 'covered' or 'developing' in Table 3.1 are not (yet) publically available.

Table 3.1. Financial asset classes covered by climate-alignment assessment methodologies

Methodology	Listed equity	Private equity	Corporate debt	Sovereign bonds	Real estate	Infra-structure
2DII PACTA	🟩	🟨	🟩	🟥	🟨	🟥
Arabesque S-Ray Temperature Score	🟩	🟥	🟥	🟥	🟥	🟥
FTSE x Beyond Ratings' method	🟥	🟥	🟥	🟩	🟥	🟥
Carbone 4 Finance Carbon Impact Analytics (CIA)	🟩	🟥	🟩	🟩	🟥	🟩
Carbon Risk Real Estate Monitor (CRREM)	🟥	🟥	🟥	🟥	🟩	🟥
CDP-WWF Temperature Ratings	🟩	🟥	🟥	🟥	🟥	🟥
EcoAct ClimFIT temperature	🟩	🟥	🟥	🟥	🟥	🟥
I Care & Consult SB2A/SBAM	🟩	🟥	🟥	🟥	🟥	🟥
LO Portfolio Temperature Alignment Tool (LOPTA)	🟩	🟥	🟥	🟥	🟥	🟥
Mirova Alignment Method	🟩	🟥	🟩	🟥	🟥	🟥
MSCI's Implied Temp Rating	🟩	🟨	🟨	🟥	🟥	🟥
Ninety One Net Zero Sovereign Index	🟥	🟥	🟥	🟩	🟥	🟥
Ortec Finance Climate ALIGN	🟩	🟩	🟩	🟩	🟩	🟥
right. based on science XDC model	🟩	🟨	🟨	🟩	🟩	🟥
S&P Sustainable1 (formerly Trucost) Paris Alignment	🟩	🟨	🟩	🟥	🟨	🟥
TPI (Carbon Performance)	🟩	🟥	🟩	🟨	🟥	🟥

Asset class coverage by methodology provider: 🟩 Covered 🟨 Developing 🟥 Not covered

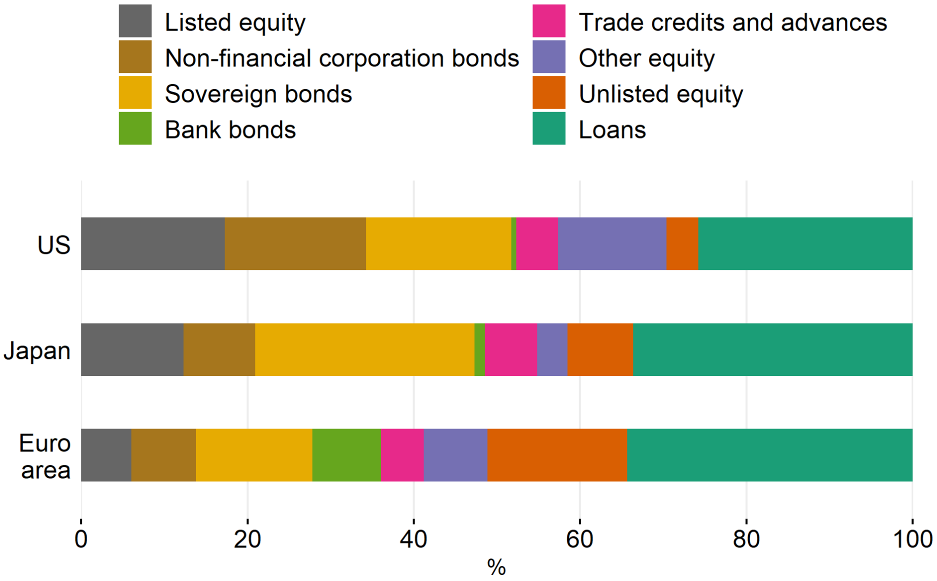
Note: Last updated in September 2022.
Source: Authors based on publicly-available information and, for some providers, bilateral consultations.

The underrepresentation of several large asset classes in climate-alignment assessment methodologies may result in an incomplete assessment of the alignment of financial portfolios. Although some initial methodologies have been developed for sovereign bonds and real estate, these asset classes would benefit from further methodological developments. For instance, the methodology developed by the Carbon Risk Real Estate Monitor (CRREM) can inform methodological developments by other providers expanding to real estate.

Figure 3.1 illustrates the relative importance of different financial instruments in three developed countries' different jurisdictions, namely the United States, Japan and the Eurozone.

- Loans (e.g. to corporates or households) represent the largest financing source in all three jurisdictions but are difficult for third parties to assess given data confidentiality and public unavailability. Analyses of private equity face similar data limitations.
- Sovereign bonds represent between 10% and 30% of instruments used for in the aggregate financing of economic sectors.
- On the other hand, such aggregate view typically does not separate out investments in the real estate and infrastructure asset classes mentioned above, but includes them under the general categories of "equity" and "bonds".

Figure 3.1. Financing structures of the euro area, US and Japanese economies



Note: By type of instrument. 10-year average between 2009 and 2018.
Source: Adapted from (ECB, 2020[52]).

It stems from the above that the limited availability of climate-alignment assessments for certain financial assets may result in not capturing a range of underlying actors, activities, as well as economic and physical assets responsible for significant portions of GHG emissions. Such partial coverage may also result in unintended incentives. For example, asset holding could move from listed to unlisted companies, which are currently less scrutinised by climate-alignment methodologies. Such transfers could mean that on aggregate emissions are not reduced. As an illustration, the six largest Western listed oil companies sold almost $44bn of fossil-fuel assets between 2018 and 2022 mainly to private-equity firms (The Economist, 2022[53]).

3.2. Choice of GHG performance metrics

In measuring the GHG performance of financial assets, climate-alignment assessment methodologies can use a variety of metrics. They can also choose different timelines as well as differ in the types and scopes of emissions they cover. Comparing the different approaches that methodology providers have chosen can help to improve understanding of their advantages and disadvantages. Further, as discussed at the end of the section and in conclusions, there are complementary alignment-related metrics that can be considered in order to provide a more nuanced perspective than by only looking at GHG-based metrics.

3.2.1. Type of GHG performance metrics

Metrics to assess the GHG performance of financial assets can be in absolute or intensity terms. The exact specification of these metrics can differ depending on the financial asset class.

For corporates, three main methods currently exist to measure GHG performance:

- Absolute Emissions Contraction (AEC) is a method that considers the rate at which companies reduce their absolute emissions, irrespective of the initial emissions level (SBTi, 2020[54]). It allows companies to set absolute emissions targets, defined as an overall reduction in the amount of

GHGs emitted to the atmosphere by a target year relative to a base year. The reduction rate of their emissions can then be compared to the reduction rate in the absolute emissions of a scenario.

- The Sectoral Decarbonisation Approach (SDA) is a method that derives physical emissions intensity pathways for companies based on sectoral emissions and activities pathways from existing mitigation scenarios (Krabbe et al., 2015[55]). Companies can set physical intensity targets that can be compared to sectoral pathways.
- Economic Intensity Contraction (EIC) is also an intensity-based method but it uses economic outputs instead of physical outputs in the denominator (SBTi, 2020[54]). One common approach under this method is the GHG per Value Added (GEVA) approach (Randers, 2012[56]).

Table 3.2. Overview of GHG performance metrics for corporates

	Advantages	Disadvantages	Data needs	Data availability
AEC: Absolute Emissions Contraction (Rate of change in GHG emissions)	• Emissions reductions are predictable • Less data intensive • More clearly relates to the remaining carbon budget and climate impacts of cumulative carbon emissions • Can be applied to all asset classes • Incentivises efficiency improvements and substitution of higher-emitting products or technologies with lower emitting alternatives	• Increased GHG performance can be due to decreased output rather than improved performance • Could disincentivise business growth, even for activities with a better climate performance. This particularly affects start-ups and young companies	Low	High
SDA: Sectoral Decarbonisation Approach (GHG emissions divided by physical output)	• Reflects GHG performance and efficiency improvements regardless of entity size, business growth and price changes • Applicable to homogenous sectors, companies and asset classes • Incentivises both efficiency improvements and growth into or expansion of lower-emitting products or technologies	• Data intensive • Difficult to apply to companies with diverse activities and in heterogeneous sectors • Absolute emissions could still increase while intensity-based climate performance improves	High	Low
EIC: Economic Intensity Contraction (GHG emissions divided by economic output)	• Reflects GHG performance and efficiency improvements regardless of entity size • Applicable to non-homogenous sectors and companies • Economic/Financial denominator is easy to understand for an investor audience • Relates more closely the decoupling between emissions and the economy • Incentivises both efficiency improvements and growth into or expansion of lower-emitting products or technologies	• Volatile with macroeconomic conditions may make it difficult to track true changes in GHG performance • Absolute emissions could still increase while intensity-based climate performance improves • Difficult to assess the PA consistency of projections for economic denominators (e.g. GDP).	Medium	Medium

Note: Data needs refers to both needs on corporate GHG emissions data and other corporate output data such as production volumes, value added or financial performance. Data availability is generally higher for listed than unlisted companies, however, the relative availability remains the same.

Source: Authors based on (SBTi, 2021[57]; Schwegler et al., 2022[12]; Rekker et al., 2022[58]) and on publicly-available information from and bilateral consultations with methodology providers.

Different corporate GHG performance metrics have different advantages and disadvantages (SBTi, 2021[57]), as summarised in Table 3.2. In the AEC approach, the contribution to total emissions reductions is predictable and transparent. Practically, the AEC approach also has the advantage of requiring less data. On the other hand, emissions reductions can be the consequence of a decline in output instead of an improvement of performance. To address this concern, intensity-based metrics are typically considered. Physical intensity metrics reflect GHG performance and efficiency improvements regardless of entity size and business growth. The SDA approach allows for better comparison across corporate assets within the same and homogenous sector. On the other hand, data requirements are higher (see Box 3.2), and companies with diverse activities may find it difficult to define a single common metric. EIC metrics provide more flexibility to companies with diverse activities. However, this metric can be volatile based on changing financial performance, e.g. revenues in the denominator can fluctuate regardless of changes in emissions efficiency, and are subject to extrinsic factors including economic and financial macro-conditions. The metric can therefore change drastically regardless of changes in emissions linked to physical outputs, which makes it less environmentally robust.

Box 3.1. Applicability to private equity: unlisted large companies and SMEs

Several obstacles challenge the integration of climate-alignment assessments for private equity (Ceres & SustainAbility Institute by ERM, 2021[59]). These include more limited access to quality data compared to listed equity, the lack of a universal standard for setting net-zero goals and inconsistent regulatory requirements globally. Although there is currently no universally accepted methodology on setting net-zero targets, private equity firms and their portfolio companies can implement methodologies used by listed firms such as the SBTi.

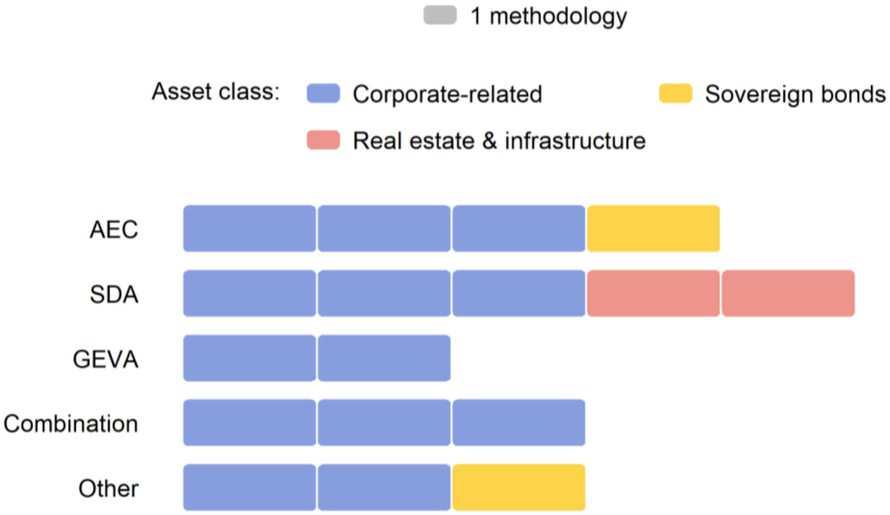
Generally, data required for current climate-alignment assessments are not available for SMEs. SMEs have a lower capacity to generate data on historic emissions and targets. To this end, the SBTi has developed a simplified net-zero target setting methodology for SMEs (SBTi, 2021[57]). The methodology is less stringent than for large listed firms, seeing the more limited resources SMEs have compared to large corporations. Unlike larger companies, the SBTi does not require SMEs to set targets for their Scope 3 emissions. The OECD Guidance on Transition Finance also proposes a tailored approach for SMEs on a number of elements included in corporate transition plans, such as on the inclusion of scope 3 emissions in reporting and target-setting (OECD, 2022[24]).

Current climate-alignment assessment methodologies follow a variety of approaches, but an intensity-based approach is most common across asset classes (Figure 3.2). Especially, methodologies for corporates, infrastructure and real estate most often rely on intensity-based metrics. Providers using the SDA metric are typically using similar denominators, such as kWh for the electricity sector and tons of cementitious product in the cement sector. For the GEVA approach, providers often use revenue instead of value added, as data is more available. Providers that also consider corporate debt aside from listed equity, typically use enterprise value in the denominator.

For corporates, consultations with methodology providers highlighted that different perspectives on corporate climate performance translate into different choices of metrics:

- Several providers mentioned that the GEVA approach is more intuitive for investors than other approaches such as SDA. Reasons for this include that the financial denominator is easy to understand for an investor audience, that GEVA relates more closely the decoupling between emissions and the economy, and that GEVA may better reflect the business case for corporates. Moreover, this metric is often preferred to achieve a larger coverage of companies rather than a selection in particularly emissions-intensive sectors.
- On the other hand, some providers prefer the AEC approach as it more clearly relates to the remaining carbon budget and climate impacts of cumulative carbon emissions. It may, therefore, be more suited for assessments towards climate mitigation policy goals.
- Some providers noted that SDA takes into account several limitations of other approaches, such as size, growth and price changes. However, this approach is more data-intensive and hence often limits the coverage of assets in a portfolio. Hence, several providers combine SDA with other approaches to achieve a more comprehensive coverage of companies in a given portfolio.

Figure 3.2. Number of methodologies using a given type of GHG performance metric



Note: AEC is Absolute Emissions Contraction, SDA is Sectoral Decarbonisation Approach, and GEVA is Greenhouse Gas Emissions per Value Added. Combination refers to a mix of the three previously mentioned approaches and others.
Source: Authors' analysis based on publicly-available information and, for some providers, bilateral consultations.

As each metric comes with pros and cons, a dashboard of indicators may be more insightful. Additional to the different perspectives taken by the methodology providers, some methodologies are developing complementary metrics, e.g. on the recent GHG performance of corporates. This adds an element of credibility when the main alignment metric considers corporate targets in the far future. Over time, indicators on the actual performance against corporate targets will become more essential to evaluate actual progress. In order to provide a more nuanced perspective, to include credibility considerations, and to link more closely to real-economy actions, there is also a need to look beyond GHG emission-based metrics only. Here, one approach consists of analysing forward looking capacity, production and capital expenditure[10] plans of companies. This is notably done by PACTA (2DII, n.d.[60]).

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[10] Capital expenditure refers to money spend by corporates to purchase, maintain, or upgrade their physical assets, such as buildings and equipment. It relates more closely to real-economy decision-making.

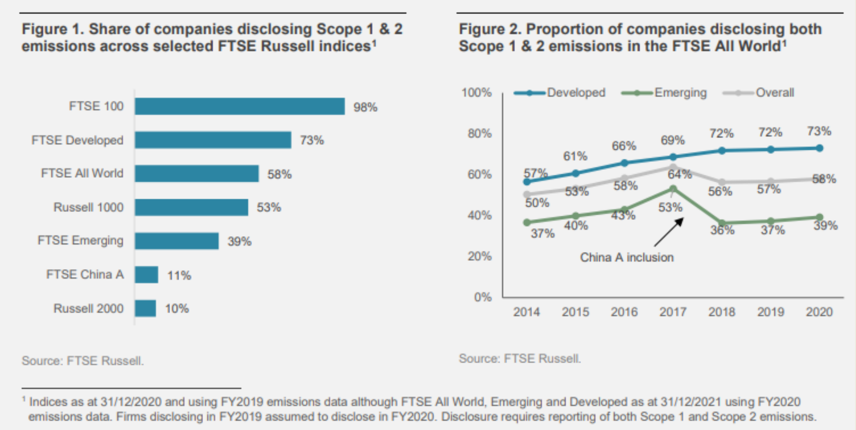
Box 3.2. Corporate data sources used by climate-alignment assessment methodologies

As Table 3.2 shows, different methodologies have different data needs. Current data gaps for corporate-related financial asset assessments encompass several dimensions: availability (coverage, granularity, accessibility), reliability (quality, auditability, transparency) and comparability (NGFS, 2022[61]). Such data limitations are more acute for the SDA and EIC approaches because more types of data are needed additional to historical and projected emissions.

Sources of historical entity data

Current and historical emissions can be self-reported by a company or modelled by the methodology provider (or an external data provider) (PAT, 2020[10]). Historical data needed for corporates, depending on the methodology, include absolute emissions, production outputs, value added or revenue. Some providers, such as CDP and TPI, rely solely on self-reported disclosure by companies in their climate-alignment assessments (CDP & WWF, 2020[62]). This may also provide an incentive to companies to improve disclosure. Many other providers also rely on modelled data, at least to some degree. When methodologies aim to rely primarily on reported emissions, disclosure is often too limited to achieve sufficient coverage for a portfolio analysis (Figure 3.3). Moreover, reported emissions may be unverified. Modelled data helps improve coverage especially for entities in emerging and developing economies and for unlisted companies. On the other hand, modelled data increases uncertainty as it is based on assumptions and, often, on sectoral averages.

Figure 3.3. Share of companies disclosing Scope 1 and 2 emissions



Source: (Simmons et al., 2022[63]).

Sources and assumptions of forward-looking entity data

Forward-looking data collected by climate-alignment assessment providers typically refer to emissions reduction targets, more rarely also to planned capital expenditure. This data needs to be self-reported by the entities. In the absence of such targets, historical emissions intensities are often held constant by methodology providers to understand the gap between where the entity would be in the future if it did not change and where it needs to be to be climate aligned. Alternatively, providers may assume that past average subindustry or company-specific trends in emissions intensity and activity growth continue (e.g. (S&P Global and Natixis, 2021[64])). For intensity-based metrics, companies need to disclose either emissions intensity-based targets or projections of the respective denominator, such as production volumes or revenue. In case the latter is not included, current volumes or revenue could be assumed constant to the target date.

For sovereign bonds, the AEC and EIC approaches can in principle be used as well. However, only few alignment assessment methodologies have been developed to date. In their Climate Liabilities Assessment Integrated Methodology (CLAIM), FTSE-Beyond Ratings calculate a country's projected GHG performance based on the targeted reductions in absolute emissions as implied by its NDC (Emin et al., 2021[65]). Several climate-alignment assessment providers are in the process of also developing a methodology for sovereign bonds. For instance, the methodology provider *right. based on science* is developing on intensity-based metric, in terms of CO_2e per capita (Robinson-Tillett, 2021[66]). Such physical intensity metric is preferred by *right. based on science* over an EIC approach in terms of emissions per GDP as the latter could disproportionally disfavour developing countries, which have lower GDP per capita.

Investors in sovereign debt need rigorous metrics that gauge the climate-alignment of national policies (Domínguez-Jiménez and Lehmann, 2021[67]). A range of tools, not explicitly designed to be used by the financial sector, have or are being developed to assess countries' climate mitigation performance based on different quantitative and qualitative metrics. Examples of such work include forthcoming work by the OECD under the International Programme for Action on Climate for instance and work done by Climate Action Tracker (Climate Action Tracker, 2022[68]).

Existing methodologies for **infrastructure and real estate** follow the SDA. For example, CRREM uses floor area as a denominator (CRREM, 2020[69]). For Carbone 4's 2-Infra methodology, the denominator depends on the use of the infrastructure asset: e.g. km for a road, kWh for an electricity plant (Carbone 4, 2020[70]).

3.2.2. Temporal perspective and coverage of metrics

The temporal boundary of a GHG performance metric can drive alignment results (Thomä, Dupré and Hayne, 2018[71]). There are three elements to consider the temporal perspective of a GHG performance metric, namely whether it is backward- or forward-looking, whether it considers a short medium or long time period, and whether the metric is only compared with a scenario at a certain point in time or across a time period.

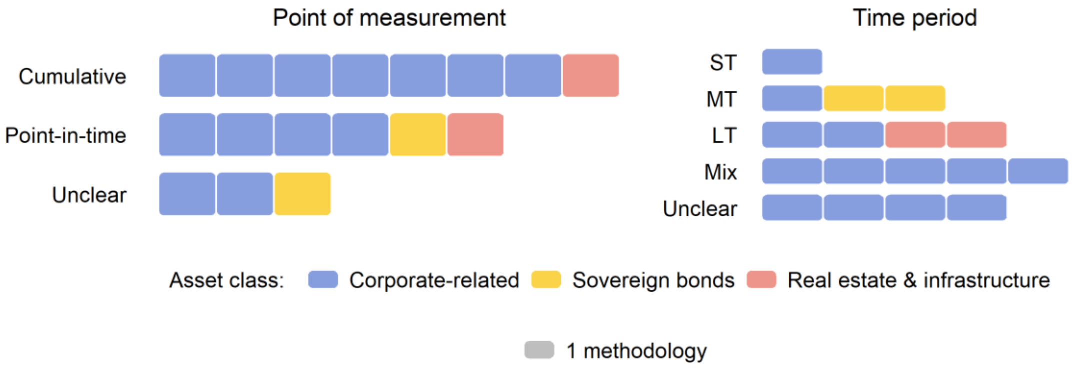
Metrics with backward-looking and forward-looking perspectives can serve different purposes. Backward-looking metrics can be used for an ex-post assessment of alignment, analysing whether an entity has followed a scenario in the past (Institut Louis Bachelier et al., 2020[11]). On the other hand, forward-looking metrics are more dynamic as they aim to assess whether an entity is on track to comply with the remaining carbon budget for a certain temperature goal. Past performance does not necessarily correlate with future performance. Indeed, metrics based solely on historical data may not be well suited to assess climate-alignment due to non-linearity, non-stationarity, path-dependencies and endogeneity issues (Bingler, Colesanti Senni and Monnin, 2021[42]).

In terms of time period, while each choice and action at any point in time matters, 2025, 2030 and 2050 are all important policy milestones towards reaching the PA temperature goal. The most recent IPCC assessment indicates 2025 as the year when global emissions should peak, as early action is essential in reducing risks of crossing climate tipping points. Further, global emissions need to reach net-zero between 2045 and 2055, in order to limit warming to 1.5 °C with no or limited overshoot (IPCC, 2022[72]). While the PA and its accompanying decision call for long-term low-greenhouse gas emission development strategies, countries also submit short-term targets to 2030 in their NDCs (Meinshausen et al., 2022[73]). Many countries are setting targets to reach net zero by mid-century or shortly thereafter, although the scope and coverage of such targets can vary widely (Jeudy-Hugo, Lo Re and Falduto, 2021[74]). Long-term strategies can substantially shape short- and mid-term priorities, policies and investment pipelines, leading to significant cost reductions in the long term by avoiding stranded assets (Falduto and Rocha, 2020[75])..

Methodological recommendations for corporate-related financial assets are consistent with these considerations. SBTi requires that corporate targets and mitigation performance assessments should cover a minimum of five years and a maximum of 10 years (SBTi, 2021[57]). SBTi further recommends companies to set long-term targets and set near-term milestones at five-year intervals. The rationale for this is that setting long-term net-zero targets encourages planning to manage the long-term risks and opportunities connected with climate change. These may include the creation of new services and markets and the need for large capital investments that offer GHG benefits. Further, some research also pointed out the importance of measuring progress from a base year at 2015 or earlier to capture emissions reductions that have been achieved well before 2020 and since the adoption of the PA (Rekker et al., 2022[58]).

In terms of point of measurement, the comparison of a GHG performance metric with a scenario can happen at one point-in-time or over a time period. The alignment of a metric assessed in a certain point in time can be driven by the year of choice (Institut Louis Bachelier et al., 2020[11]). The assessment of a metric over a time period can be either done through the assessment of the change in the trend of the metric or the cumulative difference between the metric and the scenario over years.

Figure 3.4. Number of methodologies following a given temporal perspective



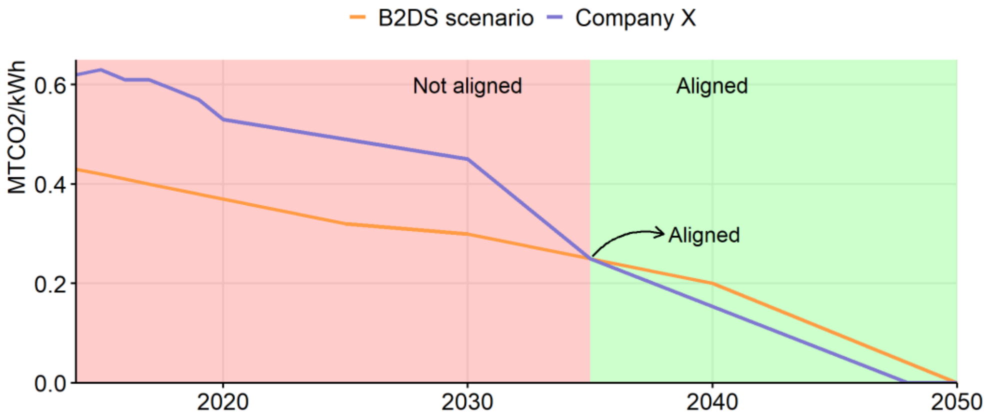
Note: ST is short term, meaning until 2025. MT is medium term, meaning until 2030-2035. LT is long term, meaning until 2050 and beyond.
Source: Authors' analysis based on publicly-available information and, for some providers, bilateral consultations.

For corporates, existing climate-alignment assessment methods rely on a range of different temporal perspectives (Figure 3.4). Some methodologies only consider the short term, some only the long term, and some consider both resulting in multiple assessment results for multiple years. For example, Arabesque and CDP assess alignment by comparing GHG performance in 2030 and 2050. PACTA, on the other hand, only considers the next five years as the assessment methodology relies on forward-looking corporate production and capital expenditure plans, which typically don't extend further in time. Based on consultations (see Acknowledgements), many providers see a need to track near-term targets and alignment, as it may better predict early action. Further, there is almost an even contribution of methodologies considering just a snapshot (i.e. point-in-time) or cumulative emissions over a time period. While the majority of methodologies are purely forward-looking (based on targets), S&P Sustainable1 takes into account a medium-term historical and medium-term forward looking period in its GHG performance metric. Some of the other providers also make use of such information, but rather to produce complementary metrics rather than as an integral part in the alignment metric methodology.

For sovereign bonds, existing climate-alignment assessment methodologies consider the medium-term (Figure 3.4). Based on consultations (see Acknowledgements), this view is supported because the submission of long-term national targets to the UNFCCC are not mandatory under the PA. Existing climate-alignment assessment methods for investments in **infrastructure and real estate** take an even longer-term perspective, owing to the long lifespan of underlying physical assets.

Figure 3.5 illustrates with a stylised example the potential impact of the choice of temporal perspective. Considering the example, long-term point-in-time metrics without interim points of measurement (e.g. in 2030) or cumulative measurement may find that assets are aligned (in e.g. 2050) while they emit more than the carbon budget would allow.

Figure 3.5. Stylised example of point-in-time alignment assessment over time for an electric utility



Note: B2DS is a Below 2 Degrees scenario. Company X shows the decarbonisation trajectory of a fictive company.
Source: Authors.

3.2.3. Types and scopes of greenhouse gases in metrics

The coverage of GHG emissions in climate-alignment assessment methodologies relates to two aspects: the types of GHGs and the scope of emissions covered. This section illustrates that while the coverage of types of GHGs follows a similar logic across asset classes, the categorisation in terms of scope of GHG tends to differ depending on the asset class covered. Corporate-related, real estate and infrastructure financial assets rely on GHG accounting according to the scope 1, 2 and 3 categorisation[11], whereas metrics for sovereign bonds rely on country's national-level GHG inventories.

To understand the full extent of global warming, economic actors should measure and disclose total emissions of all types of GHGs or in CO_2-equivalent terms, i.e. both GHGs with lifetimes around 100 years or longer, notably CO_2 and nitrous oxide, and Short-Lived Climate Forcers (SLCFs), notably methane and some hydrofluorocarbons (IPCC, 2022[72]). Some research further suggests that governments and corporations should indicate the separate contribution of each type of GHGs to total CO_2-equivalent emissions in their targets and measurement of progress (Allen et al., 2022[76]).

For corporates, building on the GHG Protocol, the SBTi requires that GHG performance metrics (relating to both historic emissions and targets) cover at least 95% of company-wide Scope 1 and 2 emissions and account for all relevant Scope 3 emissions[12] (SBTi, 2021[57]). Scope 3 emission relate to the responsibility of companies along their value chain, both upstream and downstream, a core element of RBC due diligence standards that address the role of business in causing, contributing and directly linking to adverse environmental impacts along supply chains and business relationships (see Section 2.2). The relevance

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[11] Scope 1 are direct emissions from owned or controlled assets, Scope 2 indirect emissions from the generation of purchased energy, and Scope 3 are indirect emissions from any other up- and down-stream activities related to the company's product (World Resources Institute & World Business Council for Sustainable evelopment, 2004[83]). These were defined via the GHG Protocol, a reference point for corporate level reporting and accounting.

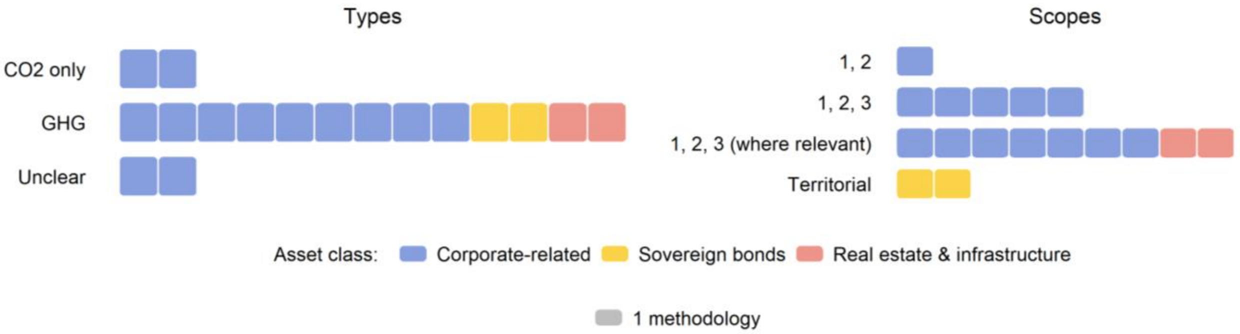
[12] Relevant emissions are determined based on the average share of emissions each category represents for an average company in a given sector.

of Scope 3 emissions, which relate to the company value chain both upstream and downstream, depend on the sector and where across the value chain the company sits. Estimates indicate they are especially important in sectors such as oil and gas and car manufacturing, for which they account for the majority of emissions across the three scopes (Hertwich and Wood, 2018[77]).

Most climate-alignment assessment methodologies consider all types of GHGs and the widest scope possible based on available data (Figure 3.6). All methodology providers for corporate assets include both Scope 1 and 2 emissions. A large majority also aim to include Scope 3 although limited data availability and quality is a major challenge (Thomä, Dupré and Hayne, 2018[71]). As a result, some methodologies choose to only include Scope 3 emissions when they represent a significant portion of total emissions. Those that do include Scope 3 emissions often rely on modelled or estimated data, as further discussed in Box 3.2).

For real estate and infrastructure, similarly, methodologies include non-CO_2 GHGs and Scope 3 emissions where relevant and based on the availability of data or estimates. For example CRREM includes Scope 3 of real estate in terms of tenant electricity and embodied carbon in reference to retrofits (CRREM, 2020[69]).

Figure 3.6. Coverage of types and scopes of GHGs for each methodology provider



Note: GHGs refers to all relevant GHGs in respective sectors. Methodologies including Scopes 1, 2, 3 reflects that they include all scopes regardless of their relevance to a specific sector. Methodologies including Scopes 1, 2, 3 (where relevant) reflects that they include those scopes that are relevant for a given sector.
Source: Authors' analysis based on publicly-available information and, for some providers, bilateral consultations.

For sovereign bonds, existing climate-alignment assessment methodologies, as well as those under development at the time of writing, attribute all GHG emissions within the territory of the country to the central government as debt issuer (Figure 3.6). Indeed, the central government has a formative role in determining the future path of GHG emissions through policies, regulation, taxation and subsidies (Domínguez-Jiménez and Lehmann, 2021[67]). The IPCC's Task Force on National Greenhouse Gas Inventories first issued guidelines in 1994. The 2006 version of such IPCC guidelines (IPCC, 2006[78]), refined in 2019 (IPCC, 2019[79]), is the current standard that countries[13] are expected to follow. On that basis, the scope of a national inventory has to, in principle, cover all anthropogenic GHG emissions (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3) produced on its territory in energy, industrial process and product use, agriculture land use change and forestry, and waste sectors. The guidelines provide extensive information on how to compile an inventory, including in terms of method to estimate emissions (in simple

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[13] Under the UNFCCC Parties are required to submit a national inventory of anthropogenic emissions by sources, and removals by sinks, of all greenhouse gases (GHGs), Annex I countries as part of their Biennial Reports, non-Annex I Parties as part of their national communications.

terms multiplying an emission factor by activity data). In practice, not all non-Annex I Parties to the UNFCCC may have the capabilities to report comprehensively.

Box 3.3. Corporate boundaries

For corporate-related assets, ownership boundaries could be an important aspect in defining the analytical scope of both alignment assessments in terms of geography and business activities, especially for large conglomerates (Thomä, Dupré and Hayne, 2018[71]). The corporate boundaries can affect the level of emissions. These considerations should be reflected in GHG accounting. Ownership boundaries relate questions of how to account subsidiaries in annual accounts and partially owned assets. In this context, the GHG Protocol defines three different approaches for determining the organisational boundaries of corporate GHG inventories:

- Operational control: A company accounts for 100% of the emissions from operations at which it has the full authority to introduce and implement operating policies. It does not account for any of the emissions from operations in which it owns an interest but does not have operational control.
- Financial control: A company accounts for 100% of the emissions from operations at which it can direct financial and operating activities with a view to gaining economic benefits from those activities.
- Equity share: A company accounts for GHG emissions from operations according to its share of equity in the operation. The equity share reflects economic interest, which is the extent of rights a company has to the risks and rewards flowing from an operation.

The boundaries of targets and metrics should be the same for each asset/company (SBTi, 2021[57]). The choice of these or other approaches may be specific to the accounting objective, and indeed will not necessarily be consistently applied in one annual report of a company. This can be a challenge for climate-change alignment tracking initiatives that divide one by the other.

Such production-based approach forms the basis for the UNFCCC reporting guidelines of annual inventories (UNFCCC, 2014[80]). These inventories provide information on the development of GHG emissions at national level over time, as well as, for Annex I Parties only, represent the scenario from which national GHG reduction targets are set (see Section 3.2.1).[14]

As a result of differences in corporate and national GHG accounting, and as further discussed in Section 3.4, combining assessments for different types of financial assets (e.g. sovereign and private-sector bonds) at the level of a financial portfolio results in methodological difficulties and inconsistencies, notably an intractable double-counting problem. Notably, accounting for scope 3 emissions can lead to double- or multiple-counting of the same emissions by individual actors along the corporate, real estate or infrastructure asset value chain. This may not be an issue for assessing the alignment of individual economic actors and assets (where on the contrary it may result in enhanced ambition and action), nor, more generally, for intensity-based metrics. However, such multiple counting

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[14] The main methodological alternative consists in compiling a consumption-based inventory, which captures GHG emissions occurring within and outside the national boundaries due to consumption, whether produced domestically or imported, i.e. emissions embodied in trade netting out exports. In almost every EU country, consumption-based emissions are higher than those arising from local production as captured in UNFCCC inventories, as is the case in most developed countries as demonstrated by OECD Green Growth indicators (OECD, 2020[145]). In developing countries, the situation is different: some have both low production- and demand-based GHG emissions, while others have higher production- than demand-based emissions (IPCC, 2022[72]). At the time of writing, the only known country intending to set an official target for consumption-based emissions was Sweden (Climate Home News, 2022[146]).

can pose an environmental integrity issue when trying to aggregate corporate GHG metrics to reconcile them with national, sectoral and global carbon budgets.

3.2.4. Treatment of offsets and avoided emissions in metrics

Climate science and literature treat **offsets** with caution, notably in terms of the risk they pose of delaying or replacing actual GHG reductions, as well as in relation to their environmental integrity and additionally. In the context of net-zero emissions, the urgency of absolute emission reductions remains (Fankhauser et al., 2021[81]). These reductions need to be front-loaded and to cover all emission sources. This means carbon dioxide removals should be used cautiously and the use of carbon offsets should be regulated effectively. There are many questions around the integrity and additionally of offsets. For example, over half of the carbon offsets allocated in the Clean Development Mechanism (CDM) went to projects that would very likely have been developed anyway, i.e. lack of additionally (Calel et al., 2021[82]). The sale of offsets in the CDM may in fact have significantly increased global emissions.

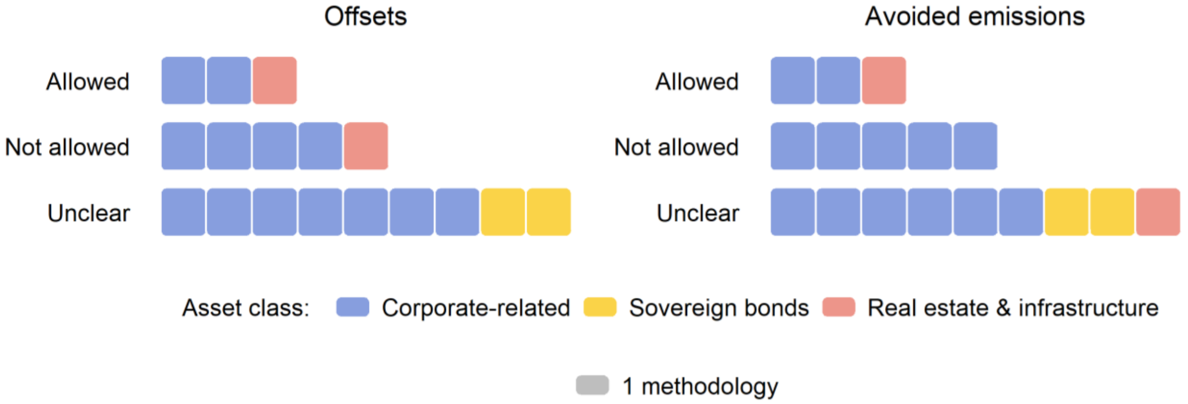
In this context, the SBTi standard states that offsets cannot be counted as reductions towards meeting a near-term target (SBTi, 2021[57]). Companies must account for reductions resulting from direct action within their operations or value chains. Moreover, the GHG protocol treats biogenic CO_2 (both sequestration, e.g. uptake by forests, and emissions, e.g. burning biomass) as separate from Scope 1, 2 and 3 emissions (World Resources Institute & World Business Council for Sustainable evelopment, 2004[83]).

Avoided emissions are currently defined and understood differently by different communities. For a country, in the context of international carbon markets, avoided emissions refer to activities that avoid potential sources of stored GHG emissions from being emitted to the atmosphere within its territory, such as the non-exploitation of fossil fuel reserves, maintaining land use and agricultural practices that retain already-stored carbon, and avoided deforestation (Jeudy-Hugo, Lo Re and Falduto, 2021[74]). For corporates, avoided emissions typically refer to emissions avoided during the use phase, by a company's customer compared to using a more carbon-intensive product than the less-carbon intensive product from the company, e.g. appliances that more energy efficient than comparable models available on the marketplace. A similar logic can applies to real estate and infrastructure.

In all cases, there are no agreed methods or standards to count counterfactuals and calculate avoided emissions. For corporates, avoided emissions do not occur during the product's life cycle inventory. Consequently, SBTi does not allow avoided emissions to be included in GHG performance metrics and requires that they are accounted for and reported separately from Scope 1, 2 and 3 emissions, including any Scope 3 metric or target (SBTi, 2021[57]). Further, assumptions regarding avoided emissions are vulnerable to the risk of non-permanence of the underlying activities. In the case of countries for instance, "fossil fuels could be kept in the ground (or deforestation could be avoided) for the time in which financial support from the sale of international credits is received, and subsequently extracted (or deforested, respectively)" (Jeudy-Hugo, Lo Re and Falduto, 2021[74]).

Many methodologies for the different asset classes considered do not explicitly state how offsets are treated, a few also allow avoided emissions (Figure 3.7). Arabesque Temperature Score methodology is one of the few methodologies that explicitly states that it does not take emissions offsetting into account, referring to the GHG Protocol and the SBTi (Arabesque, n.d.[84]). Further, PACTA in particular does not account for offsets and avoided emissions as its methodology focusses on technology shift and capital expenditure rather than emissions targets.

Figure 3.7. Treatment of offsets and avoided emissions by methodology providers



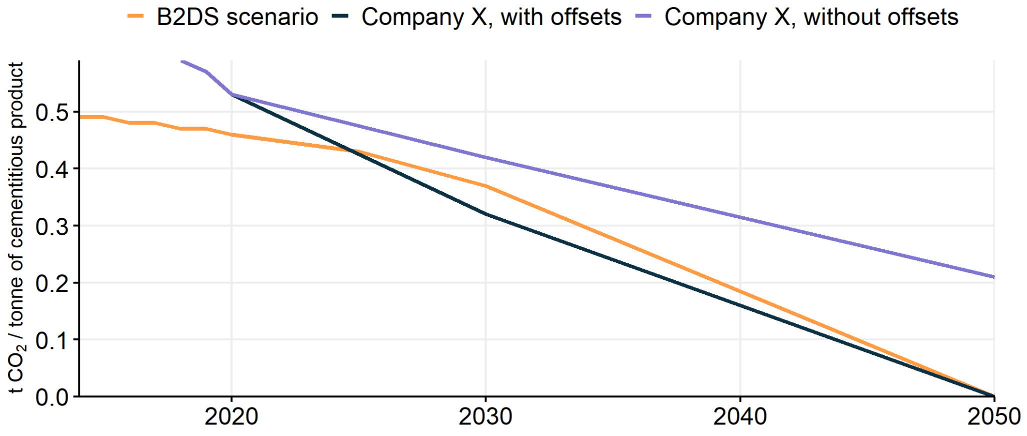
Note. Unclear typically means that the methodology provider does not explicitly state if or how offsets or avoided emissions are treated.
Source: Authors' analysis based on publicly-available information and, for some providers, bilateral consultations.

The lack of clarity on how offsets are treated in climate-alignment assessment methodologies may be a consequence of the lack of clarity and transparency of the use of offsets in metrics, targets and plans of economic actors themselves. An analysis of 25 major global companies with climate pledges found that companies are not yet transparent about their use of offsets (NewClimate Institute and Carbon Market Watch, 2022[85]). Lawmakers have picked up on this limitation. For instance, in March 2022, the U.S. Securities and Exchange Commission (SEC) proposed a rule on mandatory climate-related disclosure, which would require listed companies to disclose how offsets are used in their emissions reduction strategies (SEC, 2022[86]).

Indeed, to ensure the environmental integrity of alignment assessments, companies tracking and reporting systems need to separate the reliance on offsets, both in emissions accounting as well as in the context of emission reduction targets. Figure 3.8 shows how the inclusion of offsets can make a difference for climate-alignment results, taking the example of a cement company that aims to reduce its CO_2e emissions per tonne of cementitious product produced by 40% between 2020 and 2030. If in fact, the company plans half of its reduction through offsets, the 2030 intensity excluding those offsets would not be aligned.

For sovereign bonds, as explained in Section 3.2.3, the alignment assessment relates directly to country-level metrics, GHG inventory as well as targets. Similarly to company targets, national targets are typically unclear on whether and the extent to which they intend to rely on carbon offsets (Black et al., 2021[87]). As is the case for corporate-related financial assets, this lack of clarity negatively impacts the environmental integrity of climate-alignment assessments of sovereign bonds, which in turn can question their relevance in contributing to measure progress towards climate mitigation policy goals.

Figure 3.8. Stylised example of the treatment of offsets in the decarbonisation pathway of an electric utility



Note: B2DS is a Below 2 Degrees scenario. Company X shows the decarbonisation trajectory of a fictive company.
Source: Authors.

3.3. Selection of climate change mitigation scenarios

Generally, carbon budgets calculated by scientists apply to the global atmosphere. Translating these into GHG reduction scenarios for countries, sectors, companies and other entities or asset classes requires hypotheses and, in some areas, value judgements (Fankhauser et al., 2021[81]). Initiatives assessing climate alignment in finance may use different sources for such scenarios, define different sectoral and geographic specificity and may or may not consider their relevance and applicability to both developed and developing countries.

3.3.1. Scenario data and information sources

Many institutions worldwide provide climate change mitigation scenarios, as illustrated by the over 3,000 quantitative scenarios submitted to the IPCC's Sixth Assessment Report (AR6) database[15] and assessed in the most recent IPCC publication (IPCC, 2022, p. Chapter 3[8]). This database provides an overview of the wide range of modelled emission pathways and scenarios in the existing literature.

Emissions scenarios project the evolution of GHG emissions based on a set of internally consistent assumptions about future socio-economic conditions and related mitigation measures (IPCC, 2022[72]). In the AR6 database, about half of modelled emissions scenarios are built on cost-effective approaches, relying on least-cost emission abatement options globally to reach a certain temperature goal. The majority of modelled scenarios do not make assumptions about global equity.

While IPCC publications consider a wide range of scenarios, some are more prominent. The Shared Socioeconomic Pathways (SSP) is a collection of scenarios based on five narratives describing alternative socio-economic developments (Riahi et al., 2017[88]), which were used for the IPCC sixth Assessment Report (AR6). The Representative Concentration Pathways (RCP) are a set of four scenarios containing emission, concentration and land-use projections with detailed spatial data (van Vuuren et al., 2011[89]). They underpinned the IPCC fifth Assessment Report (AR5). Additional to the pathways, the IPCC

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[15] The International Institute for Applied Systems Analysis (IIASA) hosts the scenarios and data used in the IPCC reports (Byers et al., 2022[147]). This includes the IAMC 1.5°C Scenario Explorer (Huppmann et al., 2019[142]), which covers the pathways used in the Special Report on Global Warming of 1.5°C (IPCC, 2018[140]).

considers an approach to calculate the remaining carbon budgets for different temperature objectives (IPCC, 2022[72]).

Other individual scenarios may provide more insights on sectors and regions, depending on the analytical purpose and target audience they have been designed for, such as scenarios developed by the:

- The International Energy Agency (IEA): The IEA has developed a set of scenarios in its World Energy Outlook (IEA, 2021[90]). It also published further global and macro-regional pathways for broad sectors in their Energy Technology Perspectives (IEA, 2020[91]).
- The Network for Greening the Financial System (NGFS): The NGFS is building its own Climate Scenarios Database, which currently consists of six scenarios classified in three categories: orderly transition, disorderly transition, and hot house world (Bertram et al., 2021[92]). These scenarios are being designed with the help of climate scientists and build on the socio-economic assumptions in the SSP scenarios.
- The European Commission's Joint Research Centre (JRC): The JRC has developed its so-called POLES model which simulates technology dynamics and can be used to generate scenarios under its Global Energy and Climate Outlook (GECO) for different regions (Després et al., 2018[93]; Keramidas et al., 2021[94]).
- The Institution for Sustainable Futures (ISF): The ISF has developed the One Earth Climate Model (OECM) scenarios, which are somewhat unique because they consider sector classifications used in financial and economic accounting rather than the IPCC sector classifications (i.e. GICS) (Teske et al., 2022[95]).

Further, some institutions have built scenarios for specific sectors and countries. For example, the En-ROADS initiative, IRENA World Energy Transitions Outlook (WETO) 1.5°C Pathway, Greenpeace advanced energy (r)evolution, deep decarbonisation pathways project, and the US EIA's Annual Energy Outlook (CPI, 2020[96]; Institut Louis Bachelier et al., 2020[11]; IRENA, 2021[97]).

Most of the existing climate-alignment assessment methodologies reviewed in this paper rely on one or a few of the above mentioned scenarios, as summarised in Table 3.3. IEA scenarios currently dominate, with over half of the methodologies for corporate-related assets considering IEA scenarios for their climate-alignment assessments. They are also particularly used for more sector-specific financial assets such as real estate (CRREM, 2020[69]). Some scenarios are only considered by one of the providers (e.g. scenarios from the JRC by PACTA).

While climate-alignment assessment methodologies for other asset classes than corporates may rely on similar scenario sources as those used by corporate-specific methodologies, they often undergo more transformations because additional assumptions may be added. Alternatively a few methodologies develop or use proprietary scenarios, e.g. Carbone 4 CIARA, a methodology specifically developed for infrastructure investments, relies on a scenario provided by Enerdata (Carbone 4, 2020[70]).

Methodology providers typically update their methodologies as new versions of the same scenario become available. This is illustrated by the multiple IEA Sustainable Development Scenarios (SDS) in Table 3.3. Further, during consultations (see Acknowledgements), several providers indicated that the potential use of scenarios from NGFS and ISF will be explored more in future iterations of their methodologies. The providers right. based and PACTA already allow users to choose a scenario among multiple options. This allows users to compare multiple scenarios for the same temperature rise instead of a single scenario for each temperature outcomes, as is the case for most providers.

Table 3.3. Main climate change mitigation scenarios for 2°C or below used by the methodologies reviewed

Scenario	Model	GHGs covered	Emissions sources	Global carbon budget	Temperature rise (and likelihood)	Horizon
International Energy Agency (IEA)						
NZE	WEM 2021	CO_2	Energy and industrial processes	500 $GtCO_2$, 2020-2050	1.5°C (50%)	2050
SDS	WEM 2021	CO_2		?	1.65°C (50%)	2050
SDS	WEM 2020	CO_2		?	1.65°C (50%)	2050
SDS	WEM 2019	CO_2		880 $GtCO_2$, 2018-2070	1.65°C (50%) / 1.8°C (66%)	2040
SDS	ETP 2020	CO_2		?	1.8°C (66%)	2070
B2DS	ETP 2017	CO_2		750 $GtCO_2$*, 2015-2100	1.75°C (50%)	2060
2DS	ETP 2017	CO_2		1170 $GtCO_2$*, 2015-2100	2°C (50%)	2060
European Commission's Joint Research Centre (JRC)						
GECO 1.5°C uniform	POLES JRC 2021	All GHGs	All (Energy and industrial processes, AFOLU)	500 $GtCO_2$, 2020-2100	1.5°C (50%)	2070
GECO 1.5°C Differentiated	POLES JRC 2021	All GHGs		500 $GtCO_2$, 2020-2100	1.5°C (50%)	2070
GECO 1.5°C	POLES JRC 2020	All GHGs		300-330 $GtCO_2$, 2018-2100	1.5°C (66%)	2050
GECO 2°C	POLES JRC 2020	All GHGs		870-920 $GtCO_2$, 2018-2100	Below 2°C (50%)	2050
Network for Greening the Financial System (NGFS)						
NGFS2 Net-Zero 2050	GCAM 5.3, MESSAGEix-GLOBIOM_1.1, REMIND-MAgPIE 2.1-4.2	All GHGs	All (Energy and industrial processes, AFOLU)	400 $GtCO_2$, 2011-2100	1.5°C (50%)	2100
NGFS2 Divergent Net Zero Policies	GCAM 5.3, MESSAGEix-GLOBIOM 1.1, REMIND-MAgPIE 2.1-4.2	All GHGs		400 $GtCO_2$, 2011-2100	1.5°C (50%)	2100
NGFS2 Below 2°C	GCAM 5.3, MESSAGEix-GLOBIOM 1.1, REMIND-MAgPIE 2.1-4.2	All GHGs		1000 $GtCO_2$, 2011-2100	Below 2°C (67%)	2100
NGFS2 Delayed transition	GCAM 5.3, MESSAGEix-GLOBIOM 1.1, REMIND-MAgPIE 2.1-4.2	All GHGs		1000 $GtCO_2$, 2011-2100	Below 2°C (67%)	2100
Institution for Sustainable Futures (ISF)						
OECM 1.5°C	OECM	All GHGs	Energy	450 $GtCO_2$*, 2015-2050	1.5°C (50%)	2050
OECM 2°C	OECM	All GHGs		590 $GtCO_2$*, 2015-2050	Below 2°C (80-85%)	2050
ISF Net Zero	OECM	All GHGs		400 $GtCO_2$*, 2020-2050	1.5°C (66%)	2050

Note 1: Last updated in July 2022. Scenarios or scenario sources referenced by the online documentation of or through consultations with climate-alignment assessment methodology providers are included. Proprietary scenarios are not included. The table also does not reflect methodologies that use an absolute carbon budget or the full database of scenarios captured by the IPCC fifth or sixth assessment.

Note: 2: The * in the column 'Global carbon budget' refers to budgets excluding AFOLU emissions. Likelihood refers to the probability of staying below a given temperature rise by 2100.

Note 3: The acronyms refer to the following. GHG: greenhouse gas, AFOLU: Agriculture, Forestry and Other Land Uses, NZE: Net Zero Emissions, SDS: Sustainable Development Scenario, B2DS: Beyond 2°C Scenario, IEA: International Energy Agency, 2DS: 2°C Scenario, WEM: World Energy Model, ETP: Energy Technology Perspectives, GECO: Global Energy and Climate Outlook, POLES: Prospective Outlook on Long-Term Energy Systems, JRC: Joint Research Centre, NGFS: Network for Greening the Financial System, OECM: One Earth Climate Model, ISF: Institute for Sustainable Futures, GCAM: Global Change Analysis Model, MESSAGEix: Model for Energy Supply Strategy Alternatives and their General Environmental Impact, GLOBIOM: GLobal BIOsphere Management, REMIND: REgional Model of Investment and Development, MAgPIE: Model of Agricultural Production and its Impact on the Environment.

Source: Authors.

Based on consultations, the choice of the IEA is motivated by its sectoral specificity, which alternative scenarios may lack (at the time of writing), especially prior to the more recent OECM scenarios. On the other hand, the addition or public availability of more geographical specificity is desired. Consultations further highlighted that IEA scenarios are often complemented with other scenarios and data because they either do not sufficiently cover a 1.5 degrees objective (i.e. prior to the release of their net zero roadmap (IEA, 2021[98])) and do not cover non-CO_2 GHGs. A ratio may be applied to the IEA scenarios to add non-CO_2 GHGs. The latter may be done using information from other scenarios in the IPCC database or by interpolating industry trends using data points from academic papers, information from industry representation organisations or other institutes e.g. methane tracker. Another, adjustment that may be made is including Carbon Dioxide Removal (CDR).

Some methodologies, for both corporate- and sovereign-related assets, consider the IPCC remaining carbon budgets instead of scenario pathways. For example, MSCI currently uses the Global 2°C Carbon Budget (MSCI, 2021[99]) based on the IPCC Special Report on 1.5 °C, but this may be updated to a 1.5°C carbon budget using newer publications. Further, the FTSE-Beyond Ratings method for sovereign assets reconciles national budgets with the global emissions budgets for different temperature goal as published by the IPCC.

Finally, it should be noted that in addition to GHG emission trajectories, scenarios can provide a wide range of information and data associated with such trajectories, e.g. underlying assumptions about the evolution of underlying capacity and production volumes. Pending such information and data are made publicly available, they can be used as input to a more comprehensive and nuanced analysis. As discussed in other parts and in the Conclusions and implications chapter of the paper, this can form part of future dashboards of indicators that would include but not be limited to GHG-based metrics and assessments.

3.3.2. Temperature outcomes and uncertainty based on scenario(s) used

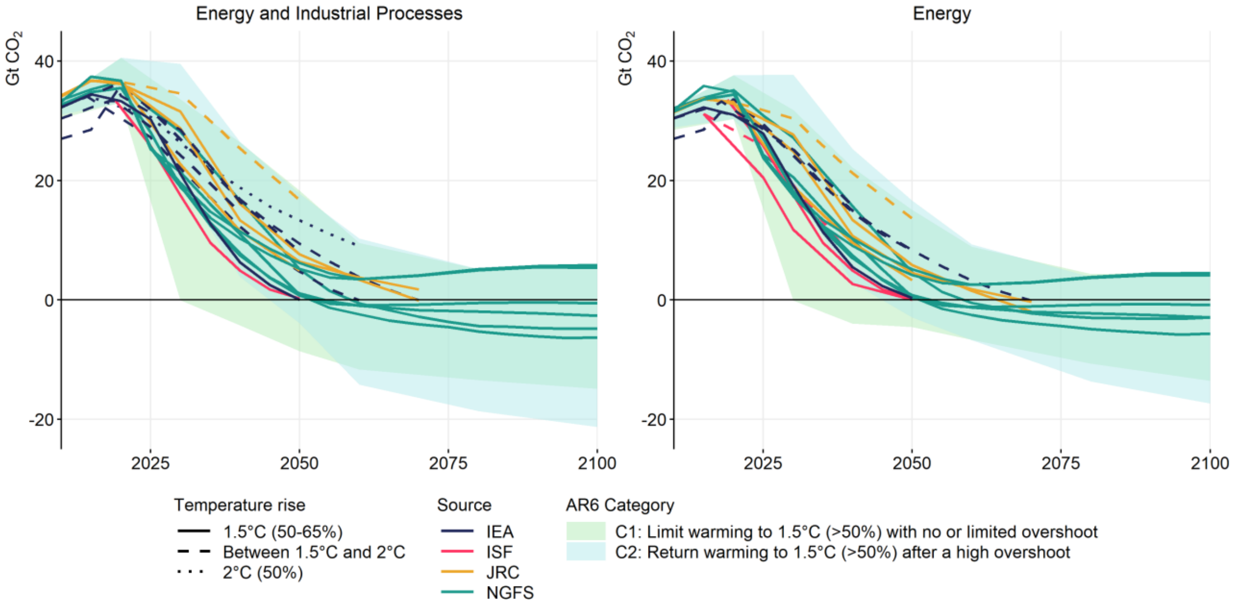
Climate scientists can calculate the remaining carbon budget for a given temperature goal. This is because there is a near-linear relationship between cumulative anthropogenic CO_2 emissions and the global warming they cause. Each 1,000 $GtCO_2$ of cumulative CO_2 emissions is assessed to likely cause a 0.27°C to 0.63°C increase in global surface temperature with a best estimate of 0.45°C. This quantity is referred to as the transient climate response to cumulative CO_2 emissions (TCRE) (IPCC, 2021[100]; Rogelj et al., 2019[101]; Matthews et al., 2009[102]).

Carbon budgets calculated in this way to be consistent with a certain temperature outcome, can be used as boundary conditions for mitigation scenario pathways. Temperature outcomes of scenarios can also be calculated using so called climate emulator models, which are reduced complexity climate models (IPCC, 2022[72]). Either way, the scenarios come with a probability of how likely they are to keep temperature rise below a certain degree.

shows the likelihood of staying within a certain temperature rise for each scenario used by the climate-alignment methodology providers. For example, while the IEA NZE scenario is characterised by a 50% likelihood of keeping global warming below 1.5 degrees Celsius by 2100, the ISF Net Zero scenario is characterised by a 67% likelihood for such temperature increase.

Different scenarios can represent different ways to reach a given temperature objective. Figure 3.9 shows the pathways of the different scenarios considered by the methodology providers for different temperature alignments. It highlights the fact that the choice of any single scenario will have an impact on the alignment result for a given asset. In part to address this issue, the CDP-WWF Temperature Ratings methodology starts with the full sample of scenarios captured by the IPCC hosted by the IIASA database. It then applies a range of selection criteria, e.g. scenarios with early action and low reliance on unproven carbon removal technologies. Sources of scenario uncertainties will be further explored in follow-up OECD analysis to the present paper.

Figure 3.9. Comparison of climate change mitigation scenario pathways used by methodologies



Note: Scenarios listed in Table 3.3 are included. For some scenarios only data for the combined emissions from "energy and industrial processes" and for some only for "energy" could be found. The AR6 Category envelopes are calculated as the maximum range in the years 2010, 2020, 2030, 2040, 2050, 2060, 2080, 2100.
Source: Authors.

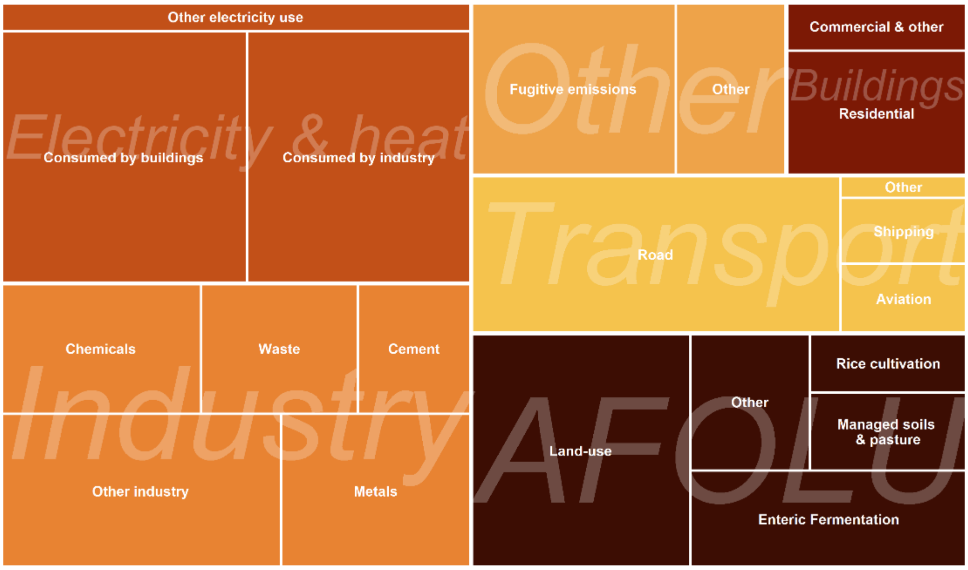
Most methodologies use scenarios for a few different temperature outcomes and define alignment of an entity based on the most ambitious scenario it is aligned with. However, the communication of climate-alignment assessment results typically does not refer back to the likelihoods of staying within the temperature rise that a given asset is aligned with.

A few methodologies aim to calculate an exact temperature rise that is implied by the under- or overshoot- of an entity, assuming a similar emission profile for all other entities. For example MSCI converts the company-level relative emissions over-/undershoot to degrees of warming using the TCRE approach. Similarly, the FTSE-Beyond Ratings method calculates the ratio of emissions under a country's NDC and emissions the country can emit under a 2 degrees scenario (Emin et al., 2021[65]). Then, it applies this to the global carbon budget consistent with 2 degrees warming, and finally, applies the TCRE to this.

3.3.3. Sectoral scope and specificity

As presented in Figure 3.10, different sectors have different emissions profiles. Each sector is characterised by different mitigation levers and different marginal abatement costs (IPCC, 2022[8]; IEA, 2021[98]). For example, the industry sector is both emissions-intensive and particularly hard to abate as many of the required net-zero technologies cannot be deployed at full scale yet (IEA, 2018[103]; Bataille et al., 2018[104]; OECD, 2022[105]).

Figure 3.10. Sectoral contribution to global GHG emissions in 2018



Note: The surface of each square represents the share that subsector contributes to global GHG emissions. AFOLU refers to Agriculture, Forestry and Other Land Use.
Source: Authors' calculations based on (Lamb et al., 2021[106]).

The timing of GHG reductions in a given sector depends on abatement costs, the availability of CDR options, near-term emissions levels and the amount of non-CO_2 abatement (IPCC, 2022[8]). As a result, different scenarios make different assumptions about the scale and speed of emissions reductions over time and, as a result, the timing of reaching net-zero emissions in each sector (IEA, 2021[98]). These differences in sectoral assumptions lead to different investment needs (IPCC, 2022[72]) and hence different assessments of alignment for a given physical and financial asset.

Integrated Assessment Models (IAMs) can include sectoral specificities but cannot match the granularity of sector-specific pathways that can be developed from sectoral studies. However, sector-specific models may miss potential feedbacks and cross-sectoral linkages that are captured by IAMs (IPCC, 2022[8]). Nevertheless, sectoral models and IAMs are complementary as sectoral models can include more sectoral detail and mitigation options, while IAMs include all emissions sources.

For corporate-related assets, every methodology reviewed, for which information was available, considers some degree of sectoral specificity in its alignment assessment. However, the scope of sectors covered may differ. For example, PACTA and TPI only cover the emissions-intensive sectors as these are considered most relevant to the needed transition. Methodologies aiming to cover all sectors (such as (Arabesque, n.d.[84]), (MSCI, 2021[99]), (right. based on science, n.d.[107]) or (S&P Global, 2020[108])) need to match sector classifications defined for economic purposes (e.g. NACE or GICS) with sector classifications defined for the purposes of tracking GHG emissions and designing scenarios (e.g. IPCC sectors). As became apparent during consultations, such mappings are challenging and require some judgement calls, notably because the nature of companies' activities is typically better characterised based on granular (4-digit) sub-sectors, which GHG data and scenarios typically cannot match. Such issues are even more challenging when one company is active in multiple sectors.

For sovereign bonds, sectoral specificity is less relevant as sovereign bonds are typically issued without being earmarked to finance a specific sector. As a result, existing methodologies for sovereign bonds conduct sector-agnostic alignment assessments based on national-level GHG data and scenarios derived from IAMs. **For real estate and infrastructure**, on the other hand, sectoral specificity is especially relevant. Relevant methodologies aim to distinguish property and infrastructure types and related decarbonisation pathways. For example, the climate-alignment assessment methodology for infrastructure by Carbone 4 distinguishes 65 asset types in energy, mobility, water, tertiary buildings, waste and telecoms (Carbone 4, 2020[70]).

3.3.4. Geographic scope and granularity

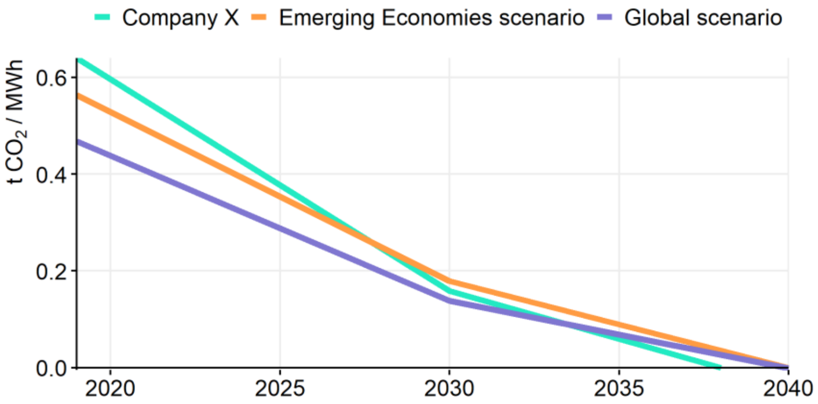
The geographic granularity of the scenarios used by the climate-alignment assessment methodologies has an impact on the alignment results of financial assets. Exclusively relying on global mitigation pathways prevents from taking into account technical, political and social considerations at the regional and national level (Jiang, Peters and Green, 2019[109]).

However, going from global to national mitigation scenarios is challenging (van Soest, 2022[110]). IAMs and studies on GHG and carbon neutrality have mainly been developed at the global level (van Soest, den Elzen and van Vuuren, 2021[111]). National and sectoral models can be used to study national mitigation scenarios with high granularity. However, their application in isolation does not make it possible to shed light on whether such scenarios are in line with the global carbon budgets and the PA temperature goal. For the latter, global IAMs are needed as they provide the boundary conditions in the form of carbon budgets across countries (Schaeffer et al., 2020[112]). These challenges are relevant to the financial sector and its climate-alignment assessments.

Looking at forward-looking mitigation information put forward by countries themselves, NDCs, submitted to the UNFCCC give an indication of the national political intentions at an aggregate level without providing sector-specific information. Further, when combined and added up, available analyses, by e.g. UNEP (2021[113]), indicate that they do not currently make it possible to reach the PA temperature goal. Besides NDCs, Parties to the UNFCCC should strive to formulate and communicate long-term low greenhouse gas emission development strategies. However, given the resources and capacities needed to put such strategy in place (Rocha and Falduto, 2019[114]), they remain limited (51 as of June 2022) and mostly stemming from developed county Parties (Aguilar Jaber et al., 2020[115]). Moreover, their sectoral specificity and granularity is not sufficient to be used as input to financial asset alignment assessments.

For corporate-related financial assets, all climate-alignment assessment methodologies reviewed rely on global scenarios. A few, such as PACTA and TPI, include scenarios for macro-regions for a subset of their assessments, where such regional breakdown is available from the scenarios. Global scenarios may be suitable for globalised companies and sectors, e.g. automotive, cement. However, many smaller companies, but also large companies in certain sectors typically have their main operations within one macro region. For example, TPI now considers regional scenarios for electric utilities (Dietz et al., 2021[116]). Whether corporate pathways are compared to global or regional scenarios can significantly impact alignment results. For example in Figure 3.11, fictive company X with all its operations in emerging economies would already be considered aligned with the illustrative scenario for emerging economies in 2030, while it would only align with the more ambitious global scenario around 2034. However, most corporate-focussed methodologies do not currently explicitly mention considerations for developing countries and/or distinctions that may result from different national circumstances.

Figure 3.11. Stylised example of company alignment against a regional scenario for the power sector



Note: Company X is a power producer with all of its assets located in emerging economies.
Source: Adapted from (Dietz et al., 2021[116]).

For sovereign bonds, real estate and infrastructure, climate-alignment assessment methodology providers typically build on global or regional scenarios. They however, then need to downscale these themselves as alignment assessments in such asset classes require country-specific scenarios, which may or may not include considerations of equity and differentiated responsibilities and capacities. Downscaling methodologies are discussed in the next section 3.3.5.

Climate change mitigation scenarios are crucial inputs to climate-alignment assessment methodologies. Methodology providers depend on the climate policy community to provide scenarios with more geographic and sectoral detail. This was also echoed by an OECD industry survey conducted in the context of preparing a guidance on transition finance, where 69% of respondents stated that the lack of such pathways is a key obstacle to identifying companies committed to a Paris-aligned transition trajectory (OECD, 2022[24]).

3.3.5. Downscaling scenarios to entities

To assess the alignment of a financial asset, the alignment scenario needs to be scaled down to the level of that asset, e.g. a company for corporate-related financial assets, a country for sovereign bonds, and a specific physical asset for infrastructure and real estate. The main barrier to downscaling is that it requires value judgement and agreement on burden sharing, i.e. the absolute or relative share and speed of emission reductions assigned to the entity. Therefore, the discussion on downscaling scenarios to the asset-level builds on the discussion in Section 3.3.4 of global versus national pathways (especially for sovereign bonds where the asset-level entity is a country), as well as relating to sectors (Section 3.3.3).

For corporate-focussed methodologies, a scenario needs to be assigned to each firm, additional to being specific to the sector of that firm. Even when methodologies do not explicitly assign the scenario they rely on to individual companies, they make implicit assumptions about the speed at which companies need to decarbonise. There are a few existing approaches to compare entities to sector-level scenarios or to explicitly allocate macro scenarios to entities (Institut Louis Bachelier et al., 2020[11]; Schwegler et al., 2022[12]; SBTi, 2021[57]).

- In the *contraction approach*, a company is considered aligned if it reduces emissions at the same speed as the sectoral scenario. In this case, a fixed reduction rate is set for absolute emissions or carbon intensities for all companies in a given sector or overall in the economy (Figure 3.12

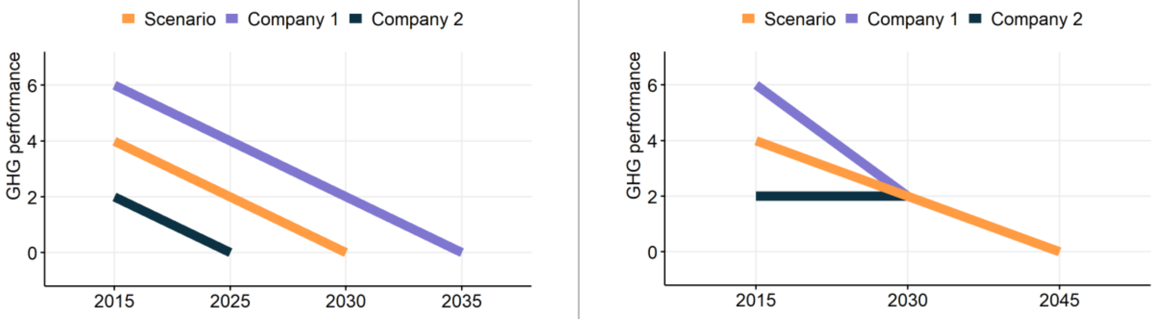
panel A). The expansion approach is a variation of this approach for methodologies that assess for example production-based pathways of corporates assets focussed on renewable energy.

- In the *convergence approach,* a company is considered aligned if it converges towards the (sector-level) scenario by a given point in time. In this case every company in a given sector needs to achieve the same climate performance, typically in intensity-based terms, at that point in time (Figure 3.12 panel B). Hence, entities that are already performing well have to improve relatively less to be aligned. A slight variation of this approach is to assess a company as aligned if it convergences towards a range anywhere at or below the scenario by a given point in time.

Figure 3.12. Stylised examples of different approaches for downscaling climate mitigation scenarios to entities

Panel A: Contraction approach

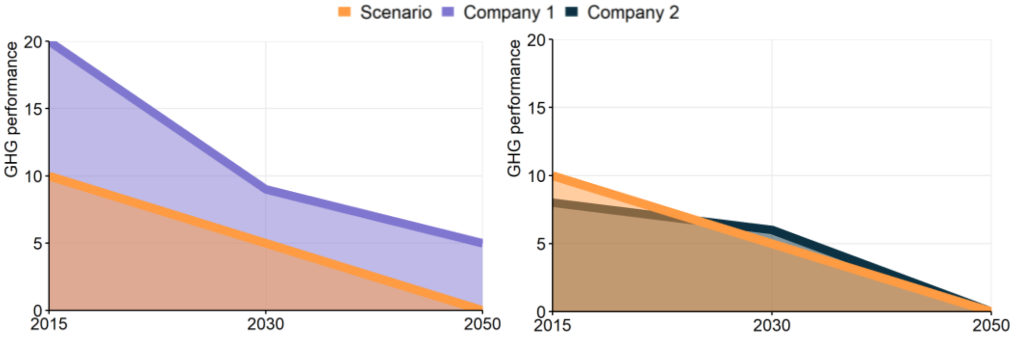
Panel B: Convergence approach



Alignment when the reduction rate is the same as in the scenario.

Alignment when the performance level is the same as in the scenario at time x, here 2030.

Panel C: Fair-share approach: example for two companies with the same market share



Alignment when the carbon budget of a company is the same as or less than the carbon budget under the scenario.
In this example, company 1 and 2 have to comply to the same scenario, as they have the same market share in the same sector.

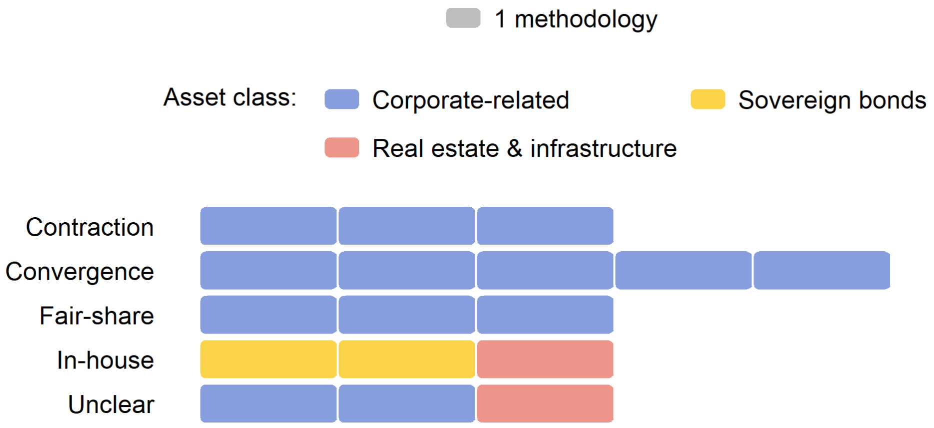
Note: GHG emissions performance could be in terms of absolute emissions (e.g. tCO_2e) or emissions intensity (e.g. tCO_2e per ton of steel). Contraction approach is typically used for absolute-based metrics, convergence for intensity-based metrics.
Source: Authors based on (Schwegler et al., 2022[12]).

- In the *fair-share approach*, a company-specific carbon budget or scenario is allocated to each company. A few variations are possible.
    - The market-share approach distributes the sectoral scenario proportionally to companies' market share (by revenue, production or capacity for example). For example, two companies in the same sector with the same market share could receive the same carbon budgets while having different emissions profiles (Figure 3.12 panel C).
    - The historic-responsibility approach considers cumulative historic contributions and distributes the remaining sectoral budget on that basis. This implies for instance that entities having emitted below the budget level in the past may temporarily surpass the budget in the future.

- The economic-efficiency or least-cost approach distributes the sectoral scenario based on relative cost or efficiency, which is similar to what the IEA Energy Technology Perspectives scenarios did to distribute global carbon budgets to sectors. This requires company-level data on abatement costs, which makes this approach challenging.

Most climate-alignment assessment methodologies for corporate equity and bonds follow a convergence approach (Figure 3.13). On that basis, companies that are currently more emissions-intensive will need to reduce emissions faster than companies that are already closer to the scenario. The convergence approach may be best suitable for large companies with global operations where activities may be less clearly linked to specific countries. On the other hand, a contraction approach is common for absolute emissions-based metrics, where companies need to reduce emissions at the same rate, regardless of their current and past emissions. However, companies may have different abatement cost curves, investment capacities and access to financing, especially in developing countries, which could call for a differentiated approach.

Figure 3.13. Approaches to downscaling scenarios by methodology providers



Source: Authors' analysis based on publicly-available information and, for some methodologies, bilateral consultations with the providers.

As discussed in section 3.3.4, downscaling global to national scenarios is challenging. Few scenarios, which have both national and sectoral specificity, are available. Therefore, climate-alignment methodologies for sovereign bonds, real estate and infrastructure developed their own approaches to downscaling scenarios to the country-level. For example, the FTSE-Beyond Ratings method developed a probabilistic approach to determine the most likely carbon budget for each country (Emin et al., 2021[65]). Their approach starts from the Kaya equation, which multiplies population, GDP per capita, energy intensity, and carbon intensity, breaking it down into 15 criteria. Based on these, two million simulations that test multiple ways of combining criteria are run. Another example is the scenarios developed by CRREM for real estate, which downscale global scenarios for the buildings sector based on current country performance and forward looking considerations (CRREM, 2020[69]). In this context, the further development of national-level scenarios, including by countries themselves, would greatly facilitate alignment assessments for asset classes that require such granularity.

3.4. Approach for assessing alignment at the financial portfolio level

The previous sections looked at how climate-mitigation alignment is assessed for individual investments or financial assets, e.g. an equity investment or holding in one company, the purchase or holding of bonds issued by a specific corporate or government. Aggregating results for individual financial assets to the portfolio level adds another layer of complexity as it requires weighing the contribution of different assets across different sectors (the assessment of which typically relies on sector-specific scenarios and metrics), as well as adjusting for the potential double counting of emissions where relevant (PAT, 2020[10]). These issues become even more complex when considering portfolio-level aggregation across multiple asset classes, e.g. corporate-related equity and debt, sovereign bonds, real estate and infrastructure.

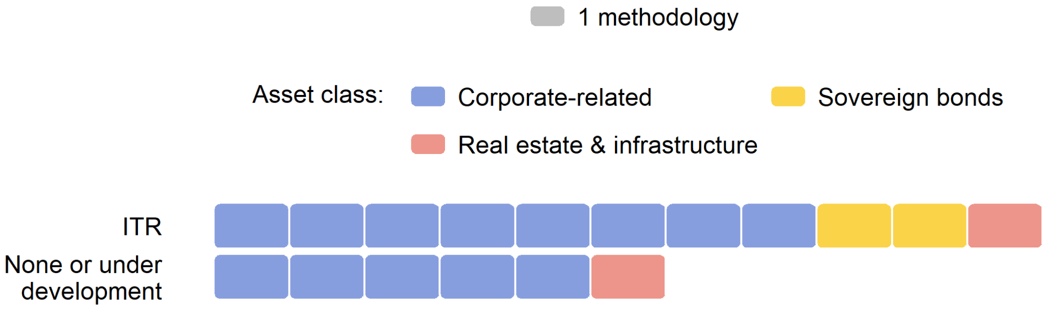
3.4.1. Metric at the portfolio level

Similarly to what can be done at asset level (see Section 3.2.1), portfolio-level alignment can be assessed in different ways (PAT, 2021[45]; GFANZ, 2022[117]).

- The most complex is the Implied Temperature Rise (ITR) or degree warming metric, which takes the form of a global warming outcome if the global economy was to exhibit same level of performance as the financial portfolio being assessed (SBTi, 2022[118]; PAT, 2020[10]). These are typically based on measuring financed emissions of a portfolio (PCAF, 2020[38]). Similar to asset-level analysis, financed emissions from a portfolio can be calculated in absolute terms or intensity-based. There are two types of intensity metrics, namely sector-based physical emissions intensity and weighted average economic carbon intensity (SBTi, 2022[118]).
- A slightly simpler variation of the ITR to assess portfolio-level alignment is the scenario divergence model which estimates a percentage deviation compared with a scenario but does not calculate an exact temperature (PAT, 2021[45]).
- Other metrics include a binary target measurement or share of a portfolio with climate-aligned targets (PAT, 2021[45]; Schwegler et al., 2022[12]).

Among the climate-alignment assessment methodologies reviewed as part of the present analysis, many are still developing their portfolio-level assessments metric (Figure 3.14). The ones that have already developed one all follow an Implied Temperature Rise (ITR) approach.

Figure 3.14. Portfolio-level metric used by methodology providers



Note: ITR refers to Implied Temperature Rise.
Source: Authors' analysis based on publicly-available information and, for some providers, bilateral consultations.

3.4.2. Aggregation approaches

To estimate a portfolio's ITR, an approach for aggregating asset-level assessments needs to be chosen. This can either be done by going back to asset-level under- or over-shoot of emissions and aggregating bottom-up, or by taking a simple weighted average of asset-level assessments (PAT, 2020[10]). In both cases, the exact calculations using these approaches may differ by asset class.

Corporate equity and debt

Methodologies to aggregate corporate equity and debt portfolios are still in the making, but some approaches have been developed (Schwegler et al., 2022[12]; Institut Louis Bachelier et al., 2020[11]; CDP & WWF, 2020[62]; Thomä, Dupré and Hayne, 2018[71]; GFANZ, 2022[46]; PAT, 2020[10]):

- In the *aggregated budget approach*, the over- or under-shoot of each corporate asset is summed. This can be done either for total corporate emissions or the share of those emissions financed by the respective investor. In particular, the latter approach compares the sum of "owned" projected GHG emissions against the sum of "owned" carbon budgets for the underlying holdings. This brings the additional complexity that financed or owned emissions and carbon budgets of the company need to be calculated explicitly.
- For the *weighted average approach*, the asset-level alignment metrics (e.g. ITR) are weighted based on the relative weight of each company in the portfolio. This weight can either be defined by the ownership stake of a financial institution for equity portfolios or the enterprise value for bonds portfolios.
- A third approach combines the first and second approach. The *portfolio-owned approach* weighs the asset-level alignment metrics by their respective proportion of company emissions financed by the investor.
- Other variations are possible and being explored: the enterprise value and cash emissions weighted temperature score approach, the total assets emissions weighted temperature score approach, or the revenue owned emissions weighted temperature score approach.

Currently, there is no clear dominant aggregation approach across climate-alignment assessment methodology providers for corporates, which use different approaches, sometimes tailored for different users of their methodology. For example, CDP uses a weighted average approach, but within that is still considering several options of weighing (CDP & WWF, 2020[62]). In contrast, MSCI uses an aggregated budget approach (MSCI, 2021[99]).

Additional to portfolio aggregation across all economic sectors, assets could be aggregated by sector, as is done by PACTA (2DII, n.d.[60]). Such sectoral portfolio aggregation is especially relevant for methodologies that use sector-specific metrics and focus on corporate assets that are emissions-intensive and either transitioning or being phased out, as well as on corporate assets that are developing climate solutions (e.g. in the renewable energy sector). This is a different perspective that is particularly relevant to inform active engagement strategies with investees.

Other asset classes

Similar to corporate equity and bonds, individual climate-alignment assessments for sovereign bonds can be aggregated at the portfolio level using an aggregate budget or a weighted average approach. Assessments can be aggregated on the basis of market values of respective bonds or national contributions to total emissions or GDP. For example, FTSE-Beyond Ratings propose to use the weighted average approach based on the bonds' market value (Emin et al., 2021[65]).

For real estate and infrastructure portfolios, both the aggregated budget approach and the weighted average approach can be used as well. Carbone 4's infrastructure methodology uses a combination of both approaches. It takes the over- or under-shoot of each asset. Then, it weighs these asset-level result based on the holding share of the asset manager (Carbone 4, 2020[70]). The Carbon Risk Real Estate Monitor calculates an aggregate-level average GHG intensity based on the floor area of each real estate asset (CRREM, 2020[69]).

Complexity of aggregation across asset classes

As shown in Table 3.1 in section 3.1, methodologies are currently underdeveloped for several asset classes and a limited number of methodology providers cover multiple asset classes. The providers having developed or acquired methodologies for different asset classes include PACTA, Carbone 4 and right. based on science, and some further providers are in process of doing so as well, e.g. S&P Sustainable1. As a result, there only have been very limited attempts to date to produce portfolio-level alignment assessments across multiple asset classes.

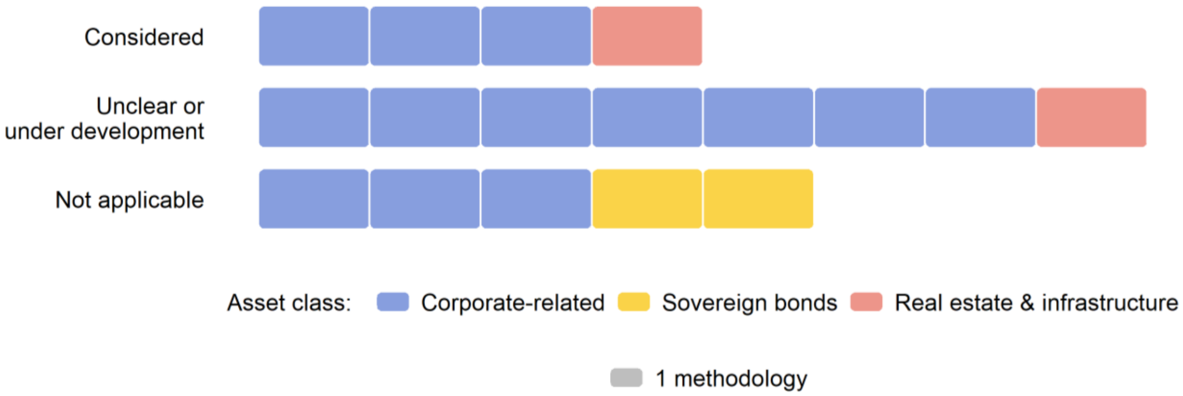
In any case, calculating a portfolio-level alignment metric across multiple asset classes requires further methodological assumptions and adds significant complexity compared to aggregation within a given asset class. This is notably due to the fact that, as discussed in Sections 3.1 to 3.3, the methodologies to assess alignment at the level of individual assets differ from one asset class to the other, especially if expanding beyond corporate-related assets. Further, as mentioned above, metrics and resulting alignment assessments can differ from one economic sector to the other, thereby further making it even more difficult to derive a meaningful portfolio-level assessment. Hence, portfolio-level alignment assessment across asset classes and sectors may not necessarily produce robust and reliable results, which in turn could question their relevance for informing progress towards climate mitigation policy goals. With this in mind, further developments in this area would in any case warrant cautiousness, full methodological transparency and clear communication of uncertainties and error margins.

3.4.3. Double counting of emissions

International-level collective assessment of progress towards global carbon budgets and the PA temperature goal requires minimising double counting of GHG emission reductions and avoidance across actors, including investors and financial institutions. Within the investment and financial value chain, double counting of emissions can occur at multiple levels, namely between financial institutions co-financing the same entity or activity, between transactions within the same financial institutions, across different asset classes, as well as within the same asset class (PCAF, 2020[38]). Double-counting is problematic for portfolio-level assessments of climate alignment if GHG emissions that are counted double are interpreted as actual total emissions into the atmosphere, or if the double-counting distorts the ITR calculation within the portfolio (Schwegler et al., 2022[12]).

Approaches to adjust for double counting are still in the early stages of development (Portfolio Alignment Team, 2020[119]). As a result, most methodologies do not currently explicitly clarify how they adjust for double counting (Figure 3.15), although most indicated that this is an area they are working on. *Right. based on science* is one of the few methodologies that currently explicitly adjusts for double counting by only including 50% of Scope 2 and Scope 3 emissions when aggregating to the portfolio-level (right. based on science, n.d.[107]). This is an area for further methodological work in order to develop less arbitrary approaches, for instance those that take into account the extent to which supply chains of companies within an investor portfolio actually overlap.

Figure 3.15. Methodology providers considering double counting



Note: Not applicable means that the methodology either does not include Scope 3 emissions or does not have an aggregate portfolio-level metric.
Source: Authors’ analysis based on publicly-available information and, for some providers, bilateral consultations.

4. Illustration of results from climate-alignment assessments

Methodology providers assess financial assets as aligned or misaligned from a mitigation perspective if the underlying assets contribute to economic systems that are consistent with GHG pathways that limit warming to the PA temperature goal. As detailed in Chapter 3, individual methodologies, however, differ in perspective, scope, metrics, methodological assumptions and input GHG reduction scenarios. This chapter illustrates differences in assessment results across anonymised methodology providers. The aim in doing so is not only to illustrate the impact of these differences, but also to highlight that different climate-alignment assessment results may sometimes be complementary rather than always contradictory.

The main focus of the chapter is on results from corporate-related alignment assessment methodologies since, as summarised in Table 3.1 and detailed throughout Chapter 3, only very few methodologies have been fully developed for other asset classes, thus preventing meaningful comparisons of results. Still, the chapter explores some examples for other asset classes, including sovereign bonds. Further, consistent with the metrics used by the majority of alignment assessment methods (see Section 3.2), this chapter relies on GHG-based alignment assessment results, while acknowledging that other metrics can be complementary for a more holistic assessment of financial sector alignment.

4.1. Illustration of results for listed corporate equity

4.1.1. Overlaps and differences in corporate alignment assessment results

The following analyses considers a selection of companies in eight emissions-intensive sectors across seven macro-regions. The companies are selected based on size and region of headquarters within the eight selected emissions-intensive sectors. They are typically part of the CA100+ focus companies[16]. Robustness was checked by performing the analysis on an additional sample of companies with similar characteristics. The analysis illustrates the climate-alignment assessment results based on a selection of six climate-alignment assessment providers, for which data was either publicly available or shared by the methodology provider with the authors. The six methodologies can differ greatly across the different dimensions analysed in Chapter 3. Some methodologies assess alignment in the short- and medium-term, or both. Results are separated.

Figure 4.1 shows that every individual company in the sample is assessed as not aligned by 2050 by at least one provider. However, the comparison also shows that not a single company in the selection has the same climate-alignment assessment. The correlation among assessments for the same companies is low. Indeed, companies assessed as aligned with a 1.5 degrees scenario by one provider, can be assessed

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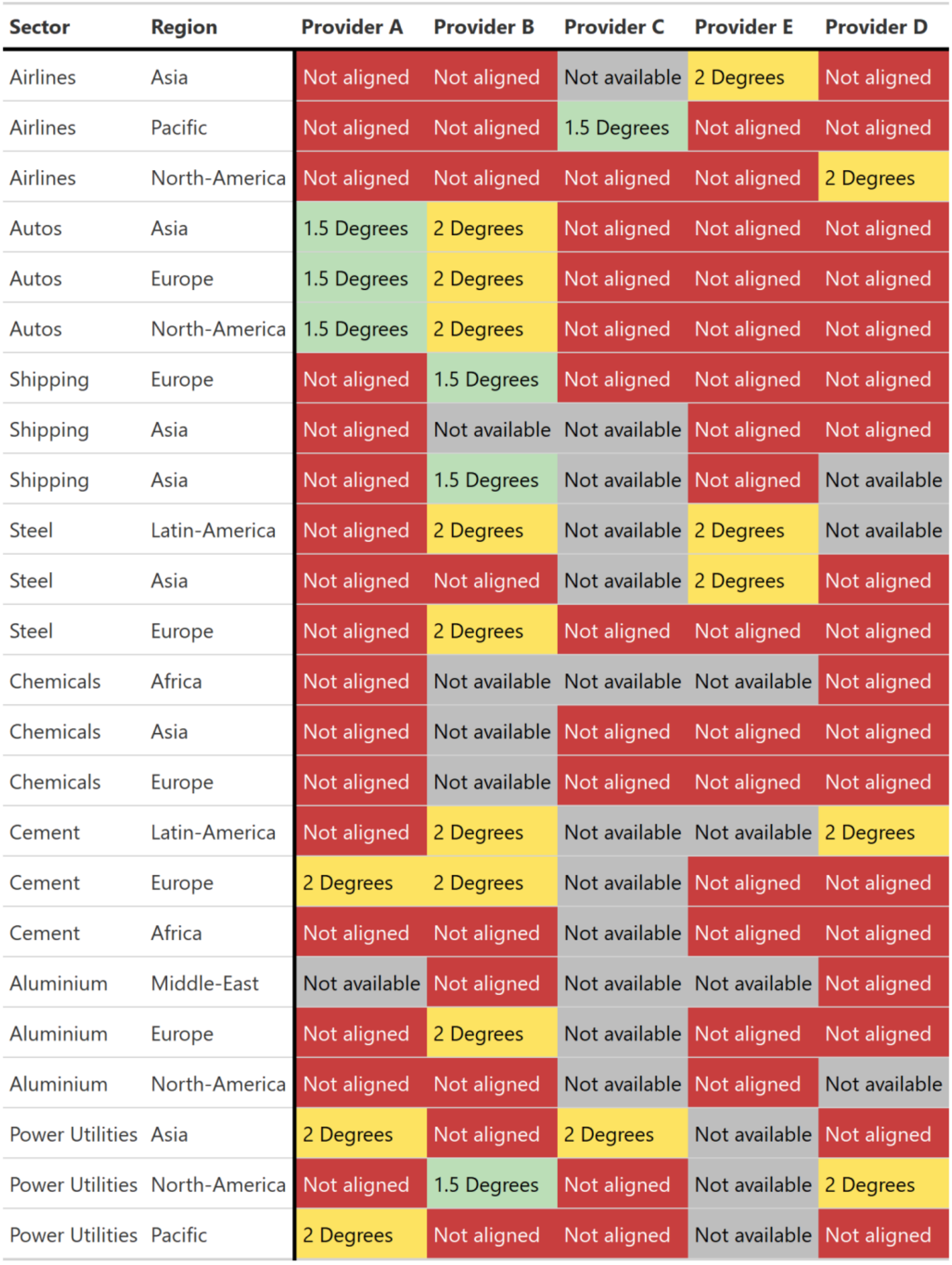
[16] CA100 has selected 166 focus companies for increased engagement by its members. These companies were identified as key to driving the net-zero emissions transition and contribute directly or indirectly to up to 80% of corporate industrial GHG emissions (CA100, n.d.[149]).

as not aligned by all others. Still, Provider B most frequently finds that a company is aligned. Figure 4.1 also illustrates that most providers run into issues on data availability. Moreover, these illustrations show a continued need for data availability and consistency. Even for listed corporate equity, where methodologies are available, the level of uncertainty is high.

Figure 4.1. Results of long-term alignment assessments for selected corporates



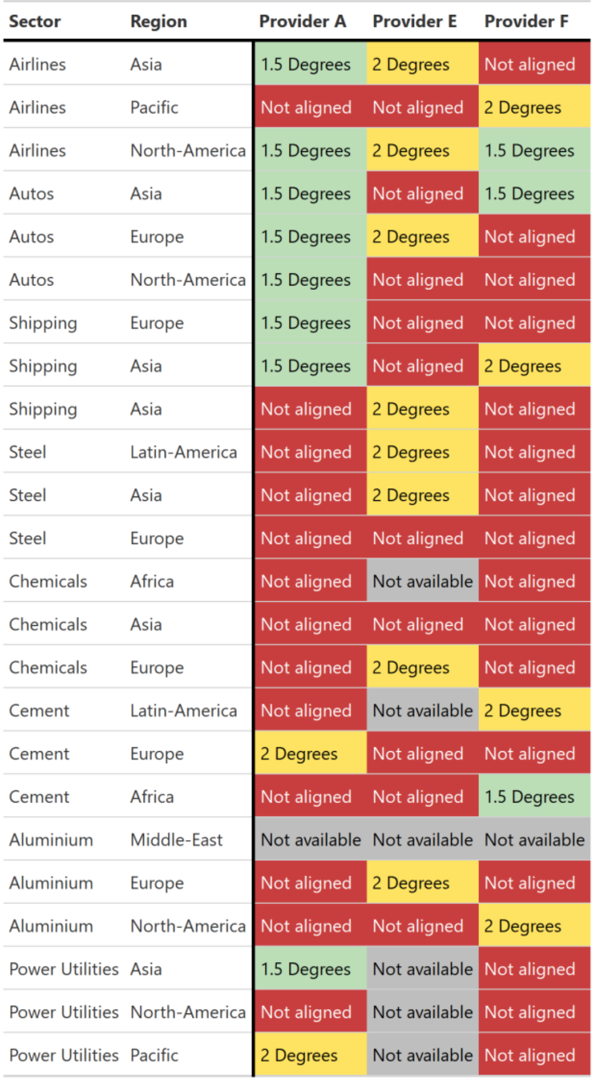
Sector	Region	Provider A	Provider B	Provider C	Provider E	Provider D
Airlines	Asia	Not aligned	Not aligned	Not available	2 Degrees	Not aligned
Airlines	Pacific	Not aligned	Not aligned	1.5 Degrees	Not aligned	Not aligned
Airlines	North-America	Not aligned	Not aligned	Not aligned	Not aligned	2 Degrees
Autos	Asia	1.5 Degrees	2 Degrees	Not aligned	Not aligned	Not aligned
Autos	Europe	1.5 Degrees	2 Degrees	Not aligned	Not aligned	Not aligned
Autos	North-America	1.5 Degrees	2 Degrees	Not aligned	Not aligned	Not aligned
Shipping	Europe	Not aligned	1.5 Degrees	Not aligned	Not aligned	Not aligned
Shipping	Asia	Not aligned	Not available	Not available	Not aligned	Not aligned
Shipping	Asia	Not aligned	1.5 Degrees	Not available	Not aligned	Not available
Steel	Latin-America	Not aligned	2 Degrees	Not available	2 Degrees	Not available
Steel	Asia	Not aligned	Not aligned	Not available	2 Degrees	Not aligned
Steel	Europe	Not aligned	2 Degrees	Not aligned	Not aligned	Not aligned
Chemicals	Africa	Not aligned	Not available	Not available	Not available	Not aligned
Chemicals	Asia	Not aligned	Not available	Not aligned	Not aligned	Not aligned
Chemicals	Europe	Not aligned	Not available	Not aligned	Not aligned	Not aligned
Cement	Latin-America	Not aligned	2 Degrees	Not available	Not available	2 Degrees
Cement	Europe	2 Degrees	2 Degrees	Not available	Not aligned	Not aligned
Cement	Africa	Not aligned	Not aligned	Not available	Not aligned	Not aligned
Aluminium	Middle-East	Not available	Not aligned	Not available	Not available	Not aligned
Aluminium	Europe	Not aligned	2 Degrees	Not available	Not aligned	Not aligned
Aluminium	North-America	Not aligned	Not aligned	Not available	Not aligned	Not available
Power Utilities	Asia	2 Degrees	Not aligned	2 Degrees	Not available	Not aligned
Power Utilities	North-America	Not aligned	1.5 Degrees	Not aligned	Not available	2 Degrees
Power Utilities	Pacific	2 Degrees	Not aligned	Not aligned	Not available	Not aligned

Note: Results are latest available assessments for alignment in 2050. ITR results are assigned to the relevant category as this illustration aims to show the level of alignment and exact temperature results come with a higher level of uncertainty. 'Not aligned' means not aligned with a 2 degrees or below scenario as assessed by the methodology provider. 'Not available' means either not enough data to apply the methodology or no methodology available for that sector by the provider.
Source: Authors' calculations based on data from five selected providers.

Assessment results for the selected companies for the medium term hint at similar conclusions as for the long-term assessments (Figure 4.2). Nearly all corporates are assessed as not aligned by at least one provider. While there are relatively more corporates assessed as aligned by 2030-2035 than by 2050, fewer methodologies assess medium-term alignment and alignment is generally weak.

Better understanding of the robustness and integrity of these results is important because alignment assessments are increasingly being used both for reporting purposes as well as to contribute to informing investment decisions. Based on such mis-alignment results investors may consider the possibility of divesting, now or at a given point of time in the future from certain assets and change their asset allocation (Schwegler et al., 2022[12]; Church of England's National Investing Bodies, 2022[120]; Responsible Investor, 2021[121]; Reuters, 2020[122]).

Figure 4.2. Results of medium-term alignment assessments for selected corporates



Sector	Region	Provider A	Provider E	Provider F
Airlines	Asia	1.5 Degrees	2 Degrees	Not aligned
Airlines	Pacific	Not aligned	Not aligned	2 Degrees
Airlines	North-America	1.5 Degrees	2 Degrees	1.5 Degrees
Autos	Asia	1.5 Degrees	Not aligned	1.5 Degrees
Autos	Europe	1.5 Degrees	2 Degrees	Not aligned
Autos	North-America	1.5 Degrees	Not aligned	Not aligned
Shipping	Europe	1.5 Degrees	Not aligned	Not aligned
Shipping	Asia	1.5 Degrees	Not aligned	2 Degrees
Shipping	Asia	Not aligned	2 Degrees	Not aligned
Steel	Latin-America	Not aligned	2 Degrees	Not aligned
Steel	Asia	Not aligned	2 Degrees	Not aligned
Steel	Europe	Not aligned	Not aligned	Not aligned
Chemicals	Africa	Not aligned	Not available	Not aligned
Chemicals	Asia	Not aligned	Not aligned	Not aligned
Chemicals	Europe	Not aligned	2 Degrees	Not aligned
Cement	Latin-America	Not aligned	Not available	2 Degrees
Cement	Europe	2 Degrees	Not aligned	Not aligned
Cement	Africa	Not aligned	Not aligned	1.5 Degrees
Aluminium	Middle-East	Not available	Not available	Not available
Aluminium	Europe	Not aligned	2 Degrees	Not aligned
Aluminium	North-America	Not aligned	Not aligned	2 Degrees
Power Utilities	Asia	1.5 Degrees	Not available	Not aligned
Power Utilities	North-America	Not aligned	Not available	Not aligned
Power Utilities	Pacific	2 Degrees	Not available	Not aligned

Note: Results are latest available assessments for alignment in 2030 or 3025. ITR results are assigned to the relevant category as this illustration aims to show the level of alignment and exact temperature results come with a higher level of uncertainty. 'Not aligned' means not aligned with a 2 degrees or below scenario as assessed by the methodology provider. 'Not available' means either not enough data to apply the methodology or no methodology available for that sector by the provider.
Source: Authors' calculations based on data from three selected providers.

While most climate-alignment assessment providers use similar corporate data and information sources, individual providers choose different GHG performance metrics based on their respective advantages and disadvantages, as discussed in Section 3.2. Such choice, in turn, contributes to explain variations in results observed in Figure 4.1 and Figure 4.2. Based on the company sample, alignment appears to be less frequent for methodologies using an AEC-type metric, while none-disclosure is less likely for methodologies using a GEVA metric (Figure 4.3).

Figure 4.3. Alignment assessment results for selected corporates by type of metric and temperature outcome

🟠 AEC 🔵 GEVA 🟣 SDA 🟢 Combination

Sector	Region	1.5°C	2°C	Not aligned	Not available
Airlines	Asia		🔵	🔵 🟣 🟢	🟠
	North-America		🟢	🟠 🔵 🔵 🟣	
	Pacific	🟠		🔵 🔵 🟣 🟢	
Aluminium	Europe		🟣	🔵 🔵 🟢	🟠
	Middle-East			🟣 🟢	🟠 🔵 🔵
	North-America			🔵 🔵 🟣	🟠 🟢
Automotive	Asia	🔵	🟣	🟠 🔵 🟢	
	Europe	🔵	🟣	🟠 🔵 🟢	
	North-America	🔵	🟣	🟠 🔵 🟢	
Cement	Africa			🔵 🔵 🟣 🟢	🟠
	Europe		🔵 🟣	🔵 🟢	🟠
	Latin-America		🟣 🟢	🔵	🔵 🟠
Chemicals	Africa			🔵 🟢	🟠 🔵 🟣
	Asia			🟠 🔵 🔵 🟢	🟣
	Europe			🟠 🔵 🔵 🟢	🟣
Power utilities	Asia		🟠 🔵	🟣 🟢	🔵
	North-America	🟣	🟢	🟠 🔵	🔵
	Pacific		🔵	🟠 🟣 🟢	🔵
Shipping	Asia			🔵 🔵 🟢	🟠 🟣
	Asia	🟣		🔵 🔵	🟠 🟢
	Europe	🟣		🟠 🔵 🔵 🟢	
Steel	Asia		🔵	🔵 🟣 🟢	🟠
	Europe		🟣	🟠 🔵 🔵 🟢	
	Latin-America		🔵 🟣	🔵	🟠 🟢

Note: Results are latest available assessments for alignment in 2050. Each dot represents the assessment of one methodology for the respective company. Not available means either not enough data to apply the methodology or no methodology available for that sector by the provider.
Source: Authors' analysis based on data from five selected providers of alignment assessment methodologies for corporates.

Figure 4.4 further illustrates that the temporal perspective can influence the alignment result. Based on this sample, alignment is more common for methodologies that assess alignment for a single point-in-time, whereas it appears to be harder to be aligned when the methodology considers a cumulative assessment. Cumulative alignment is, however, vital to be consistent with the remaining carbon budget for any given temperature outcome.

Figure 4.4. Alignment assessment for selected corporates' temporal perspective

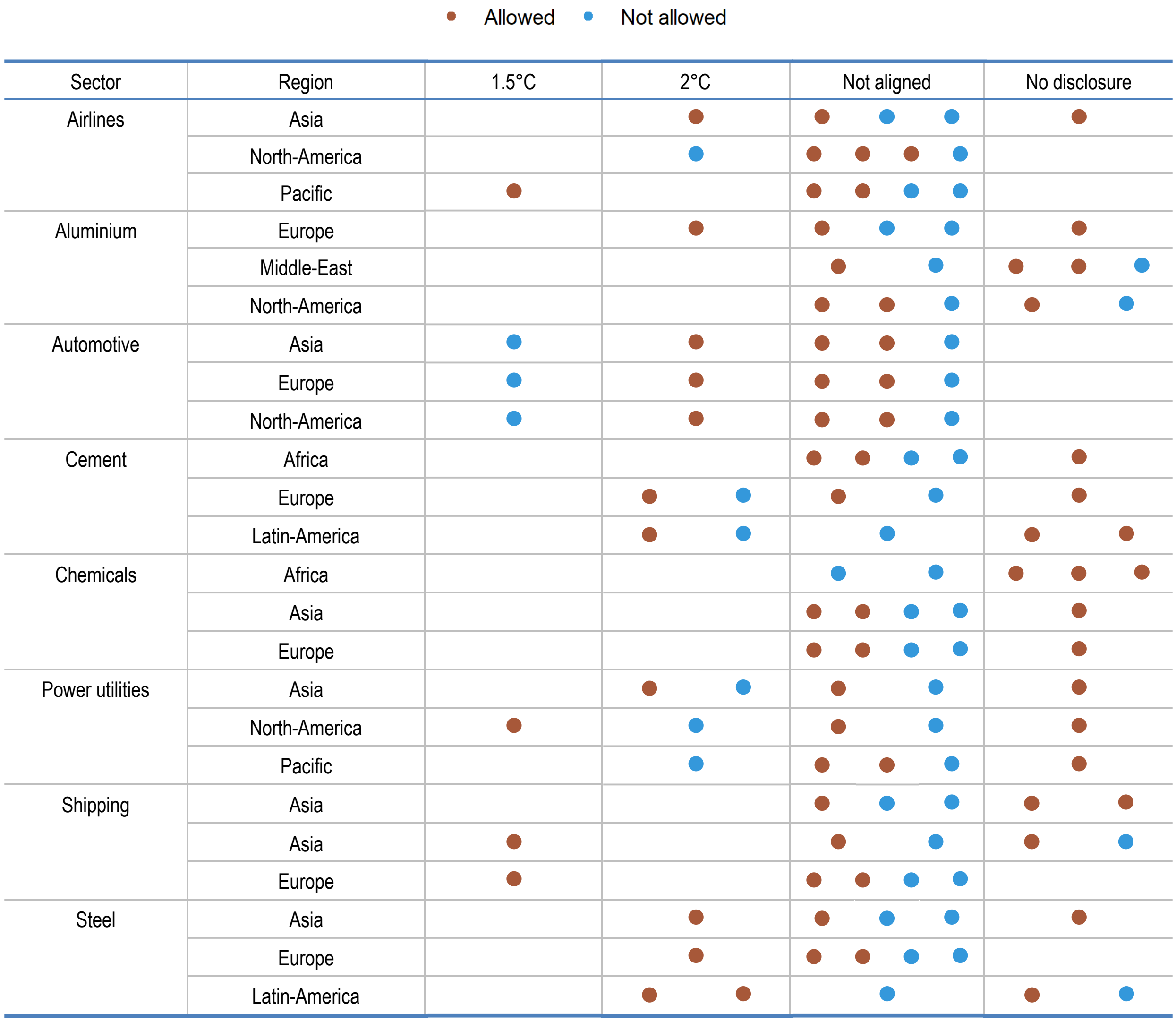
🔵 Cumulative 🔴 Point-in-time

Sector	Region	1.5°C	2°C	Not aligned	No disclosure
Airlines	Asia		🔵	🔵 🔴 🔴	🔵
	North-America		🔵	🔵 🔵 🔴 🔴	
	Pacific	🔵		🔵 🔵 🔴 🔴	
Aluminium	Europe		🔴	🔵 🔵 🔴	🔵
	Middle-East			🔵 🔴	🔵 🔵 🔴
	North-America			🔵 🔴 🔴	🔵 🔵
Automotive	Asia	🔴	🔴	🔵 🔵 🔵	
	Europe	🔴	🔴	🔵 🔵 🔵	
	North-America	🔴	🔴	🔵 🔵 🔵	
Cement	Africa			🔵 🔵 🔴 🔴	🔵
	Europe		🔴 🔴	🔵 🔵	🔵
	Latin-America		🔵 🔴	🔴	🔵 🔵
Chemicals	Africa			🔵 🔴	🔵 🔵 🔴
	Asia			🔵 🔵 🔵 🔴	🔴
	Europe			🔵 🔵 🔵 🔴	🔴
Power utilities	Asia		🔵 🔴	🔵 🔴	🔵
	North-America	🔴	🔵	🔵 🔴	🔵
	Pacific		🔴	🔵 🔵 🔴	🔵
Shipping	Asia			🔵 🔵 🔴	🔵 🔴
	Asia	🔴		🔵 🔴	🔵 🔵
	Europe	🔴		🔵 🔵 🔵 🔴	
Steel	Asia		🔵	🔵 🔴 🔴	🔵
	Europe		🔴	🔵 🔵 🔵 🔴	
	Latin-America		🔵 🔴	🔴	🔵 🔵

Note: Results are latest available assessments for alignment in 2050. Each dot represents the assessment of one methodology for the respective company. Not available means either not enough data to apply the methodology or no methodology available for that sector by the provider.
Source: Authors' analysis based on data from five selected providers of alignment assessment methodologies for corporates.

Methodological choices across other dimensions also contribute to differences in alignment results. For example, methodologies that do not allow offsets, find less companies are aligned within the sample data (Figure 4.5). Similar analysis can be done for the coverage of scopes of emissions or other dimensions. However, results were not always conclusive based on this sample.

Figure 4.5. Alignment assessment for selected corporates per consideration for offsets



🟤 Allowed 🔵 Not allowed

Sector	Region	1.5°C	2°C	Not aligned	No disclosure
Airlines	Asia		🟤	🟤 🔵 🔵	🟤
	North-America		🔵	🟤 🟤 🟤 🔵	
	Pacific	🟤		🟤 🟤 🔵 🔵	
Aluminium	Europe		🟤	🟤 🔵 🔵	🟤
	Middle-East			🟤 🔵	🟤 🟤 🔵
	North-America			🟤 🟤 🔵	🟤 🔵
Automotive	Asia	🔵	🟤	🟤 🟤 🔵	
	Europe	🔵	🟤	🟤 🟤 🔵	
	North-America	🔵	🟤	🟤 🟤 🔵	
Cement	Africa			🟤 🟤 🔵 🔵	🟤
	Europe		🟤 🔵	🟤 🔵	🟤
	Latin-America		🟤 🔵	🔵	🟤 🟤
Chemicals	Africa			🔵 🔵	🟤 🟤 🟤
	Asia			🟤 🟤 🔵 🔵	🟤
	Europe			🟤 🟤 🔵 🔵	🟤
Power utilities	Asia		🟤 🔵	🟤 🔵	🟤
	North-America	🟤	🔵	🟤 🔵	🟤
	Pacific		🔵	🟤 🟤 🔵	🟤
Shipping	Asia			🟤 🔵 🔵	🟤 🟤
	Asia	🟤		🟤 🔵	🟤 🔵
	Europe	🟤		🟤 🟤 🔵 🔵	
Steel	Asia		🟤	🟤 🔵 🔵	🟤
	Europe		🟤	🟤 🟤 🔵 🔵	
	Latin-America		🟤 🟤	🔵	🟤 🔵

Note: Results are latest available assessments for alignment in 2050. Each dot represents the assessment of one methodology for the respective company. Not available means either not enough data to apply the methodology or no methodology available for that sector by the provider.
Source: Authors' analysis based on data from 5 selected providers of alignment assessment methodologies for corporates.

Two climate-alignment assessment providers accessibly share their full universe of alignment results for listed corporate equity. Using this data, this paper finds that most listed corporate equity is assessed as not aligned or no alignment assessment is available (Figure 4.6). This finding is for instance consistent with analysis conducted by MSCI itself for its 'All Country World Investable Market Index'[17] using its ITR metric and data, which found that listed companies are collectively on a pathway to keep warming well above 2°C (MSCI, 2022[123]). While alignment results for a given company may differ across providers, alignment assessments of listed corporate equity typically tend to find mis-alignment and unavailability of assessment.

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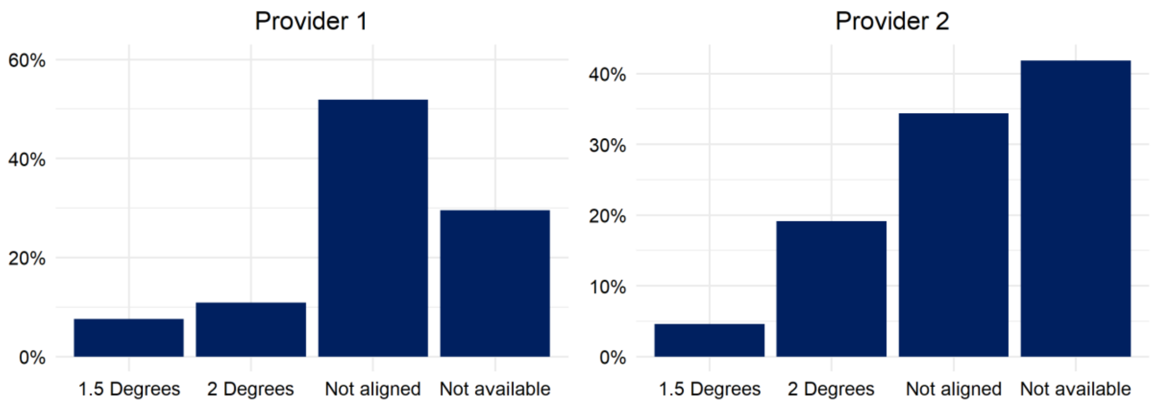
[17] This index includes nearly 10,000 large-, mid- and small-cap traded listed companies across 23 developed and 27 emerging markets.

Figure 4.6. Examples of alignment results across providers' full universe of assessments

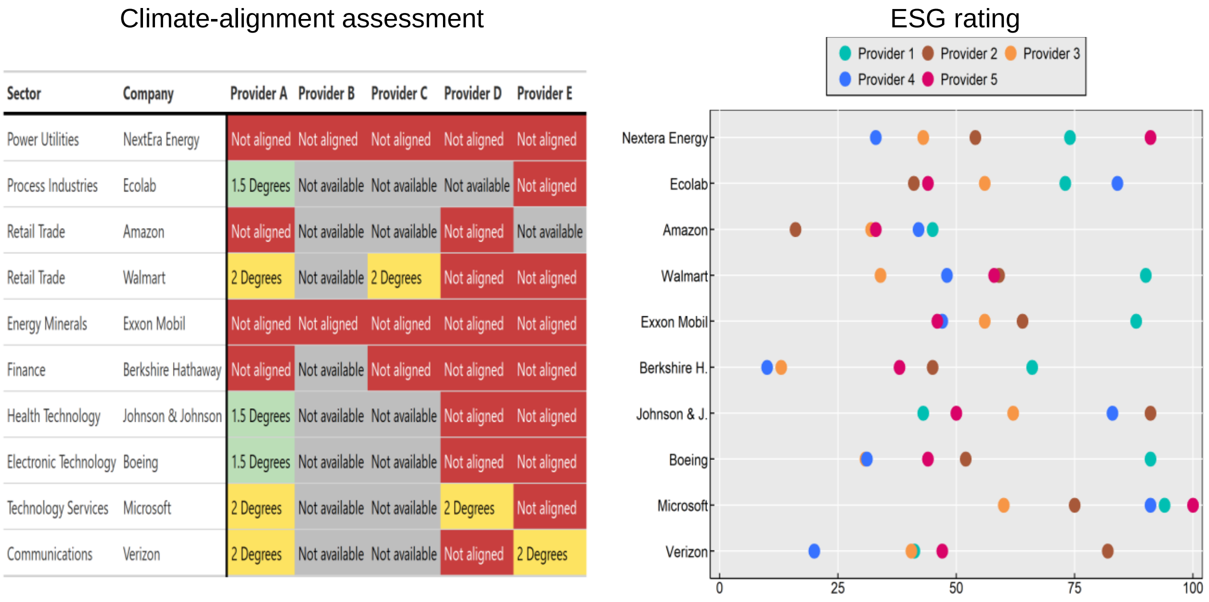


Note: Provider 1 and 2 have a different sample of corporates. Not available means either not enough data to apply the methodology to a given company or no methodology available for the sector of a given company by the provider.
Source: Authors' analysis based on data from two selected providers.

4.1.2. Parallels between corporate alignment assessment results and ESG scores

A parallel can be drawn between the variations in climate-alignment assessment scores between different methodology providers and a similar trend of climate scores within ESG assessments (Figure 4.7). Previous OECD research has highlighted a similar variation of climate mitigation-related elements within the E score. This variation may be even greater among companies and sectors that need to undergo particularly large transformations due to the net-zero emissions transition.

Figure 4.7. Climate mitigation alignment (left) and ESG ratings and issuer credit ratings (right)



Climate-alignment assessment

Sector	Company	Provider A	Provider B	Provider C	Provider D	Provider E
Power Utilities	NextEra Energy	Not aligned	Not aligned	Not aligned	Not aligned	Not aligned
Process Industries	Ecolab	1.5 Degrees	Not available	Not available	Not available	Not aligned
Retail Trade	Amazon	Not aligned	Not available	Not available	Not aligned	Not available
Retail Trade	Walmart	2 Degrees	Not available	2 Degrees	Not aligned	Not aligned
Energy Minerals	Exxon Mobil	Not aligned	Not aligned	Not aligned	Not aligned	Not aligned
Finance	Berkshire Hathaway	Not aligned	Not available	Not aligned	Not aligned	Not aligned
Health Technology	Johnson & Johnson	1.5 Degrees	Not available	Not available	Not aligned	Not aligned
Electronic Technology	Boeing	1.5 Degrees	Not available	Not available	Not aligned	Not aligned
Technology Services	Microsoft	2 Degrees	Not available	Not available	2 Degrees	Not aligned
Communications	Verizon	2 Degrees	Not available	Not available	Not aligned	2 Degrees

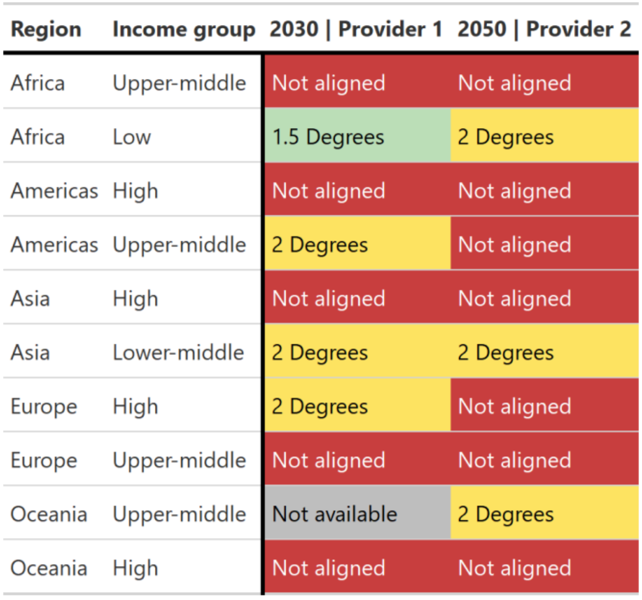
ESG rating

Note: Sample of public companies selected by largest market capitalisation as to represent different industries in the US. Alignment data is for 2022, and ESG and issuer credits ratings for 2019.
Source: Authors' analysis based on selected providers and (Boffo and Patalano, 2020[15]).

4.2. Illustration of results for sovereign bonds

Figure 4.8 shows some first illustrative results for sovereign bonds based on data shared by two providers, noting that the methodology for one of them was not assessed in Chapter 3, as the underlying information was not publicly available at the time of writing. The illustrative results cover a selection of ten countries across continents and from different income groups. The two providers provide results for different timeframes, respectively for 2030 and 2050. Besides observing that more than half of the countries are assessed as not aligned by one or both providers, deriving further conclusions would require a deeper analysis across a broader dataset and larger number of methodology providers.

Figure 4.8. Illustrations of climate-alignment results for selected sovereign bonds



Region	Income group	2030 | Provider 1	2050 | Provider 2
Africa	Upper-middle	Not aligned	Not aligned
Africa	Low	1.5 Degrees	2 Degrees
Americas	High	Not aligned	Not aligned
Americas	Upper-middle	2 Degrees	Not aligned
Asia	High	Not aligned	Not aligned
Asia	Lower-middle	2 Degrees	2 Degrees
Europe	High	2 Degrees	Not aligned
Europe	Upper-middle	Not aligned	Not aligned
Oceania	Upper-middle	Not available	2 Degrees
Oceania	High	Not aligned	Not aligned

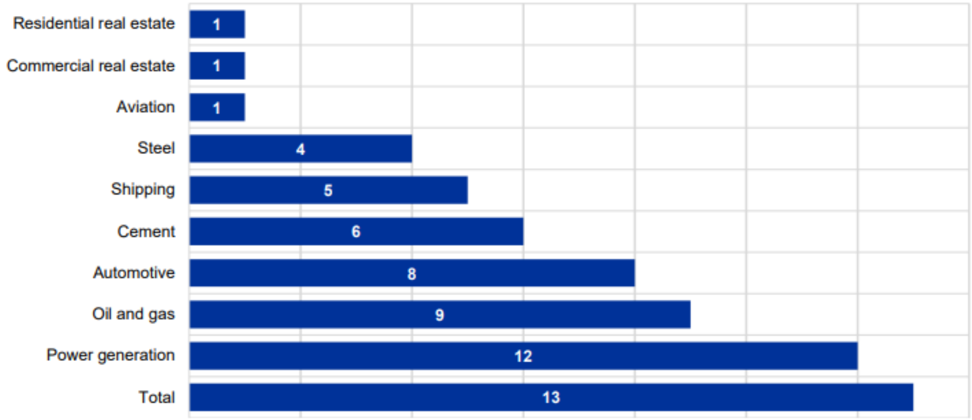
Note: 'Not aligned' means not aligned with a 2 degrees or below scenario as assessed by the methodology provider. 'Not available' means that the country was assessed by the methodology as having a non-quantifiable target. Countries and methodology providers are anonymised.
Source: Authors' calculations based on data from selected providers and income group classifications from the World Bank.

4.3. Portfolio applications by investors, banks and other financial institutions

An increasing number of financial institutions (notably commercial banks, asset owners and asset managers) are putting forward different types of GHG reduction and net-zero commitments and targets, with a vast majority from Western Europe and North America (Climate Policy Initiative, 2022[124]). However, in a recent survey, the European Central Bank (ECB) found that among commercial banks, within the Eurozone, that had put forward a commitment towards the PA, less than half have provided qualitative and quantitative information. Relating to portfolio alignment more specifically, only 13 out of 112 banks in their survey sample (covering Eurozone countries) had conducted such an assessment (ECB, 2022[125]).

Among those 13, the majority did so for corporate-related assets, notably in sectors relating to energy and industry, while only 2 did so for real estate (Figure 4.9). In terms of financial asset classes and instruments, the ECB survey finds that the following tend to be covered by financed emissions reporting: listed equity and corporate bonds (6% of all banks in the sample), business loans (4% of all banks in the sample), project finance (1% of all banks in the sample), commercial real estate (3% of all banks in the sample), mortgages (6% of all banks in the sample), and motor vehicle loans (2% of all banks in the sample).

Figure 4.9. Number of banks in the Eurozone having conducted a portfolio alignment assessment (by sector)



Note: The total European Central Bank sample survey included 112 institutions directly supervised by the ECB, within which, as per the above, only 12% (13 institutions) had conducted a portfolio alignment assessment as of 2021.
Source: (ECB, 2022[125]).

The ECB survey results for commercial banks within the Eurozone are coherent with the findings of this paper on available methodologies for financial sector and market alignment assessment, as detailed in Chapter 3. As methodological developments are still limited for certain asset classes and for aggregating asset-level assessments to the portfolio level, financial institutions may struggle assessing their portfolios.

Nevertheless, financial institutions have started using the above-mentioned methodologies. Non-exhaustive examples include:

- AXA, one of the largest insurance companies globally, which also has an asset management branch, used MSCI Carbon Delta and FTSE-Beyond Ratings methodologies to assess the warming potential of its corporate (both equity and debt) and sovereign debt holdings respectively (AXA Group, 2021[126]; AXA Group, 2022[127]). AXA chose not to aggregate those two together, as it would require additional assumptions, consistent with the findings outlined in Section 3.4 of the present paper. In 2021, the MSCI warming potential[18] assessment was of 3.3°C for corporate equity and 3.7°C for corporate debt, though with significant variations by sector (energy-related asset holdings characterised by the highest warming potential with nearly 5°C for equity and over 6°C for debt). Using FTSE-Beyond Ratings methodology, the warming potential of AXA's Sovereign Debt in 2021 reached 2°C (Figure 4.10). AXA's warming potential for sovereign bonds is relatively low because of its large AUM in France, which has a low warming potential based on FTSE-Beyond Ratings' assessment.

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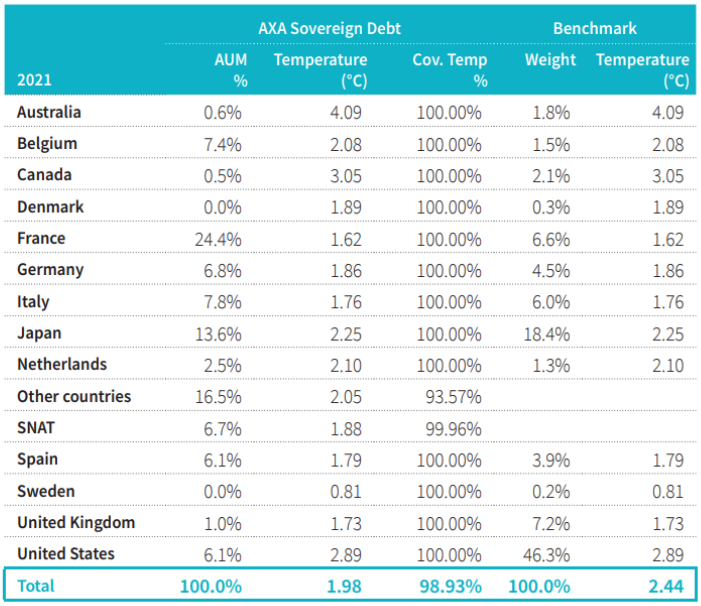
[18] The MSCI warming potential metric is now also referred to as the MSCI ITR metric.

Figure 4.10. Example of ITR ratings for AXA's sovereign bonds portfolio based on FTSE-Beyond Ratings

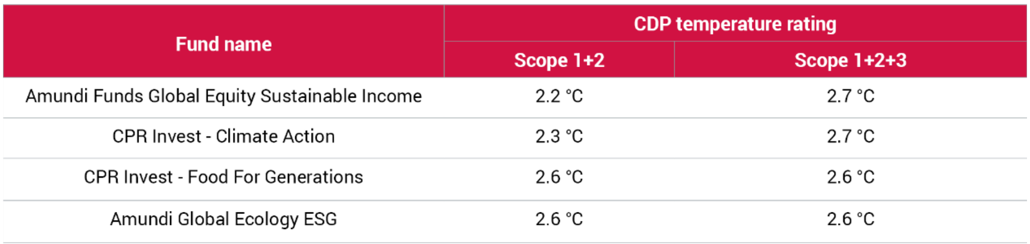


2021	AXA Sovereign Debt AUM %	AXA Sovereign Debt Temperature (°C)	AXA Sovereign Debt Cov. Temp %	Benchmark Weight	Benchmark Temperature (°C)
Australia	0.6%	4.09	100.00%	1.8%	4.09
Belgium	7.4%	2.08	100.00%	1.5%	2.08
Canada	0.5%	3.05	100.00%	2.1%	3.05
Denmark	0.0%	1.89	100.00%	0.3%	1.89
France	24.4%	1.62	100.00%	6.6%	1.62
Germany	6.8%	1.86	100.00%	4.5%	1.86
Italy	7.8%	1.76	100.00%	6.0%	1.76
Japan	13.6%	2.25	100.00%	18.4%	2.25
Netherlands	2.5%	2.10	100.00%	1.3%	2.10
Other countries	16.5%	2.05	93.57%		
SNAT	6.7%	1.88	99.96%		
Spain	6.1%	1.79	100.00%	3.9%	1.79
Sweden	0.0%	0.81	100.00%	0.2%	0.81
United Kingdom	1.0%	1.73	100.00%	7.2%	1.73
United States	6.1%	2.89	100.00%	46.3%	2.89
Total	**100.0%**	**1.98**	**98.93%**	**100.0%**	**2.44**

Note: Implied temperature rise (ITR) ratings measure the most likely global warming outcome if the global economy was to exhibit same level of ambition as a given sovereign bond. For example, if every country emits like France, then the ITR is 1.62°C according to this methodology and assessment. SNAT refers to sub-nationals.
Source: (AXA Group, 2021[126]).

- The asset manager Amundi used the CDP-WWF Temperature Ratings data to assess the climate alignment of four of its global and multisector equity funds (Amundi, 2020[128]). Figure 4.11 shows the implied temperature rise for the four selected equity funds by Amundi. Results indicate that all funds were assessed with an ITR above 2°C. The results also display a relatively low sensitivity of results to the inclusion or not of corporate scope 3 emissions.

Figure 4.11. Example of using ITR ratings for four Amundi equity funds based on CDP-WWF methodology



Fund name	CDP temperature rating	
	Scope 1+2	Scope 1+2+3
Amundi Funds Global Equity Sustainable Income	2.2 °C	2.7 °C
CPR Invest - Climate Action	2.3 °C	2.7 °C
CPR Invest - Food For Generations	2.6 °C	2.6 °C
Amundi Global Ecology ESG	2.6 °C	2.6 °C

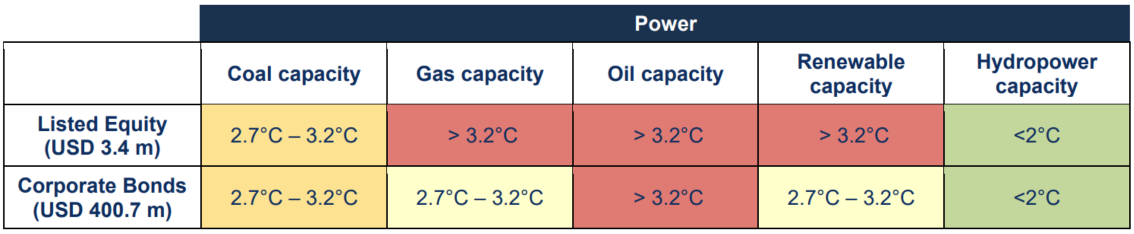
Note: Implied temperature rise (ITR) ratings measure the most likely global warming outcome if the global economy was to exhibit same level of ambition as a given equity fund.
Source: (Amundi, 2020[128]).

At the more aggregate level of national financial centres, a number of countries have tested the use of the PACTA methodology:

- Switzerland was the first to do so and has since 2017 conducted biennial assessments. PACTA Climate Tests assess alignment for global corporate equity and bonds portfolios held by Swiss financial institutions and for Swiss real estate (mortgages) portfolios held by 30 Swiss banks (PACTA, 2022[129]; 2DII, 2020[50]). Results were not aggregated across asset classes. The Norwegian government and the Financial Supervisory Authority of Norway have worked together with 2DII to use PACTA to assess the alignment of the Norwegian financial sector with the PA (2DII, 2022[130]). In particular, the study covers portfolios from 41 Norwegian financial institutions covering 70% to 90% of total assets under management by asset managers, insurance companies, and pension funds in Norway. Overall, Norwegian financial institutions are less exposed to climate-relevant PACTA sectors[19] than financial institutions in countries like Switzerland.

- Sweden has used the PACTA methodology for banks to assess its loan books. Only 2.7% of the banks' total lending to non-financial companies is in PACTA sectors. It notes that particularly real estate assets should be included to make the analysis more relevant at the portfolio level. (Finansinspektionen & Sveriges Riksbank, 2022[131]) Additionally, an alignment assessment of Swedish insurance undertakings has been performed (Finansinspektionen, 2021[132]).
- South American countries tested the climate alignment of a part of their financial sector and the individual participating institutions under the PACTA Coordinated Projects program. In Peru, the climate alignment of equity and bonds in the PACTA sectors were assessed for the five Pension Funds (2DII and the Peruvian Responsible Investment Program, 2022[133]). In Colombia, the climate alignment of the investment portfolios of 20 insurance companies were analysed (2DII, 2022[134]). Results highlight that their listed equity and corporate bonds holdings in high-carbon technologies are not on track to be aligned with the PA temperature goal, while increased capital expenditure for renewable power capacity is also needed (Figure 4.12). Additionally, the Financial Superintendency of Colombia worked together with 2DII to use PACTA to assess the alignment of the private pension funds with the PA. This assessment covered 8.1% of total assets under management.

Figure 4.12. Alignment results of investment portfolios of insurance companies in Colombia based on PACTA



	Power				
	Coal capacity	**Gas capacity**	**Oil capacity**	**Renewable capacity**	**Hydropower capacity**
Listed Equity (USD 3.4 m)	2.7°C – 3.2°C	> 3.2°C	> 3.2°C	> 3.2°C	<2°C
Corporate Bonds (USD 400.7 m)	2.7°C – 3.2°C	2.7°C – 3.2°C	> 3.2°C	2.7°C – 3.2°C	<2°C

Source: (2DII, 2022[134])

- A pilot study with a group of Malaysian banks shows that 8 out the 10 climate critical technologies assessed are not aligned with the goals of the PA (2DII and WWF Malaysia, 2022[135]). The study recommends to match loan book exposures to the real economy at the direct loan taker level and to use a portfolio weighted approach for results at the portfolio level.

While all the above examples of assessments find that none or only few of the institutions, investors or funds are currently aligned with the PA, they can help identify opportunities to take action. Investors may encourage more ambitious targets, plans and actions e.g. through engagement with investees, notably for

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[19] PACTA sectors include seven of the most carbon-intensive sectors in the economy, namely oil and gas, coal, power, automotive, cement, aviation, and steel.

corporate-related assets, or different allocation approaches[20]. However these assessment results come with a range of underlying assumptions and uncertainties, which are often not or only partly communicated and not necessarily understood by users.

Further, gaps in asset coverage by methodologies and data availability within asset classes need to be overcome in order for portfolio level assessments to become more comprehensive and reflective of the full range of underlying real economy actors and assets. Although this chapter has shown illustrative results for asset classes other than corporate equity, it remains a developing field.

Finally, as already mentioned in Chapter 3, there is potential for different methodologies and respective metrics to complement each other, and hence create a dashboard of indicators, which can include both GHG-based and capacity-based metrics. However, further research is needed to design a template of different indicators, including multiple GHG-based indicators that would complement each other well providing a full picture of real-economy action. The Swiss Climate Scores are a first effort towards this (See Box 4.1).

Box 4.1. Swiss Climate Scores

Additional to the PACTA Climate Tests, Switzerland is proposing the *Swiss Climate Scores*, which is a set of indicators to assess progress of its financial market to transitioning to net-zero greenhouse gas emissions by 2050 (FOEN, 2022[136]). Six indicators will show how climate-friendly the companies held in Swiss financial portfolios operate today and what they plan to do in the future. The set of indicators include:

- GHG emissions
- Exposure to fossil fuel activities
- Verified commitments to net-zero
- Management to net-zero
- Credible climate stewardship
- Global warming potential or ITR, i.e. alignment assessment result

The Swiss Climate Scores are a voluntary instrument that was developed in close cooperation with the financial sector and NGOs. They build on existing work by GFANZ and the TCFD. Currently, the ITR indicator is optional and no specific methodology is advised.

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[20] For example, asset allocation in a portfolio can picked by minimising the tracking error compared to a benchmark portfolio, conditional on satisfying a carbon budget which is consistent with 1.5°C temperature increase (Bolton, Kacperczyk and Samama, 2022[148]).

5. Conclusions and implications

This final chapter presents conclusions drawn based on the analysis of existing methodologies used by investors and financial institutions to assess the alignment of their financial assets and portfolios with the PA temperature goal. The focus of these conclusions is on lessons learnt and possible action points to improve the comprehensiveness and policy relevance of such financial sector alignment assessments. Based on this, areas for future research are also identified.

5.1. Climate-alignment assessment of finance: emerging concepts and initiatives

The formulation of Article 2.1c of the PA contributed to the development of the concept “climate alignment” of investments and financing by financial institutions. At an aggregate level, financial flows could be considered aligned or misaligned with the PA temperature goal if they contribute to economic systems that are consistent (or inconsistent) with such GHG pathways. However, there is no agreed or unique way of downscaling the PA’s global temperature goal to the level of individual financial assets and underlying economic sectors, actors, or countries which represents a challenge to assessing the climate-alignment of investments and financing. In any case, methodologies to assess progress towards climate alignment need to be robust, policy relevant and transparent, as they set incentives for investment decisions and influence the degree to which such decisions have an actual impact on GHG emissions or not.

Climate-alignment assessments of finance and climate-related financial risk assessments overlap but take different perspectives. The alignment assessment of finance considers the impact of the activities of economic actors on climate mitigation and resilience policy goals, so-called “environmental materiality”. Conversely, climate-related risks assessments in the financial sector consider the potential consequences that climate change and climate policies may have for their business, so-called financial materiality. This paper takes the former perspective.

Climate alignment of finance relates to both mitigation and resilience. However, efforts to define and assess finance aligned with adaptation and resilience goals remain at an early stage. Policymakers need to bring more clarity on climate resilience objectives to support more advanced developments of these efforts. This paper therefore focused on the alignment of finance with climate mitigation policy goals.

Classifying initiatives supporting the alignment of finance with the PA as coalitions, frameworks or methodologies helps clarify their respective purpose and role. Such clarity is needed within what is a dynamic and growing yet partly confusing landscape of initiatives. However, initiatives may perform multiple roles and evolve over time. Some coalitions, frameworks and methodologies have developed in close co-operation. Moreover, current initiatives mostly originate from developed countries, which can hinder their applicability and legitimacy in emerging economies and developing country contexts.

Initiatives promoting climate alignment in finance can build on and be informed by existing international frameworks and standards for business. The OECD’s Responsible Business Conduct (RBC) Due Diligence Guidance, backed by 48 countries, provides a pertinent framework addressing the impacts of financial and non-financial businesses in relation to public policy objectives, including climate policy goals. The six steps of the RBC due diligence process[21] can be particularly relevant in the context of assessing the contribution of the financial sector to GHG emissions and emissions reductions both from corporate operations and across the supply chain. Climate-alignment assessment methodologies mainly address the *tracking and assessment of progress* step.

5.2. Climate-alignment assessment methodologies for the financial sector: common practices and areas for further development

This study develops an analytical approach to analyse climate-alignment assessment methodologies for the financial sector. The dimensions are: (1) the asset class coverage, (2) the GHG performance metrics (including targets), (3) the climate change mitigation scenario(s) used to assess alignment, and (4) the approach to assess alignment at the financial portfolio level.

While portfolios of investors and financial institutions typically include a range of different asset classes, methodologies for asset classes other than corporate equity are underdeveloped. Although civil society institutions and commercial data providers are increasingly developing climate-alignment assessment methodologies for financial assets and portfolios, several large and policy relevant asset classes are not or only partially covered by existing methodologies. These include private equity, corporate bonds and loans, and real estate. This is also the case for sovereign bonds, although individual investors typically have lower ability to directly engage with and influence investees (countries) than in the case of aforelisted asset classes. Such partial coverage results in an incomplete assessment of financial portfolios and underlying real-economy assets responsible for significant portions of GHG emissions. Bonds and loans have for instance been identified as critical sources of finance for the transition of high-emission and hard-to-abate sectors.

Such gaps in coverage could undermine the environmental integrity of climate-alignment assessment methodologies and associated results. For example, financing of emissions-intensive assets can move from listed to private equity. This would improve the climate-alignment of listed equity portfolios, which are more commonly monitored. However, alignment across asset classes would not be improved and emissions in the real economy could remain at the same level. Currently, this would not be picked up due to a lack of coverage for private equity. A more comprehensive coverage of asset classes is needed, taking into account limited information availability and capacity for certain types of actors such as small and medium-sized enterprises.

Different perspectives on corporate climate alignment translates into methodology providers choosing different metrics. Different metrics have different (dis)advantages which may highlight different aspects of corporate climate performance. Three main methods currently exist: Absolute Emissions Contraction (AEC), Sectoral Decarbonisation Approach (SDA) and Economic Intensity Contraction (EIC). These three metrics are all commonly used by methodology providers but lead to a range of results that are difficult to reconcile. The advantage of the AEC approach, the only approach build on absolute emissions, is that it more clearly relates to the remaining carbon budget. Additionally, improvements in climate-mitigation performance depend solely on reductions in emissions. The EIC approach controls for entity size and business growth[22], is easier to understand for an investor audience and is relevant to

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[21] (1) embed RBC into the businesses' policies and management systems; (2) identify and assess actual or potential adverse impacts of a business' own activities as well as those in its supply chains and business relationships; (3) cease, prevent or mitigate such actual or potential adverse impacts, (4) track implementation and results, (5) communicate how impacts are addressed; (6) enable remediation of adverse impacts when appropriate.

[22] Corporate climate performance measured through approaches based on absolute emissions such as AEC can advance when companies reduce their outputs or generally decrease in size through for example selling a part of their

analyse non-homogenous sectors. The SDA, which further controls for price changes may work particularly well for industrial sectors that need to undergo large transformations in the net-zero transition. However, the AEC and SDA, both intensity-based approaches, are vulnerable to changes in e.g. business output. Using absolute approaches on the other hand makes the comparison across entities of different sizes challenging.

A range of metrics can be used for non-corporate related asset classes, thereby also reflecting different perspectives on the climate-mitigation performance of other economic actors (such as governments) and real economy assets (such as real estate and infrastructure). Coherent with the lack of methodologies for other asset classes, few metrics are available for financial asset classes that cover these. Still, several methodology providers indicated being in the process of developing metrics for non-corporate related asset classes.

The choice of scenario, and the range of assumptions and characteristics that come with it, play an important role in the alignment assessment results. Currently, the methodology providers are using scenarios from a limited number of sources, namely from the IEA, NGFS, JRC and ISF. However, scenarios for the same temperature outcome but from a different source differ in their speed of decarbonisation and in the contribution of different sectors. As scenario pathways differ across sources, so do the resulting alignment of decarbonisation pathways of financial assets. Additionally, these scenarios come with a likelihood of reaching a certain temperature outcome. Such likelihood is not currently communicated together with the alignment assessments. This information would help relay the inherent uncertainties that characterise scenarios for reaching a certain temperature objective.

Climate scenarios available to and used by climate-alignment assessment methodologies typically come with little geographical granularity. Some methodology providers have developed their own approaches to downscale global GHG emission scenarios or develop national scenarios. For sovereign bonds (issued by countries), as well as for real estate (where buildings sector characteristics differ significantly across countries), methodology providers have developed national scenarios. For corporate-related assets, many methodologies follow a convergence approach to downscale aggregate-level scenarios to individual corporate entities.

The lack of agreed methods to downscale is a significant source of uncertainty and variation in different assessments of what is climate-aligned or not. Climate change mitigation scenarios are a crucial input from the climate policy and science community. Currently, most climate change mitigation scenarios do not match the specificity needed for the climate-alignment assessments of financial assets. The development of more relevant scenarios and reference points for the use in the corporate and financial sector could include more sector- and geographically-specific scenarios.

While several global climate-mitigation scenarios used by providers include some sectoral specificity, matching input data and metrics to sectoral scenarios is challenging. Scenarios are typically produced by the climate policy and science community, while finance-related climate-performance metrics are developed by the financial sector community. Sectoral and sub-sector classifications and specificity used by each community differ. Matching data on economic sectors with sectoral GHG emissions data is for instance not straightforward. The climate policy community may therefore enhance activities in developing finance-relevant scenarios to reduce disconnects between scenarios and metrics and allow the development of improved methodologies.

Policy makers need to provide or encourage clear guidance on emission reduction target setting accounting rules, including on offsets. The results of a climate-alignment assessment can be influenced

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business. Approaches based emission intensity, such as EIC and SDA, control for this because they have a denominator that correlates with firm size, and business growth in physical or economic terms.

by both the coverage of GHG emissions as well as by the treatment of offsets[23]. The IPCC recommends economic actors to disclose all scopes and types of emissions. This is most often the intention of methodology providers, who are, however constrained by data availability and reliability. Methodologies that explicitly aim to exclude the use of offsets tend to find less alignment in corporate-related financial assets, as shown through new illustrative analysis in this paper. However, there remains much opacity about the use and inclusion of offsets. This is likely due to a lack of clarity and transparency of the use of offsets in metrics, targets and plans of economic actors themselves.

The temporal coverage of a GHG performance metric is also a strong driver of variations in alignment results, in turn affecting their policy relevance and environmental integrity. Different methodologies consider a short-, medium- or long-term time period, or a combination of those. The end year of the time period over which an investor considers an asset becomes even more important depending on whether the metric is only compared with an emissions scenario at a certain point in time or across a time period. Results from new illustrative analysis in this paper show that alignment is more frequently achieved for methodologies that assess alignment only at a certain and distant point in time in the future, e.g. 2050. Such assessments do not incentivise early action and may allow for carbon lock-in in the meantime, thereby underestimating climate impacts as cumulative emissions are what drives temperature outcomes.

Approaches for aggregating alignment results within each asset class need to be further developed in order to assess progress made by financial institutions and asset owners and managers. Several climate-alignment methodologies follow the Implied Temperature Rise metric at the portfolio level. However, this metric comes with a high degree of uncertainty. Moreover, the aggregation approaches underlying this metric for a given asset class are under development, with many potential options resulting in diverging results. Furthermore, when assets are assessed across overlapping value chains, aggregating results may cause double counting of emissions due to the inclusion of so-called Scope 3 emissions. Many methodologies do not yet have a portfolio metric, even for listed equity portfolios where asset-level assessment methodologies and results are most common.

Aggregate-level assessments of financial portfolios add another significant layer of complexity to climate-alignment assessments and can mask individual activities that may be misaligned. Available illustrations of portfolio-level alignment results show that existing assessments are not aggregated across asset classes, i.e. within a given portfolio, separate assessments are conducted for different asset classes based on different underlying methodologies. Calculating a portfolio-level alignment metric across multiple asset classes would require further methodological assumptions and complexity to those raised for aggregation within a given asset class. Hence, portfolio-level alignment assessment across asset classes may not necessarily produce robust and reliable results, which in turn could question their relevance for informing progress towards climate mitigation policy goals.

5.3. Implications and further work on measuring progress towards Article 2.1c

This paper includes new analysis and illustrations showing that alignment results differ significantly across methodology providers. These variations illustrate that climate-alignment assessments are complex and rely on a range of dimensions. They come with uncertainties and variations. Moreover, there are multiple choices of metrics that can be used, which lead to different results. Different choices and results can be useful if they can complement each other and their complementarity is clearly communicated. Additionally, although different methodologies may find different alignment results for a given company, the paper finds

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[23] When companies rely and account for offsets in their historical emissions and targets, they can improve their corporate climate mitigation performance. Therefore, if and how offsets are included influences the alignment analysis. Analogous logic applies to other economic actors such as governments.

that most corporate equity assets are not aligned. For those corporate asset with a climate-aligned target, further work can be done on relating past performance on reducing GHG emissions and reaching past short-term GHG performance targets.

Rather than being the unique indicator of progress, GHG-based alignment assessment results can be one element of a dashboard of finance-related indicators. The inclusion of complementary indicators of relevance to climate change mitigation (e.g. presence and characteristics of concrete plans to upscale climate solutions) can provide a more nuanced and holistic perspective. However, further research is needed to design a template of different indicators, including both GHG-based indicators and other indicators that would complement each other well providing a full picture of real-economy action. Furthermore, such holistic view can be extended through complementary work on assessing the alignment of finance from a resilience perspective. This could involve pilot studies across mitigation and resilience objectives, linking both, and possibly also connecting climate alignment with similar assessments for other environmental policy goals. In this context, the OECD-led Research Collaborative on Tracking Finance for Climate Action will pursue further work on indicator and dashboard development in collaboration with relevant OECD bodies and initiatives, considering both sectoral and country-level aggregation.

Research gaps on methodologies to assess climate alignment of asset classes other than corporate equity are challenging the environmental integrity and policy relevance of current assessments. The underrepresentation of several large asset classes, representing large proportions of GHGs and assets under management, challenge the environmental integrity of current climate-alignment assessments. Further analysis on private equity, corporate loans and sovereign bonds for example could be explored in follow up work. While the degree of influence investors can have on the investee depends on the asset class, a complete coverage of financial asset classes in climate-alignment assessment methodologies is desirable for two main reasons. Firs, providing a comprehensive picture of the financial sector’s holdings and investments is increasingly relevant as financial institutions and governments are starting to use such methodologies to disclose progress. Second, such methodologies set incentives for investment strategies and decisions. For example, passive and active investors may consider the possibility of rebalancing their portfolio towards relatively more climate-aligned assets.

Alignment assessments lack geographical specificity and diversity. Many of the current methodologies are developed by and for initiatives in developed countries. Literature on the relevance and applicability of such methodologies in developing countries’ contexts is limited. Work is needed to reconcile climate-alignment frameworks and assessment methodologies with both ongoing initiatives relating to transition finance in relatively less developed countries and for high-emitting or hard-to-abate sectors, as well as with principles-based approaches and taxonomies developed by individual jurisdictions.

The assumptions and uncertainties of scenarios are important and thus need to be better understood and communicated. The choice of a climate mitigation scenario heavily influences the alignment result. Initial observations from this paper can be deepened by further characterising mitigation scenarios that inform alignment assessment methodologies, as well as translating climate scenarios to better match the scope and granularity of financial and economic data from the financial system to address challenges of diverging scopes and granularity.

Assessments of the climate-alignment of finance generally depend on the availability and reliability of a large amount and range microdata. Methodology providers already mix reported and modelled data. Further work can be done to explore the use of robust proxies to address data gaps for tracking the alignment of finance both with climate mitigation and resilience policy goals. In doing so, data- and human resources-related synergies between work on climate-related alignment and risk assessments of finance could be found. A lack of data availability and consistency, even for corporate-related assets where methodologies are available, continues to challenge climate-alignment assessments. Reporting standards and third-part data verification helps improves this.

While there is a continued need for improved assessment and tracking, this remains a means to an end. Further efforts should place a strong focus on measuring the concrete impact of finance in terms of GHG reductions and improved resilience in the real economy, including via financing the upscale of climate solutions. This, however, requires addressing data and methodological challenges to go from financial to real-economy assets. In order to better to assess the impact of current efforts, enabling conditions and policy to make finance consistent with the PA goals also need to be monitored and their effects better understood.

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ASSESSING THE CLIMATE ALIGNMENT OF FINANCE

Considerations relating to metrics, methodologies, and data

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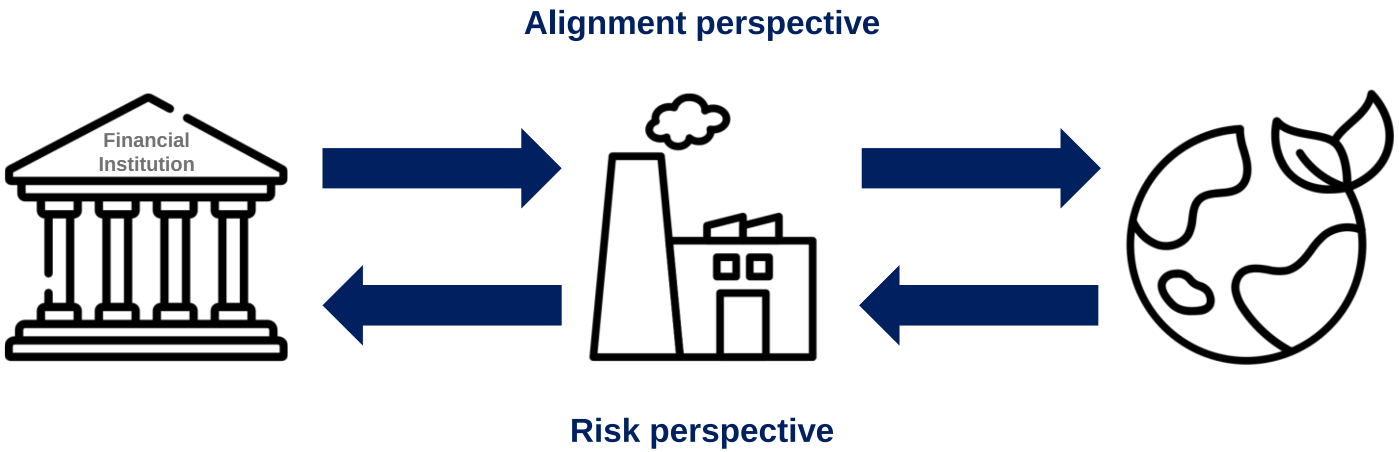
OECD
BETTER POLICIES FOR BETTER LIVES

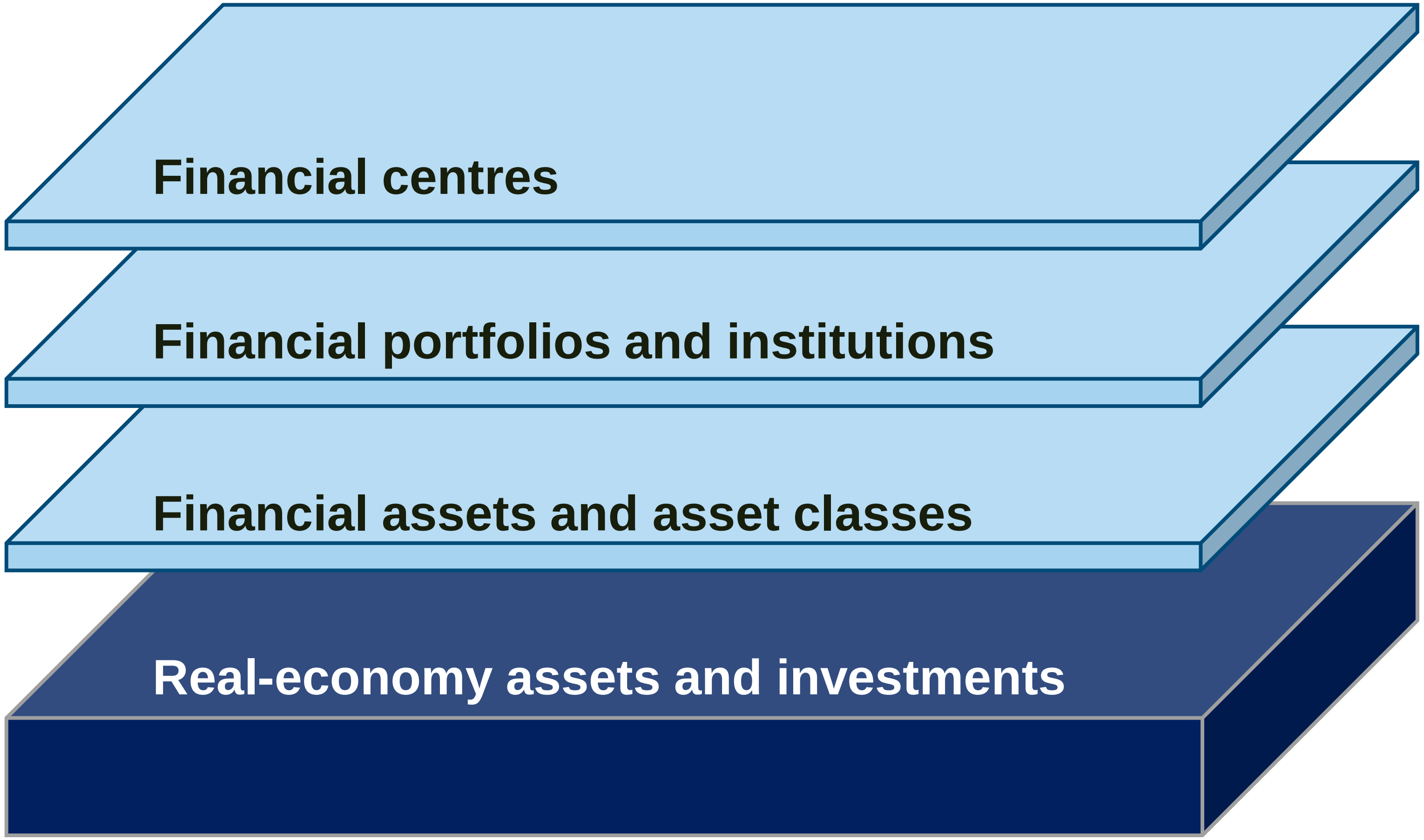
Climate alignment and risk assessments

Paris Agreement Article 2.1c: Making finance consistent with climate mitigation and resilience policy goals



Increasing number of climate-related **metrics** and **methods** to assess finance but **lack of consistency**, aggregation and evidence in terms of impacts

Metrics are needed at different levels of aggregation



Financial centres

Financial portfolios and institutions

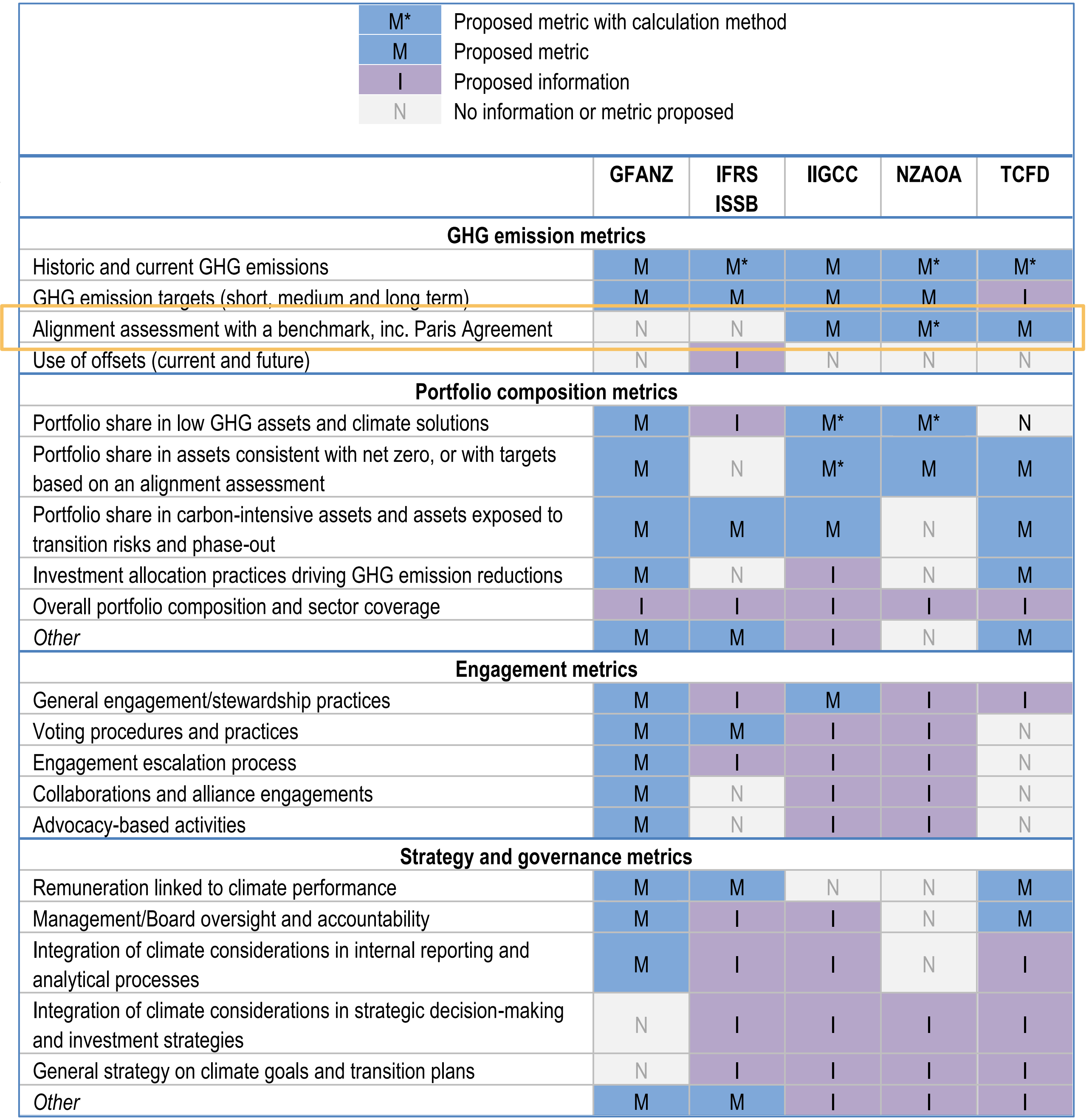
Financial assets and asset classes

Real-economy assets and investments

Using a range of metrics

Frameworks agree on categories of information

But inconsistencies, ambiguities, and gaps remain for proposed net-zero metrics

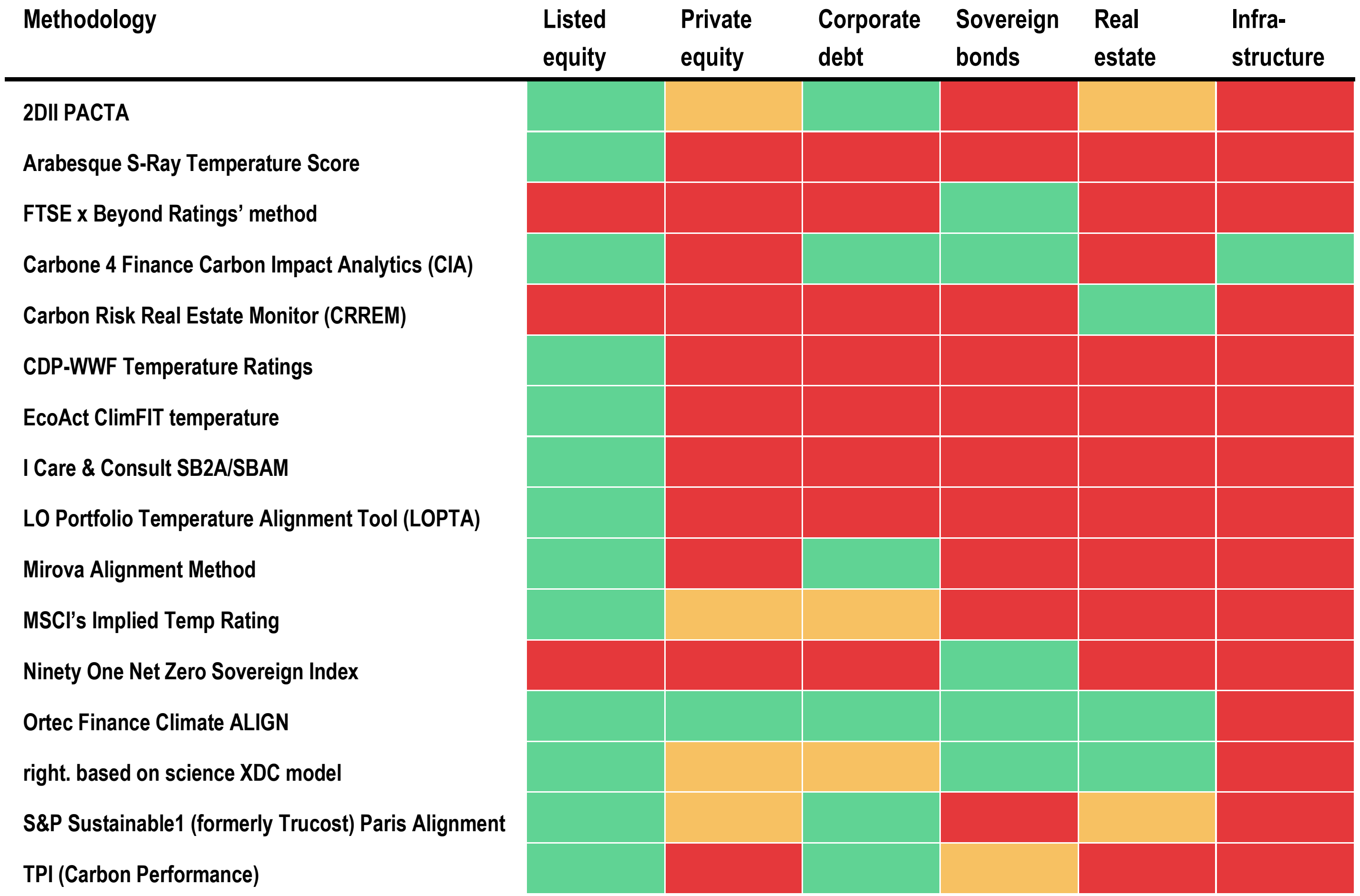


M* Proposed metric with calculation method
M Proposed metric
I Proposed information
N No information or metric proposed

	GFANZ	IFRS ISSB	IIGCC	NZAOA	TCFD
GHG emission metrics					
Historic and current GHG emissions	M	M*	M	M*	M*
GHG emission targets (short, medium and long term)	M	M	M	M	I
Alignment assessment with a benchmark, inc. Paris Agreement	N	N	M	M*	M
Use of offsets (current and future)	N	I	N	N	N
Portfolio composition metrics					
Portfolio share in low GHG assets and climate solutions	M	I	M*	M*	N
Portfolio share in assets consistent with net zero, or with targets based on an alignment assessment	M	N	M*	M	M
Portfolio share in carbon-intensive assets and assets exposed to transition risks and phase-out	M	M	M	N	M
Investment allocation practices driving GHG emission reductions	M	N	I	N	M
Overall portfolio composition and sector coverage	I	I	I	I	I
Other	M	M	I	N	M
Engagement metrics					
General engagement/stewardship practices	M	I	M	I	I
Voting procedures and practices	M	M	I	I	N
Engagement escalation process	M	I	I	I	N
Collaborations and alliance engagements	M	N	I	I	N
Advocacy-based activities	M	N	I	I	N
Strategy and governance metrics					
Remuneration linked to climate performance	M	M	N	N	M
Management/Board oversight and accountability	M	I	I	N	M
Integration of climate considerations in internal reporting and analytical processes	M	I	I	N	I
Integration of climate considerations in strategic decision-making and investment strategies	N	I	I	I	I
General strategy on climate goals and transition plans	N	I	I	I	I
Other	M	M	I	I	I

Need for comprehensive asset class coverage

Financial asset classes covered by climate-alignment rating methodologies



Methodology	Listed equity	Private equity	Corporate debt	Sovereign bonds	Real estate	Infra-structure
2DII PACTA	🟩	🟨	🟩	🟥	🟨	🟥
Arabesque S-Ray Temperature Score	🟩	🟥	🟥	🟥	🟥	🟥
FTSE x Beyond Ratings' method	🟥	🟥	🟥	🟩	🟥	🟥
Carbone 4 Finance Carbon Impact Analytics (CIA)	🟩	🟥	🟩	🟩	🟥	🟩
Carbon Risk Real Estate Monitor (CRREM)	🟥	🟥	🟥	🟥	🟩	🟥
CDP-WWF Temperature Ratings	🟩	🟥	🟥	🟥	🟥	🟥
EcoAct ClimFIT temperature	🟩	🟥	🟥	🟥	🟥	🟥
I Care & Consult SB2A/SBAM	🟩	🟥	🟥	🟥	🟥	🟥
LO Portfolio Temperature Alignment Tool (LOPTA)	🟩	🟥	🟥	🟥	🟥	🟥
Mirova Alignment Method	🟩	🟥	🟩	🟥	🟥	🟥
MSCI's Implied Temp Rating	🟩	🟨	🟨	🟥	🟥	🟥
Ninety One Net Zero Sovereign Index	🟥	🟥	🟥	🟩	🟥	🟥
Ortec Finance Climate ALIGN	🟩	🟩	🟩	🟩	🟩	🟥
right. based on science XDC model	🟩	🟨	🟨	🟩	🟩	🟥
S&P Sustainable1 (formerly Trucost) Paris Alignment	🟩	🟨	🟩	🟥	🟨	🟥
TPI (Carbon Performance)	🟩	🟥	🟩	🟨	🟥	🟥

🟩 Covered

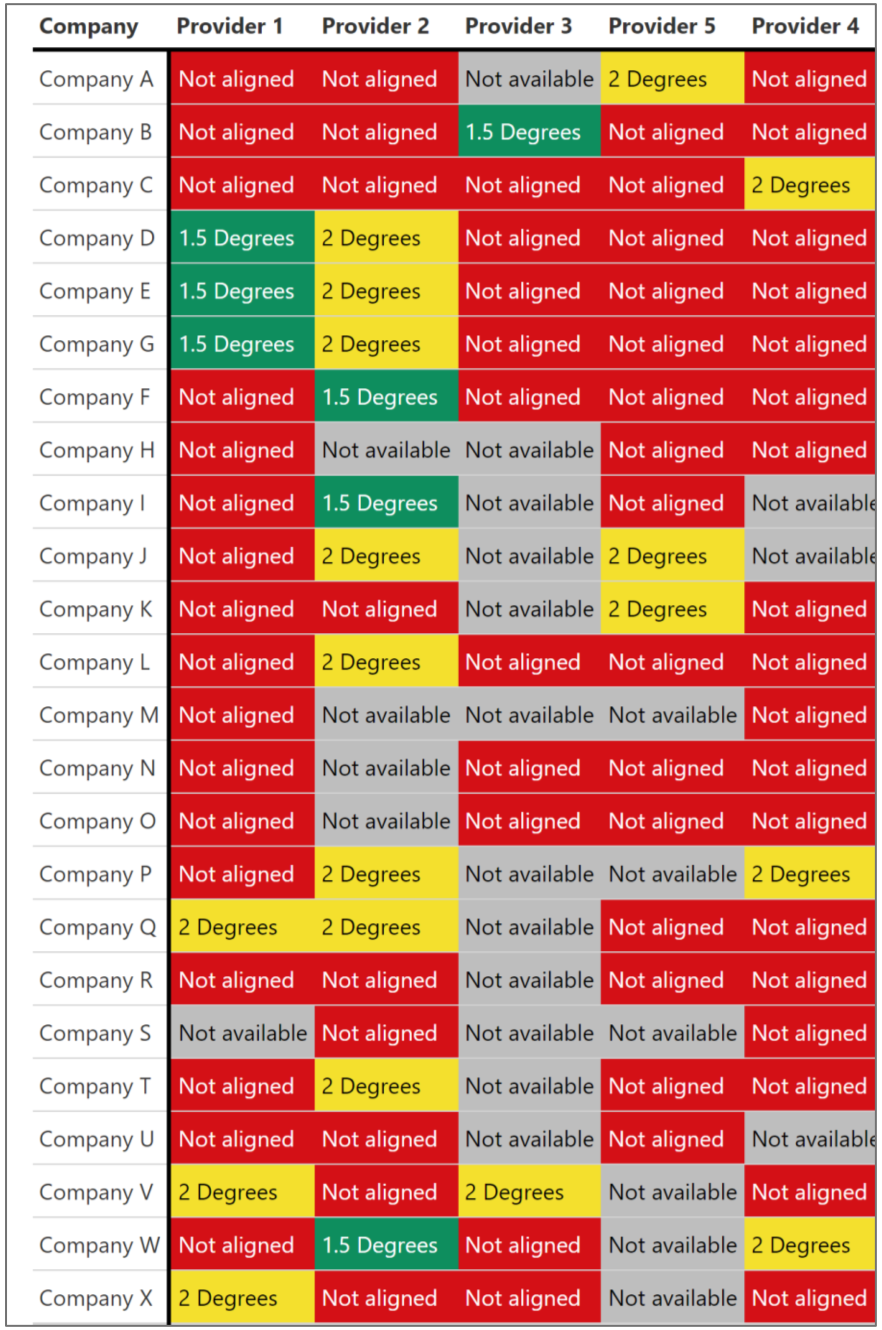
🟨 Developing

🟥 Not covered

Lack of comparability

Climate alignment ratings for 24 listed corporate equity assets

Anonymised results across 8 emissions-intensive sectors, with different firm sizes and different HQ regions



Company	**Provider 1**	**Provider 2**	**Provider 3**	**Provider 5**	**Provider 4**
Company A	Not aligned	Not aligned	Not available	2 Degrees	Not aligned
Company B	Not aligned	Not aligned	1.5 Degrees	Not aligned	Not aligned
Company C	Not aligned	Not aligned	Not aligned	Not aligned	2 Degrees
Company D	1.5 Degrees	2 Degrees	Not aligned	Not aligned	Not aligned
Company E	1.5 Degrees	2 Degrees	Not aligned	Not aligned	Not aligned
Company G	1.5 Degrees	2 Degrees	Not aligned	Not aligned	Not aligned
Company F	Not aligned	1.5 Degrees	Not aligned	Not aligned	Not aligned
Company H	Not aligned	Not available	Not available	Not aligned	Not aligned
Company I	Not aligned	1.5 Degrees	Not available	Not aligned	Not available
Company J	Not aligned	2 Degrees	Not available	2 Degrees	Not available
Company K	Not aligned	Not aligned	Not available	2 Degrees	Not aligned
Company L	Not aligned	2 Degrees	Not aligned	Not aligned	Not aligned
Company M	Not aligned	Not available	Not available	Not available	Not aligned
Company N	Not aligned	Not available	Not aligned	Not aligned	Not aligned
Company O	Not aligned	Not available	Not aligned	Not aligned	Not aligned
Company P	Not aligned	2 Degrees	Not available	Not available	2 Degrees
Company Q	2 Degrees	2 Degrees	Not available	Not aligned	Not aligned
Company R	Not aligned	Not aligned	Not available	Not aligned	Not aligned
Company S	Not available	Not aligned	Not available	Not available	Not aligned
Company T	Not aligned	2 Degrees	Not available	Not aligned	Not aligned
Company U	Not aligned	Not aligned	Not available	Not aligned	Not available
Company V	2 Degrees	Not aligned	2 Degrees	Not available	Not aligned
Company W	Not aligned	1.5 Degrees	Not aligned	Not available	2 Degrees
Company X	2 Degrees	Not aligned	Not aligned	Not available	Not aligned

Climate-alignment ratings are based on a range of assumptions and design choices

Financial asset class coverage

- Listed equity
- Private equity
- Corporate debt
- Sovereign bonds
- Real estate
- Infrastructure
- Other

Choice of GHG performance metrics

- Type of GHG performance metric
- Temporal perspective
- Types and scopes of GHGs in metric
- Treatment of carbon offsets and avoided emissions

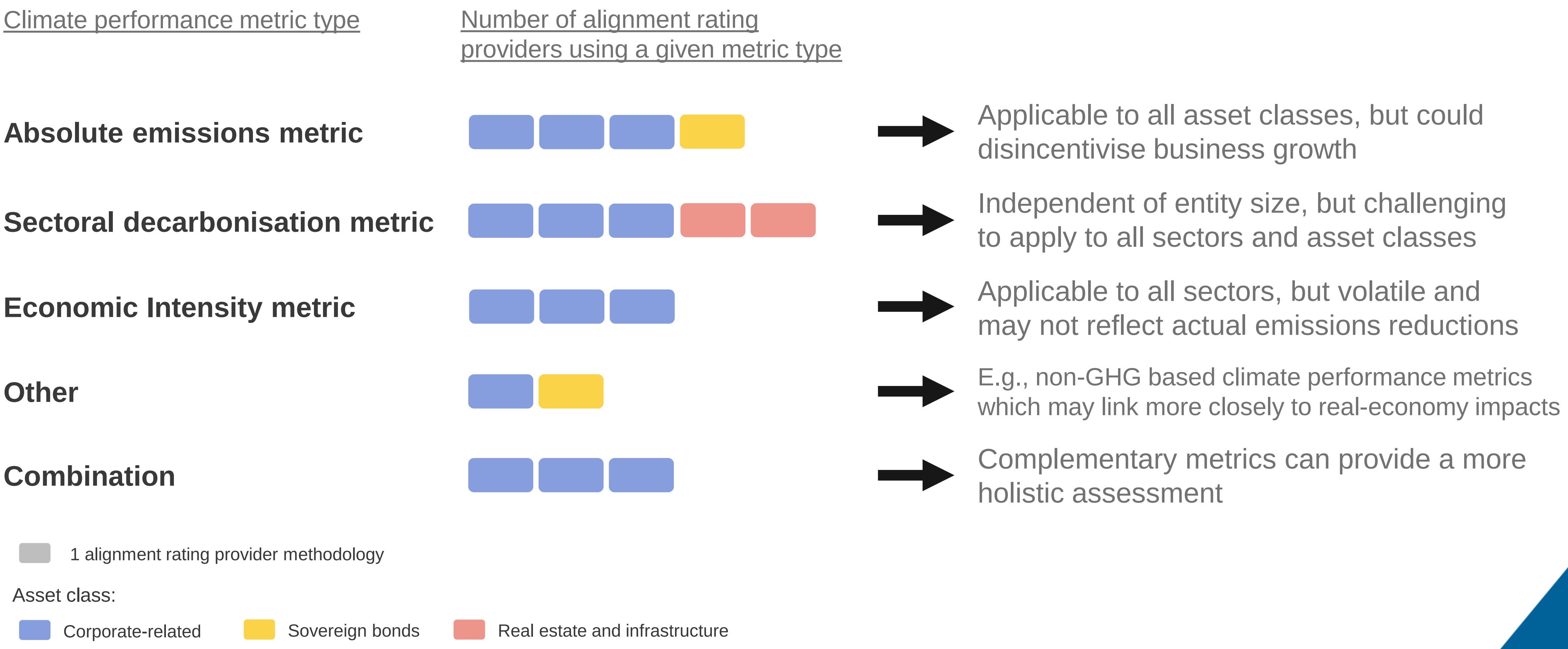
Selection of CC mitigation scenario(s)

- Data and information sources
- Temperature outcomes and uncertainty
- Sectoral scope and specificity
- Geographic scope and specificity
- Techniques to allocate scenarios to entities

Alignment at the financial portfolio level

- Metric at portfolio level
- Aggregation approach
- Double counting

Different perspectives lead to different metrics



Climate performance metric type	Number of alignment rating providers using a given metric type	
Absolute emissions metric	🟦🟦🟦🟨	→ Applicable to all asset classes, but could disincentivise business growth
Sectoral decarbonisation metric	🟦🟦🟦🟥🟥	→ Independent of entity size, but challenging to apply to all sectors and asset classes
Economic Intensity metric	🟦🟦🟦	→ Applicable to all sectors, but volatile and may not reflect actual emissions reductions
Other	🟦🟨	→ E.g., non-GHG based climate performance metrics which may link more closely to real-economy impacts
Combination	🟦🟦🟦	→ Complementary metrics can provide a more holistic assessment

⬜ 1 alignment rating provider methodology

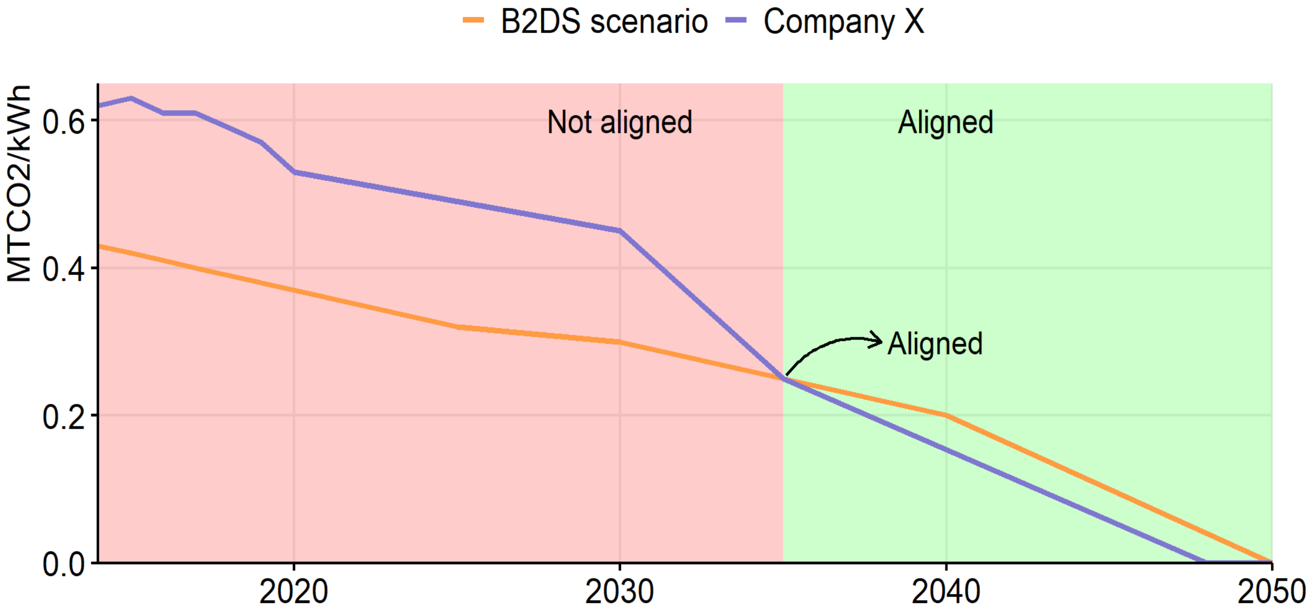
Asset class:

🟦 Corporate-related 🟨 Sovereign bonds 🟥 Real estate and infrastructure

Temporal perspective can change climate rating

Climate alignment rating providers have different temporal perspectives

- Short term – long term
- Cumulative – point-in-time
- Backward – forward-looking



Stylised example of alignment assessment
for an electric utilities company

Remaining challenges and options for metrics, methodologies and data to track climate performance in the financial sector

Metrics

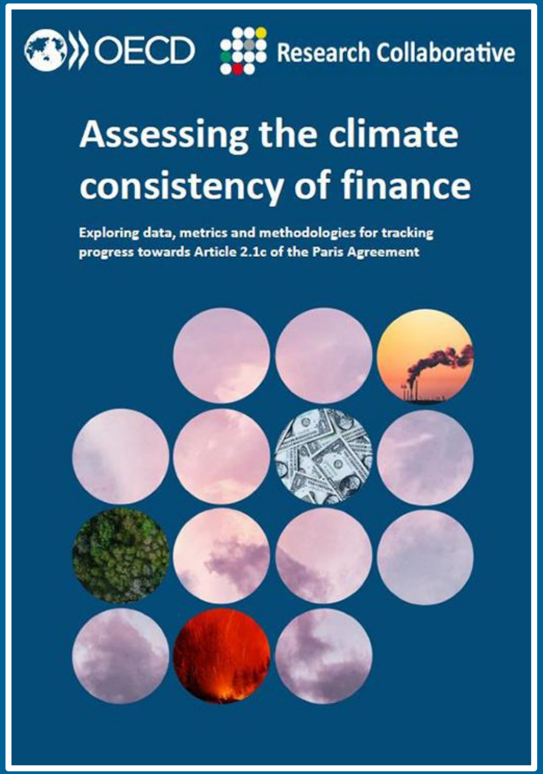
- Develop metrics at different levels of aggregation
- Fill asset class coverage gaps
- Identify pertinent sets of core yet complementary metrics

Methodologies

- Understand use cases and limitations of different methodological choices
- Enhance coordination between policymakers, climate scientists, and practitioners to support methodological developments
- Provide clear guidance e.g on use of offsets

Data

- Encourage transparent disclosure of Scope 1, 2 and 3 emissions, offsets, and targets
- Enhance interoperability across jurisdictions
- Encourage transparent disclosure of scope and underlying assumptions



OECD Research Collaborative

Assessing the climate consistency of finance

Exploring data, metrics and methodologies for tracking progress towards Article 2.1c of the Paris Agreement

Links to publications:

[Finance for Climate Action - OECD]()

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Research Collaborative
Tracking Finance for Climate Action

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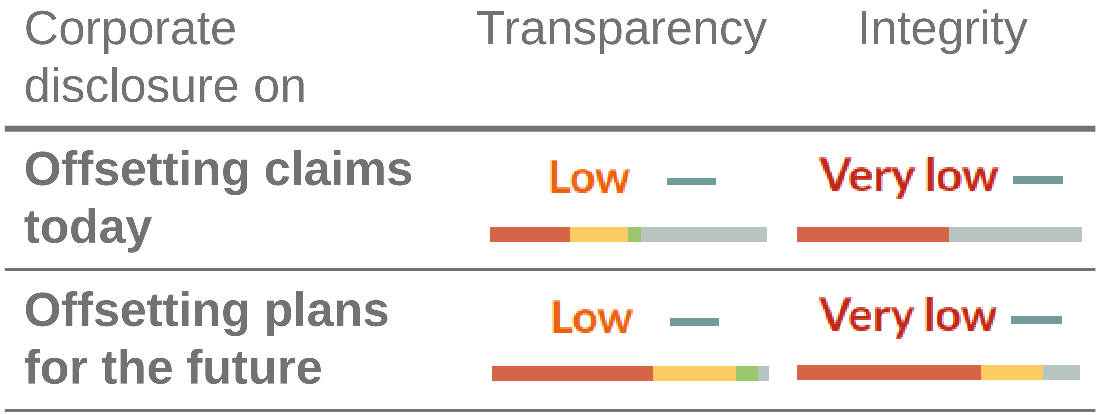
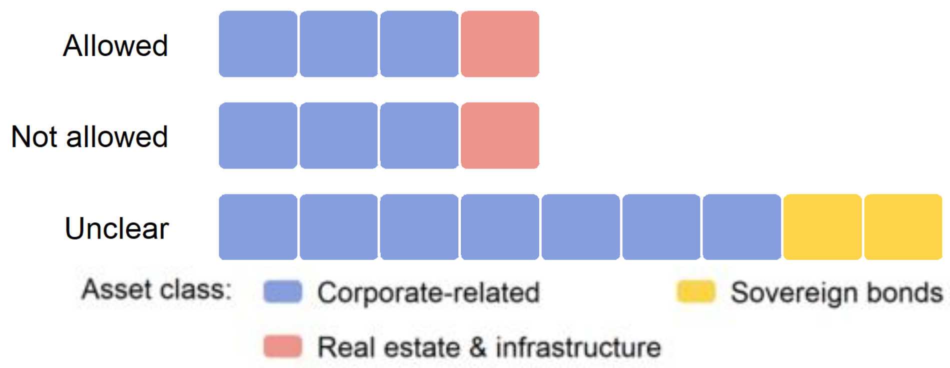
Data, transparency and credibility lacking in relation to the reliance on offsets



Corporate disclosure on	Transparency	Integrity
Offsetting claims today	Low —	Very low —
Offsetting plans for the future	Low —	Very low —

Source: NewClimate Institute (2023) Corporate Climate Responsibility Monitor 2023

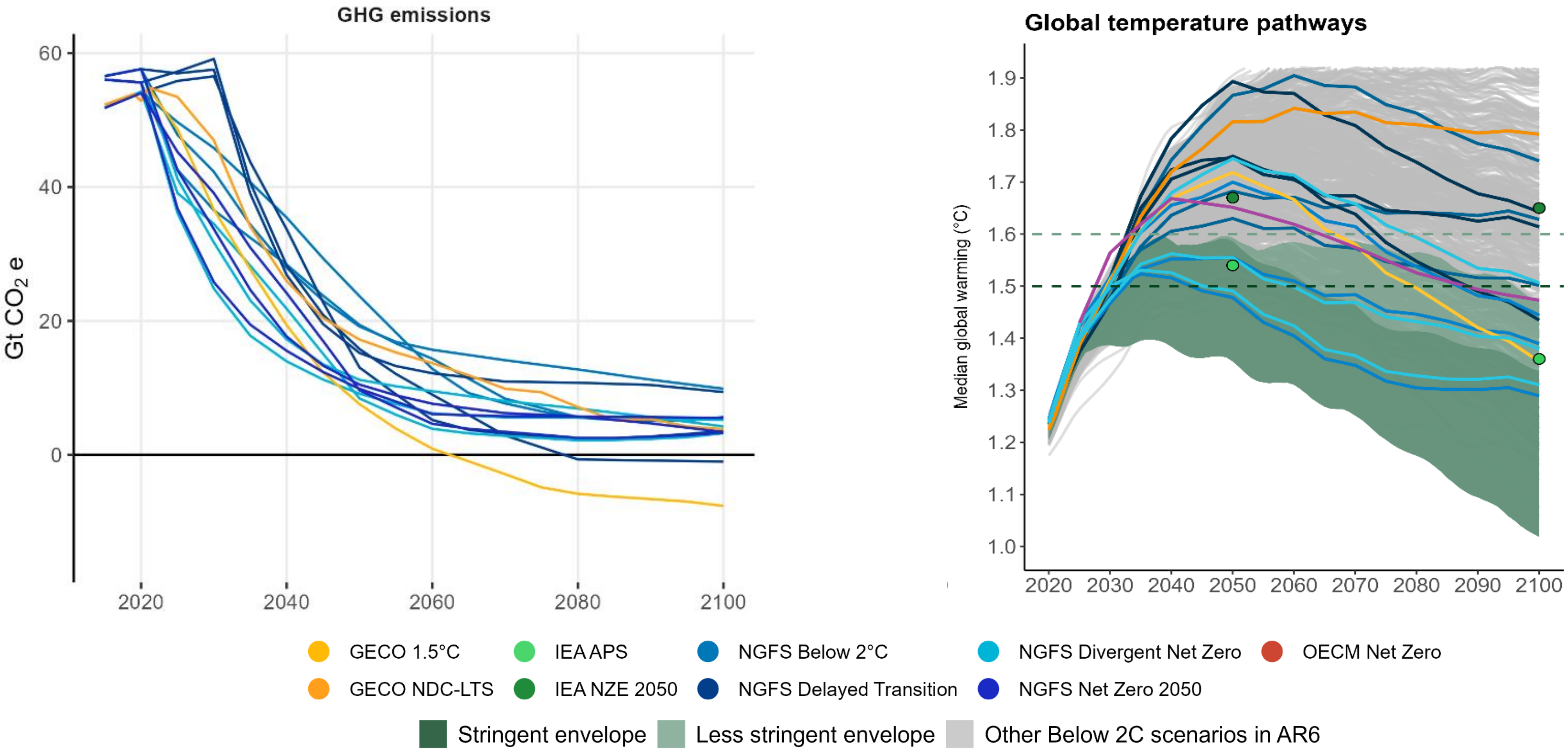
Treatment of offsets in climate rating methodologies



- Methodologies explicitly excluding the use of offsets tend to find less alignment with the Paris Agreement
- Offset data from underlying investees remain opaque

Source: Noels and Jachnik (2022)

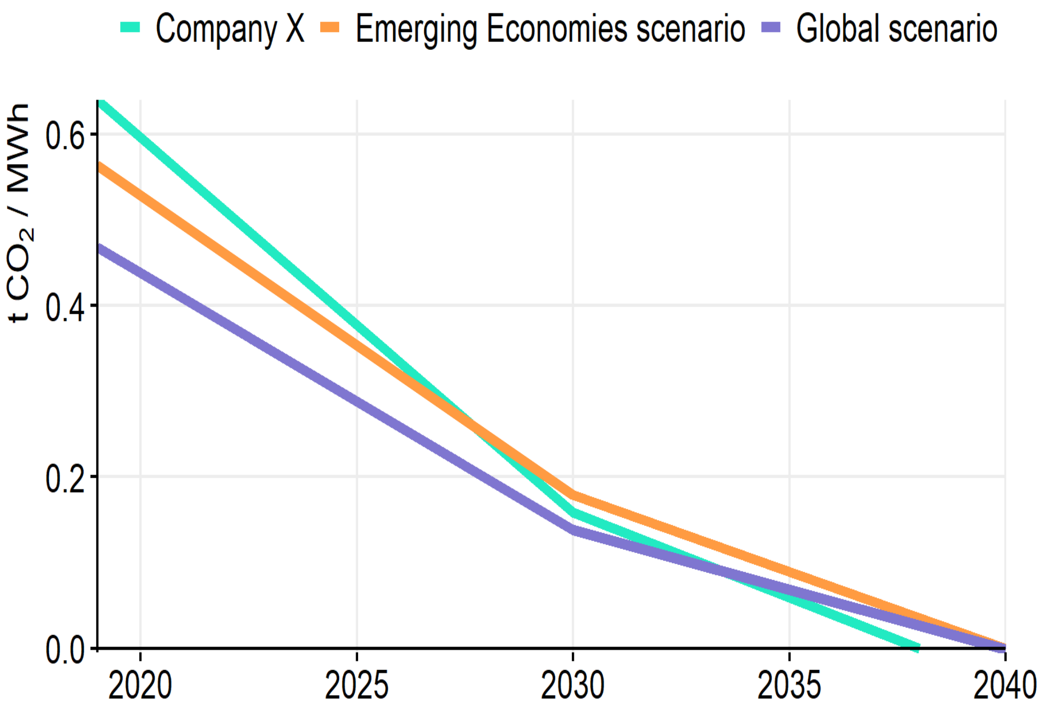
Relevance and difficulties in using scenarios as reference point for alignment assessments



Source: Noels et al (2023)

No agreed approaches to downscale scenarios resulting in different geographic granularity

Stylised example of company alignment against a regional scenario for the power sector



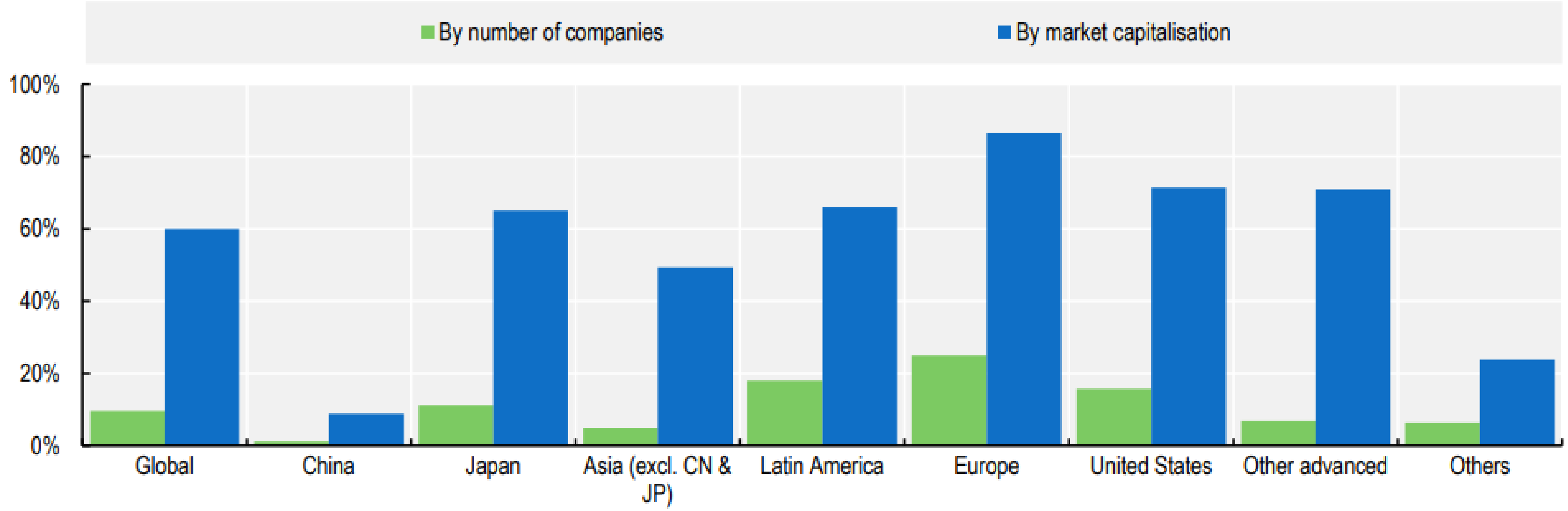
Sectoral granularity in most commonly used scenarios

Models	**IEA GEC 2022**	**POLES-JRC 2022**	**NGFS GCAM**	**NGFS MESSAGE**	**NGFS REMIND**	**UTS-ISF OECM**
From **modelled** specificity	7 regions, **26 subregions of which 6 countries**	66 regions, of which **54 countries**	32 regions, of which **15 countries**	11 regions	12 regions, of which **4 countries**	10 regions + **20 countries**
Additional granularity from ex-post **downscaling**	None	None	185 countries	185 countries	185 countries	None

Source: Noels and Jachnik (2022), Noels et al (2023)

Portfolio-level metrics require further methodological development and data completion

Disclosure of Scope 3 GHG emissions by listed companies, in 2022



Source: OECD (2024)

IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

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Climate risk in the polish banking sector – analysis of dirty and green industries[1]

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

Climate risk in the Polish banking sector – analysis of dirty and green industries

Aneta Kosztowniak, Narodowy Bank Polski and SGH Warsaw School of Economics

Abstract

The aim of the study is to estimate credit exposures and their changes in banks' portfolios in terms of sectors important for climate policy in Poland in 2013-2023. The research concerned the analysis of changes in the structure of the loan portfolio in terms of sectors relevant to climate change (CPRS) divided into groups (green, black, brown and dirty), industries (fossil fuels, electricity, manufacturing, production, transport and agriculture) and sections. The CPRS methodology was used (Battiston et al., 2017-2022). The research results showed that in the entire banking sector in Poland the share of dirty exposures decreased (to 53%) and green exposures increased (to 47%). Due to the intersectional connection, the three pillars of industries with the highest transformation risk among CPRS were: buildings, transportation, and manufacturing.

Keywords: climate risk, CPRS, credit portfolio, NACE, ESG, Poland.

JEL classification: G210, Q500, Q540, Q590.

Contents

1. Introduction

The changes introduced in connection with the implementation of Basel IV in the EU (Regulation (EU) No 575/2013 of the European Parliament and of the Council, Directive 2013/36/EU of the European Parliament and of the Council) imposed on banks the obligation to proceed with climate risks in the risk management system. The ESG climate risk is also treated as a challenge for financial stability. The European Systemic Risk Board *(ESRB)* and the European Central Bank (ECB) are actively involved in analysing and monitoring the impact of climate risk on the financial system, identifying it as one of the main systemic risks in the European Union (EU). These risks also require banks to develop appropriate strategies and change business models to minimise climate risks.

The climate risk can affect the financial system and the real economy through two risk channels (types):

- *The physical risk* includes the economic costs and financial losses resulting from the increasing severity and frequency of extreme weather events caused by the climate change. It has been at the core of the empirical literature in this field for years[1].
- *The transition risk* is related to the costs generated by the need to adapt the economy to a more sustainable and low-carbon development path. Transition risks will materialise before a significant part of the physical risk materialises, as there are adjustments to the value of financial assets that investors do not fully anticipate or hedge against. In contrast, the transition risk has received much less attention in the past, but the political and economic debate about costs and benefits of the transition to net zero carbon emissions has intensified.

According to Monasterello and Battiston (2020, pp. 52-72), there are several reasons why the risk of transfer is revealed, e.g., if the transition is late and sudden (ESRB, 2016) and thus "disordered" (NGFS, 2019).

The results of determining the value and structure of credit exposures sensitive to climate change in the banking sector in Poland fill a research gap in the scope of empirical research to date. These results also add value to the work on improvements to estimating the scale of sectors important for climate policy and their possible impact on the risk of transformation in financial institutions, specifically, in banks.

The results are important for:

1) Banks in assessing, limiting, and monitoring the ESG risk management process or disclosures of these exposures (SFDR Regulation, TCFD guidelines under CRR2).
2) The supervision of the financial market in the banking market segment.
3) The EU and national legislative institutions in the legislative and regulatory procedure.

The aim of the study is to estimate credit exposures and their changes in banks' portfolios in terms of sectors important for climate policy, which exposes

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[1] A comprehensive overview of the current state of climatological research is provided, for instance, in the regular reports of the Intergovernmental Panel on Climate Change (IPCC).

them to the risk of ESG transition in Poland in 2013-2023. To achieve the aim of the study, it is important to obtain answers to the following questions:

1. How did the loan portfolio of exposures sensitive to the climate transition risk change?
2. What changes took place in the share of green and dirty industries in the composition of the entire banking sector?
3. In which groups, industries, and sections of economic activity (NACE) are concentrated exposures sensitive to the risk of climate transition?

The following research hypotheses were formulated:

H1. In Poland, the structure of the loan portfolio in the field of green groups slowly improves and impaired loans (NPLs) in sectors important for climate policy fall, considering the initial period of economic transformation in this area.

H2. Intersectional links can be a source of risk if disruptions in individual sections affecting entire industries (spillover effects) are revealed, such as in buildings, transportation, and manufacturing.

2. Sectors Relevant to Climate Policy (CPRS) – methodology

An important method for determining exposure by groups, sectors, and sections sensitive to climate change is the Climate Policy Relevant Sectors (CPRS) method developed by S. Battiston and I. Monasterelo (2017), improved at the turn of 2019-2022, and used in the studies of EIOPA (2018), ECB (2019), and EBA (2020).

To identify the CPRS, guidelines have been prepared for the qualification of various operations according to the economic activity codes (NACE) (at the level of classes and subclasses), covering some different levels of disaggregation:

I. Groups:

- black (fossil fuels);
- brown (electricity + manufacturing + transportation),
- brownish (agriculture + buildings),
- dirty (black + brown + brownish),
- and green.

II. CPRS Main: CPRS1-fossil-fuel, CPRS2-utility-electricity, CPRS3-manufacturing, CPRS4-buildings, CPRS5-transportation, CPRS6-agriculture.

III. Individual sections – CPRS2.

IV. CPRS Granular.

The CPRS classification is widely used by practitioners and policymakers, based on the use of a classification of economic activities that is reproducible and comparable across portfolios and jurisdictions (Table 1).

The list of sectors relevant for climate policy by code classification

Table 1

CPRS sectors	NACE rev. 2, 4 codes
1 Fossil-fuel	05, 06, 08.92, 09.10, 19, 35.2, 46.71, 47.3, 49.5
2 Utility-electricity	35.11, 35.12, 35.13
3 Manufacturing	07.1, 07.29, 08.9, 08.93, 08.99, 10.2, 10.41, 10.62, 10.81, 10.86, 11.01, 11.02, 11.04, 11.06, 13, 14, 15, 16.29, 17.11, 17.12, 17.24, 20.12, 20.13, 20.14, 20.15, 20.16, 20.17, 20.2, 20.42, 20.53, 20.59, 20.6, 21, 22.1, 23.1, 23.2, 23.3, 23.4, 23.5, 23.7, 23.91, 24.1, 24.2, 24.31, 24.4, 24.51, 24.53, 25.4, 25.7, 25.94, 25.99, 26, 27, 28, 32
4 Buildings	23.6, 41.1, 41.2, 43.3, 43.9, 55, 68, 71.1
5 Transportation	29, 30, 33.15, 33.16, 33.17, 42.1, 45, 49.1, 49.2, 49.3, 49.4, 50, 51, 52, 53, 77.1, 77.35
6 Agriculture	01, 02, 03

Sources: Battiston *et al.* (2022).

Explanation: The table illustrates selected NACE codes for the first 6 CPRS Main categories. Note that when a 2-digit (or 3-digit) NACE code is indicated, it means that all 4-digit NACE codes contained in that code are mapped to the same CPRS.

The CPRS can be applied to all types of financial assets (e.g., stocks, loans, bonds) and geographic jurisdictions, thus making possible comparisons across investors. The CPRS is also fully in line with the EU taxonomy for sustainable activities. Moreover, the CPRS shall provide a standardised and practical classification of activities (at NACE Rev2 level, 4-digit) on which revenues may have a positive or negative impact in a disorderly low-carbon transition, based on their energy technology (e.g., based on fossil fuels or renewable energy). For this reason, the CPRS classification is considered a benchmark for assessing the financial risks associated with climate change and has been used by several international financial institutions to assess investors' exposure to climate transition risks. The use of CPRS methodology can be found in several reports, among other places.

- The European Central Bank (2019) provided in its June 2019 Financial Stability Report some preliminary estimates of financial institutions' aggregate exposures to the CPRS, relative to their total shares in debt securities, ranging from 1% for banks to around 9% for mutual funds.
- The European Insurance and Occupational Pensions Authority, (EIOPA, 2018, pp. 1-88) reported the aggregated CPRS exposures of EU insurance companies of approximately 13% of their total securities shares.
- The European Banking Authority (EBA, 2020), in its assessment of the financial risk of the banking system of December 2020, used the CPRS methodology to analyse the temporary risk associated with €2.4 trillion of EU bank loans.

According to the results of the studies by Battiston *et al*. (2022) for the EU countries and non-financial corporations in 2013, 2015 and 2018, based on the CPRS methodology for the equity and bond portfolio, the highest degree of the transition risk was shown by the following sectors: industry, followed by transportation and fossil fuels; electricity and buildings were exposed to the risk to a lower degree.

It is worth emphasizing that by identifying credit exposures by groups, sectors and sections (CPRS), banks can estimate their exposure to climate (ESG) risks and make decisions regarding capital requirements and reserves.

3. Empirical data

In this study of loan portfolio exposure, the methodology developed by Battiston *et al.* (2022), that is, a mapping from the NACE codes of economic activities into Climate Policy Relevant Sectors (CPRS) and into the variables of the process-based Integrated Assessment Models (IAM), is used by the Network for Greening the Financial System (NGFS) to provide its climate scenarios (according to Table 1) standards ISIC, NACE or NAICS and refers to a production process, e.g., electric power generation. Data on credit exposures come from the databases of the National Bank of Poland (NBP, 2023; NBP300).

The empirical analysis uses NBP reporting data, including the NBP300 database, i.e., banks' reports on loans to non-financial corporations. The time series included quarterly data for Q4 2013 to Q2 2023 (39 quarters). The Stata statistical package was used to calculate individual CPRS disaggregations. Data descriptive statistics are provided in the Annex (Table A.1).

The identification of credit exposures according to the CPRS methodology included three steps of the calculation:

1. The values and dynamics of CPRS exposure in total and broken down into groups: black, brown, dirty, and green.
2. Bank exposures by six main industries: CPRS1-6.
3. The exposures of CPRS exposures by NACE sections.

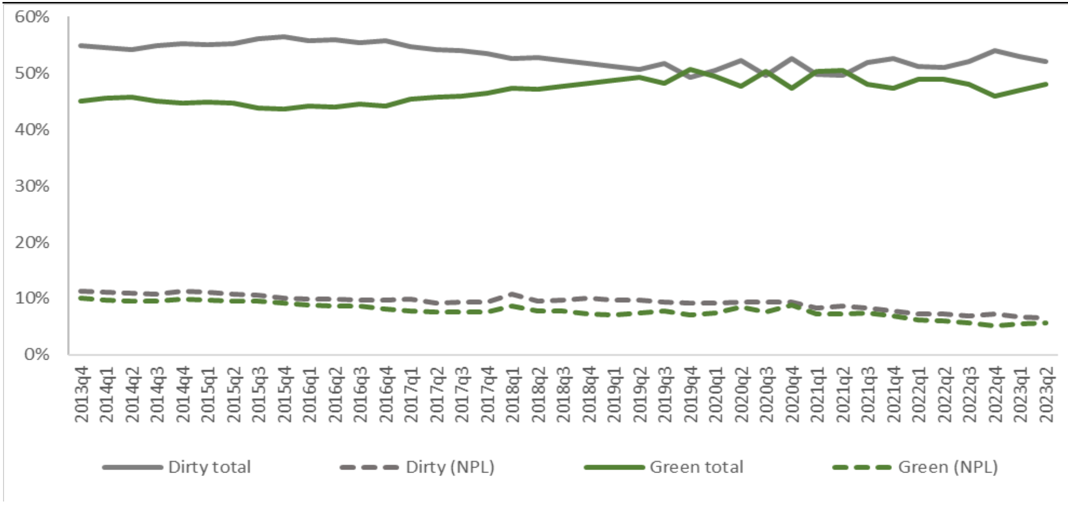
3.1. CPRS exposures according to groups

In Poland, in the years 2013-2023, the value of CPRS exposures increased by 45%, including dirty exposures by 34%, black exposures by 69%, brown exposures by 30% and green exposures by 57%. On the other hand, the average share of dirty exposures in CPRS exposures was 53% vs. 47% share of green exposures.

Comparing dirty exposures to the exposures of the entire banking sector, their share fell from 55% in 2023 to 52% in 2023, and green exposures from 11% to 9%, respectively. A noticeable trend of some improvement was also noticeable in impaired exposures (NPLs), which also showed declines (Kosztowniak, 2023a). Accordingly, the share of dirty loans (NPLs) in the banking sector exposure fell from 11% to 9%, while the share of green loans (NPLs) fell from 10% to 8% (Figure 1).

The share of dirty and green groups in the exposure of the banking sector in Poland in Q4 2013 - Q2 2022 (%)

Figure 1

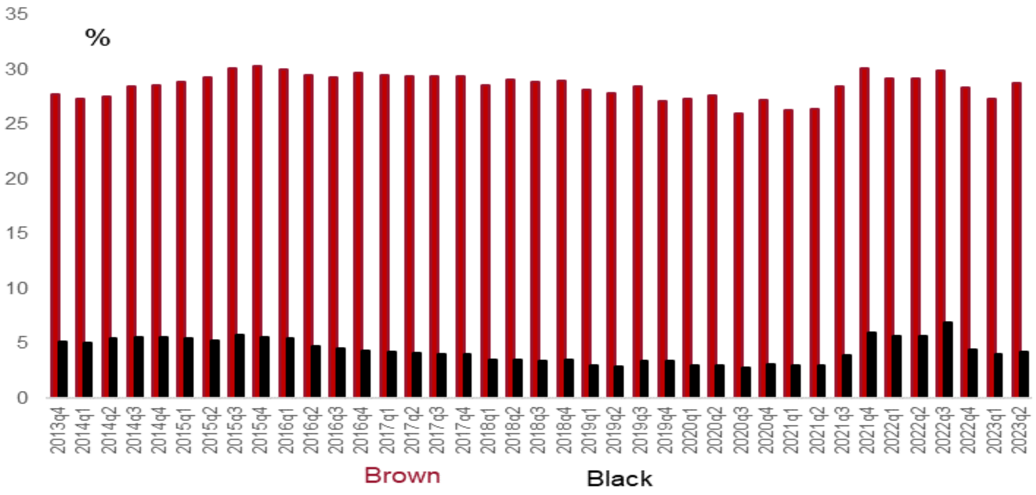


Sources: Author`s compilation based on NBP (2022), NB300 (2023).

On the other hand, when comparing credit exposures from individual climate groups to total corporate loans, their share in the years 2013-2023 remained at a similar level, with some deviations in individual years. For example, the share of brown loans in corporate loans increased from 28% in 2013 to 29% in 2023, while the share of black exposures to corporate loans fell from 5.2% in 2013 to 4.3% in 2023 (Figure 2).

The share of brownd and black sectors in corporate loans in Poland in Q4 2013 - Q2 2023 (%)

Figure 2



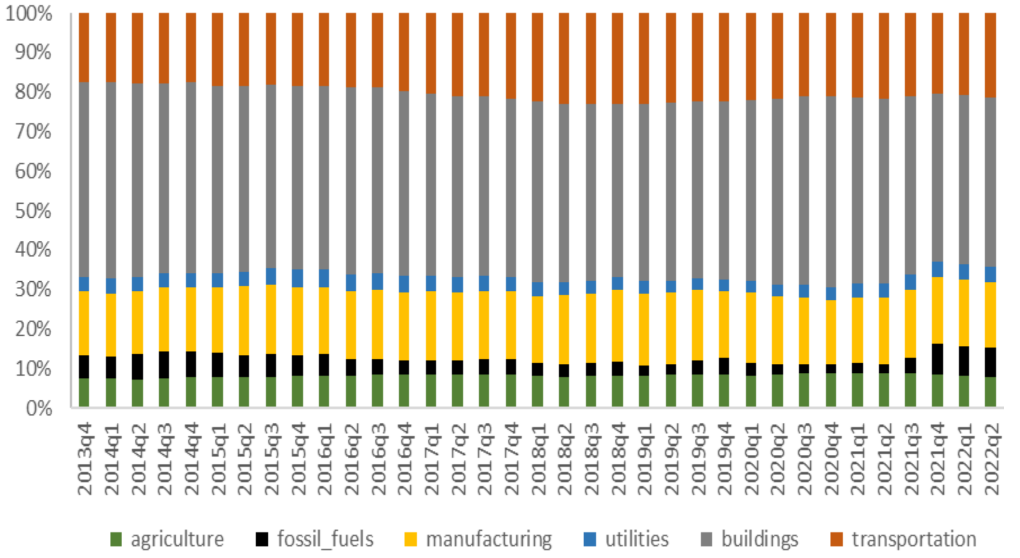
Sources: Author`s compilation based on NBP (2022), NB300 (2023).

3.2. The involvement of banks in CPRS industries and their structure

The credit exposures result of the Polish banking sector for the next degree of disaggregation, i.e., for the level of industries, prove that three industries (pillars) of CPRS, i.e. buildings, transportation and manufacturing, were of major importance in the years 2013-2022. The largest share of exposure was concentrated in the construction industry, despite its reduction by 7 pp (from 49% to 43%). The second pillar was the transportation industry, for which the exposure climbed by 4 pp (from 17% to 21%), while the third pillar of manufacturing maintained a stable share of 17% in the total CPRS (Figure 3). It is worth noting here that the three industries in Poland were also key to CPRS exposures according to the results of research for the EU countries in 2013, 201 5 and 2018 (Battiston *et al.*, 2022).

Industry exposures in total CPRS exposure in Poland in Q4 2013- Q2 2022 (%)

Figure 3

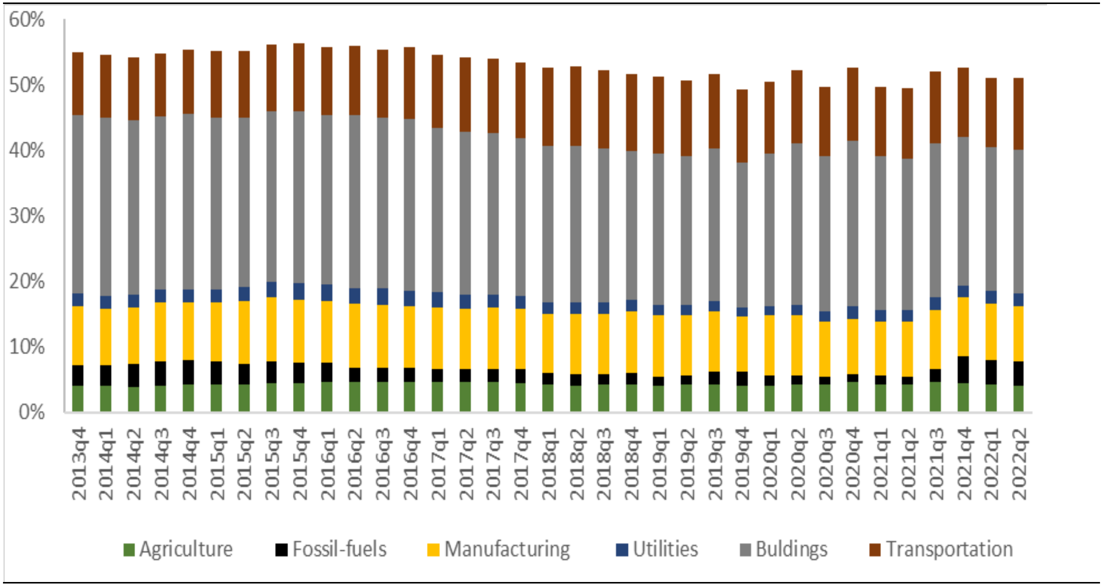


Sources: Author`s compilation based on NBP (2022), NB300 (2023).

Referring CPRS exposures to the exposures of the entire banking sector in Poland, it appears nearly 60% of the exposures relate to the transition risk. What this means is that the majority portfolio is sensitive to changes in ESG transformation risk and requires careful monitoring and supervision. Between 2013 and 2022, the buildings sector accounted for the largest share of this exposure, despite showing a contraction of 5 pp (from 27% to 22%), against an increase of 1 pp. in the transportation sector (from 10% to 11%) and a stable 9% share of the manufacturing sector (Figure 4).

The shares of CPRS industries in the banking sector exposure in Poland in Q4 2013- Q2 2022 (%)

Figure 4

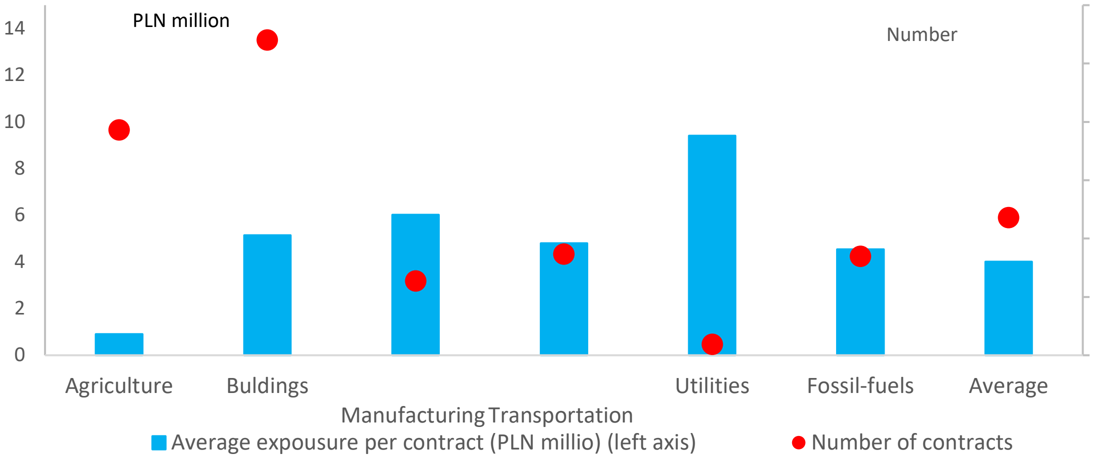


Sources: Author`s compilation based on NBP (2022), NB300 (2023).

In the analysis of transition risks, their concentration is an important issue. One of the ways to identify it is the value of credit exposure for 1 contract. In Poland, the utilities (utility-electricity) industry maintained the highest average exposure value for 1 contract in Q2 2022 (approx. PLN 9.4 million). Other unit exposures under a contract corresponded to manufacturing sector (approx. PLN 6.0 million) and buildings (approx. PLN 5 million), respectively, compared to the lowest in the agricultural sector (below PLN 1 million) (Figure 5).

Average exposure by CPRS group and number of contracts for Q2 2022 (PLN million, number)

Figure 5



Sources: Author`s compilation based on NBP (2022), NB300 (2023).

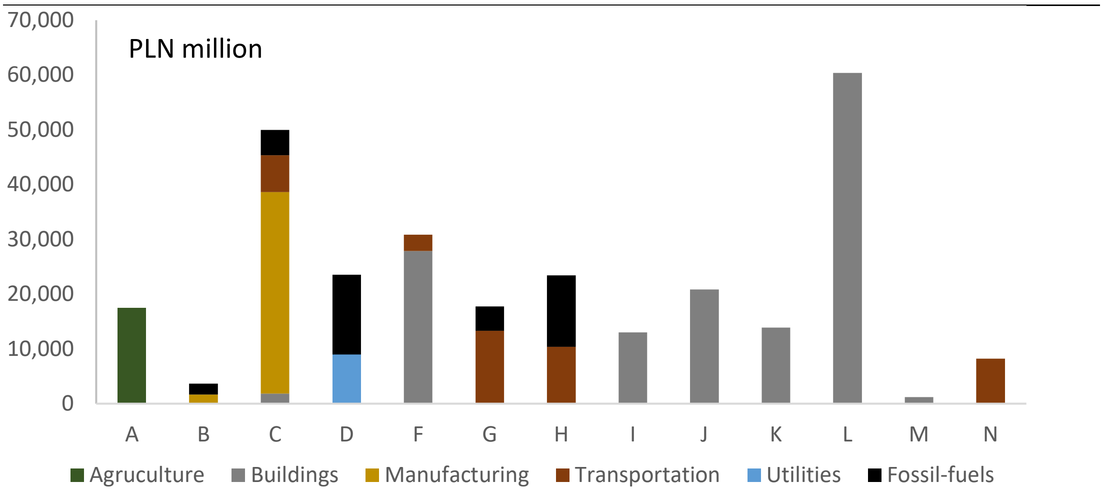
.3.3. CPRS exposure engagement by NACE sections

Since, according to the CPRS methodology, there is a permeation of the effects of a section's activities within sectors (CPRS-1-6), in the case of rising CO2 emissions, transfer and physical risks may escalate as part of the dispersion effect (*spillovers*).

According to calculations, the total level of credit exposures in Q2 2022 in section L amounted to PLN 60.4 billion, while for the entire CPRS sector - buildings – to PLN 139.0 billion, in the transportation section to PLN 13.0 billion, and for the entire transportation sector, to PLN 41.6 billion, whereas in section C, it reached nearly PLN 50.0 billion, and for the entire CPRS manufacturing sector, nearly PLN 38.5 billion, due to its dispersion to other industries, e.g. transportation, fossil fuels or buildings. It should be emphasized that the highest exposure value among the CPRS sectors was absorbed by buildings, because it is disclosed in several sections (C, F, I, J, K, L, M, N). High exposures were also maintained by the CPRS sectors in the fields of transportation (sections: C, F, G, H, N) and manufacturing (B, C) (Figure 6).

The dispersion of CPRS sectors in NACE sections, i.e. links between sections in Poland in Q2 2022 (PLN million)

Figure 6



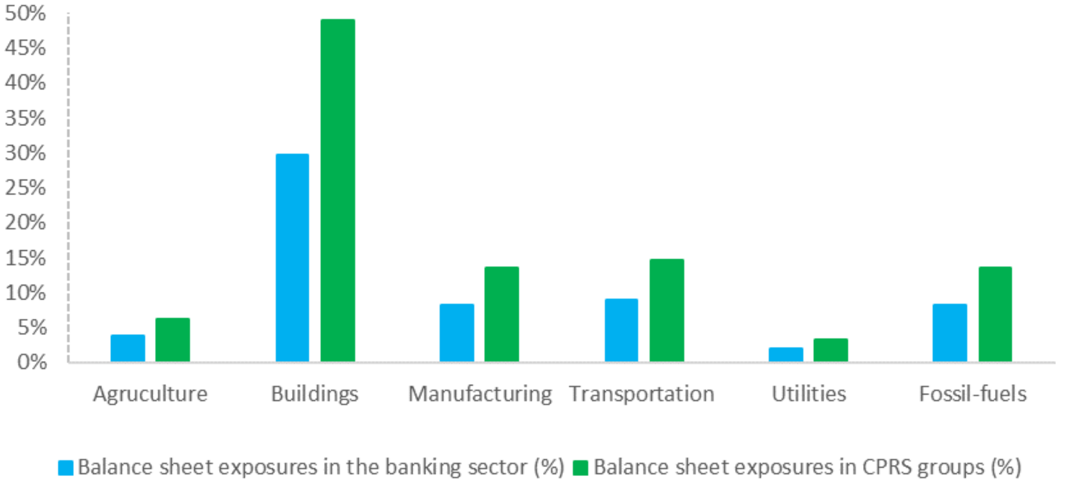
Sources: Author`s compilation based on NBP (2022), NB300 (2023).

Note: NACE sections: A - Agriculture, forestry, hunting and fishing, B - Mining and quarrying, C - Manufacturing, D - Electricity, gas, steam, hot water and air conditioning generation and supply, E - Water supply; sewage and waste management and remediation activities, F - Buildings, G - Wholesale and retail trade; repair of motor vehicles, including motorcycles, I – Activities R - Activities related to culture, entertainment and recreation related to accommodation and food services, J - Information and communication, K - Financial and insurance activities, L - Activities related to real estate services, M - Professional, scientific and technical activities, N - Administrative and support services activities.

Among bank balance sheet exposures in the CPRS industries, as well as in the entire banking sector, buildings retained the largest share. The share of banks' balance sheet exposures in CPRS in the field of buildings amounted to nearly 50%, compared to the share in the field of transportation (15%) and manufacturing and fossil fuels (14% each). The total share of other industries was less than 10%, i.e., agriculture (6%) and electricity-related activities (3%). In relation to CPRS exposures to banking sector exposures, buildings (30%), followed by transportation (9%) and manufacturing and fossil fuels (8% each) also held the largest shares (Figure 7).

Balance sheet exposures in CPRS sectors and the entire banking sector in Q2 2022 (%)

Figure 7



Sources: Author`s compilation based on NBP (2022), NB300 (2023).

4. Discussion

Climate change is associated with a substantial increase in various types of risks. One of them is the transition risk. It can be thought of as the risk resulting from the process of adjustment towards an economy with net zero carbon emissions. As this process unfolds, assets may lose value, which in turn can have repercussions for the aggregate economy. Industries with higher carbon emissions will tend to be more exposed to the transition risk as their production processes are affected more strongly by the transition. To date, however, the measurement of the transition risk is still fragmented.

There are two key challenges regarding the definition and measurement of the transition risk: (i) typically, economists measure the transition risk only by isolating certain prominent drivers, such as fiscal policies that support the reduction in carbon emissions, (ii) consequently, the associated implicit definition of the transition risk encompasses only its one or two features.

The growing attention to the transition risk has uncovered key challenges for empirical research. As Medering *at al.* (2023) point out, firstly, a precise definition of the transition risk that may guide analyses is still missing. Broadly speaking, the transition risk can be thought of as the risk resulting from the process of adjustment towards an economy with net zero carbon emissions. But this total definition is hard to operationalize. Therefore, economists typically resort to defining the transition risk by isolating drivers, for instance, fiscal policies that support the reduction of carbon emissions, but also technological change or shifts in household preferences that can render certain industries, products, or firms obsolete (NGFS, 2020). Secondly, the lack of a precise definition makes the measurement of the transition risk challenging. It is impossible to directly quantify it because the expected path (or the distribution of paths) towards a lower-carbon economy is unobservable. Rather, it must be inferred. For another part, a variety of factors shape the transition risk. As a result, a vast majority of (both theoretical and empirical) researchers rely on proxies that typically capture only one or two features of the transition risk. For instance, Ciccarelli and Marotta (2021) resort to a climate policy stringency index and the amount of green patent filings as proxies. Kaenzig (2022) relies on carbon price data from the EU ETS futures markets. In theoretical macroeconomic research, like integrated assessment models in the spirit of Nordhaus (2018), the transition dynamics are often embodied in a single variable called the social cost of carbon. In spirit, perhaps closest to our paper is Moench and Soofi-Siavash (2021), who extract shocks that explain the maximum share of variation in emission intensity at a 20-year horizon from country-level carbon emissions data.

In tandem with this risk (fiscal and transitional), it is not clear how these surrogate factors, probably endogenous, relate to the path to a low-carbon economy (Metcalf and Stock, 2020). Neither of the challenges apply to the physical risk, easily defined, and measured. Specifically, the observation of extreme weather events and the achievements of climatological research provide detailed information about physical risks. The situation is different in the case of the transition risk, for which there is no common calculation methodology. So far, different methods are used depending on the portfolio of stocks, bonds, or loans (e.g., Battistion *et al.* 2022, Meidering *et al.*,2023).

However, the CPRS method used in this study combines many economic activities (NACE) showing specific CO_2 emissions at different levels of disaggregation. Therefore, this method is multi-threaded and universal due to the availability of statistical data and can be calibrated. The empirical results of Battiston *et al*. (2022) for the EU countries on a group of non-financial enterprises in terms of market capitalization (stocks and bonds) showed that the highest degree of risk transition applies to the following industries: manufacturing, transportation, fuels, electricity, and finally buildings.

The results of research for the Polish banking sector presented in this study for the years 2013-2022 confirm the concentration of the transition risk in the following sectors: buildings, transportation, and manufacturing. Thus, the results are consistent in terms of key climate-sensitive industries, although in a slightly different gradation, which reflects the specificity of the market for Poland.

5. Conclusion

The changes introduced in connection with the implementation of Basel IV in EU countries imposed on banks the obligation to proceed with climate risks (ESG) in the risk management system in the scope of assessment, mitigation, disclosure, and monitoring of exposures sensitive to these risks. Currently, legal regulations regarding ESG can be found, among others, in the SFDR Regulation, EU Taxonomy or TCFD Guidelines.

The literature on climate risk is wide-ranging. However, regarding financial institutions, including banks, it focuses on the types of ESG risks, their modelling, supervision, or impact on financial stability. In terms of theoretical literature (as already noted), both physical risk and the results of empirical research are more extensively presented. In the case of transition risk, both theoretical and empirical analyses are at the initial stages.

One of the methods of identifying sectors relevant to climate policy and allowing to estimate the risk of transition is the methodology developed by Battiston *et al*. (2022) and used by EiOPA, the ECB, and the EBA. The advantage of this method is the identification of groups, industries, and sections of activities sensitive to climate risk exposures, enabling to determine? the risk price for the portfolio of loans of a bank or an entire domestic banking sector.

This study uses the CPRS methodology for the loan portfolio of the Polish banking sector in the years 2013-2022. Similar results were achieved in this study as according to Battiston *et al.* (2022) for the market capitalization (stocks and bonds) of non-financial companies in the EU countries. It is about confirming the existence of the highest transition risk in certain industries, i.e., manufacturing, transportation, and buildings.

The results of the study indicate that the portfolio of credit exposures in Poland, according to CPRS, showed an increase in value by 45% in 2023 compared to 2013. Almost half of the sectors important for climate policy belonged to the so-called group of dirty exposures, including mostly industry, buildings, and transportation. Nevertheless, in the involvement of the entire banking sector, there was a decrease in exposures from the dirty group (from 55% to 53%) with an increase in the share of exposures from green groups (from 45% to 47%). The share of impaired dirty exposures (NPLs) showed a slow decline from 11% to 9%, respectively, and the share of green exposures (NPLs) from 10% to 8%, indicating an improvement in loan servicing (Figure 1). These developments point to a positive trend towards a reduction in the risk of the transition if it continues in the coming years. At the same time, these results confirm the validity of ***H1***. In Poland, there are slow changes in the improvement of the structure of the loan portfolio in sectors important for climate policy, which are in the initial period of transformation in this area.

In Poland, nearly 60% of the exposures of the entire banking sector are classified as CPRS groups. These CPRS groups divided on buildings (43%), transport (21%) and industry (17%) account for the largest share of this exposure, followed by agriculture (8%), fossil fuels (7%) and electricity (4%) (Figure 3). Per 1 loan agreement, the utilities have the highest concentration of exposures in Poland (Figure 5), which is also confirmed by the EU-wide results (Batiston et al., 2022).

An analysis of CPRS exposures by activity section (NACE) showed a dispersion and thus numerous links, e.g. of the buildings with numerous sections (C, F, I, J, K, L, M, N), transport (C, F, G, H, N) and manufacturing (C and B). These results support ***H2***, i.e. that intersectional linkages can be a source of risk when distortions in individual sections affecting entire industries (*externalities*), i.e. real estate activities (Section L) or manufacturing activities (Section C), are revealed due to their broad impact on other sections (Figure 6).

Reassuming, the results of the study showed that in the years 2013-2023 the share of dirty exposures decreased (from 55% to 53%) while the share of green exposures (from 45% to 47%) of the entire banking sector increased in Poland. Buildings played a key role in shaping the exposure, due to its dominant share in CPRS groups (49%) and in the entire banking sector in Poland (30%). Due to the intersectional link, the three pillars of the industries with the highest risk of transformation among CPRS were: buildings, transportation, and manufacturing. The empirical results are important for commercial banks in the process of disclosing climate exposures, as well as for central banks monitoring these areas of activity, including potential risks of financial destabilization of the banking sector.

6. Challenges and economic policy recommendations

In assessing the exposure to climate risks, including mainly the transition, the following conditions are addressed:

1) weakening: e.g., short maturities of loans taken out, considering environmental factors already at the stage of credit analysis of projects, monopolistic position of most high-emission entities with a dominant role of the state as owner and regulator,

2) as well as strengthening: failure to consider energy-intensive entities and industries in the analysis, indirect impact on the banking sector through a change in macroeconomic factors, e.g., an increase in energy prices, job losses or an increase in public debt as a factor strengthening the s*overeign-bank nexus* risk.

Among the challenges for banks in monitoring the ESG risk in loan portfolios, the climate interactions of physical and transition with other types of risks should also be mentioned (Table 2).

Climate risks and interactions with other risks

Table 2

Risk type	Physical risk – severe weather events and long-term changes in weather patterns can contribute to:	Transition risk – new climate regulations, technologies and market sentiment can contribute to:
Credit	Decrease in the value of collateral, which in turn increases credit risk through higher LGD.	The emergence of the so-called "stranded" assets in industries with high CO_2 emissions, which in turn increases the probability of default default (through lower debt sustainability) and LGD (through lower collateral value).
Market	Impairment of assets and growth in volatility of e.g., commodities and/or FOREX.	The emergence of "stranded" assets in industries with high CO_2 emissions, which cause a sudden need to reassess e.g., equity and/or the bond market.
Operating	Destruction of real estate (e.g., bank branches), data center and operations.	Increase operational risk, e.g., by outsourcing selected activities or processes.
Other	Macroeconomic shocks increasing liquidity risk.	Negative impact on the reputation of an institution, e.g., in connection with the so-called "green washing".

Sources: Kosztowniak (2023b).

In the EU countries, including Poland, a comprehensive assessment of the transition risk for the banking sector, in addition to the ESG risk indicated in the management process and sectors important for the CPRS climate policy, would require taking into account a number of other factors such as: energy intensity of the economy, the risk of impairment of assets of the insurance sector and investment funds, or the impact of the rising price of fossil fuels and electricity on the macroeconomic situation.

The importance of estimating the transition risk stems from several facts, e.g., (i) it raises the valuation of green firms over brown firms and (ii) is accompanied by important public information e.g., changes of property taxes, etc.

The transition to a more sustainable and low-carbon economy can lead to challenges for financial stability. Administrative decisions, such as increasing the cost of carbon dioxide emission allowances or promoting cheap, low-emission technologies, will cause the operating costs of some industries to increase strongly and their profitability to fall. Financial institutions with significant exposures to carbon-intensive sectors such as energy, mining and fossil fuel processing, transportation, and buildings, for example, may experience losses due to the impairment of loan collateral, company value or even solvency.

As part of ESG risk monitoring, a group of central banks associated in the NGFS and the ESRB have formulated their recommendations for banks and other financial institutions (insurance companies, investment funds, etc.). These proposals underline the need to integrate ESG risks into risk management and prudential supervision (Kosztowniak, 2023c). These recommendations are valid because work on their development and implementation and their implementation process is still ongoing (Table 3).

NGFS and ESRB regulatory recommendations and proposals in the dimension of climate risk

Table 3

Scope	NGFS recommendations	EU and ESRB regulatory proposals
Climate risk monitoring	Central banks and supervisors are encouraged to develop methodologies for assessing climate risks (including stress tests)	A proposal by the ESRB that the ESAs integrate climate risk into their regular stress tests.
Preparation of new legal acts (taxonomy)	Regulators should develop a climate risk taxonomy to: (a) facilitate climate risk management, (b) assess the differences between "green" and "dirty" assets, (c) mobilize capital flows to "green" investments."	The European Commission is developing a taxonomy, which will be included in several initiatives, to encourage investors to channel their capital towards sustainable development activities.
Promoting strengthened disclosure requirements	Financial and non-financial institutions should consider in their activities recommendations regarding the climate risk, including TCFD (*Task Force on Climate-related Disclosures*) recommendations.	New regulation on climate disclosures and the introduction of low-carbon benchmarks
Integration of climate risk into prudential supervision structures	Central banks should integrate the climate risk into supervision and: (a) promote climate risk awareness among financial institutions, (b) set supervisory expectations, (c) integrate climate risk into prudential supervision.	Integration of climate risk management procedures with risk management policy (including the calibration of possible capital requirements as part of CRR/CRD)

Source: ECB (2019).

7. Limitations and expected future research

Among the limitations of estimating banks' credit exposures taking into account the industry approach (CPRS) are:

- They abstract from systemic consequences, more macroeconomic effects of the transition risk, e.g., the effects of an increase in energy prices, depending on its degree and timing, which may have a negative impact on the competitiveness of the entire economy (higher production costs), inter alia. This aspect may be particularly important, for example, in Poland due to the structure of energy sources. Taking this aspect into account would broaden the range of banks' assets whose valuation may be sensitive to transition risks.
- They also do not consider the impact of transition risk on state debt (the cost of measures to reduce climate risk and the consequences of its materialisation) and the valuation of Treasury securities (EPZ), as well as the limited availability of statistical data in the financial and non-financial sectors considering the impact of climate change.

When assessing the risk generated by the exposures of industries, certain limitations should be noted, e.g., in the Polish banking sector. According to the available data from the published financial statements of the largest emitting companies (*greenhouse gas*, GHG), in Poland most of the loans currently taken out will be repaid in the next 2-3 years, which leaves some freedom for the banking sector in shaping its exposure to these sectors and switching to financing low-emission projects.

In the case of Polish data collected by the NBP under the NB300 banks' reporting program, although the data allow for the selection of a specific entity (according to REGON) or the declared dominant industry or business (according to PKD), high-emission entities may be assigned to industries not related to greenhouse gas emissions, and in high-emission industries there may be low-emission entities[2]. In addition, the number of positions on carbon-intensive sectors in the Polish banking sector varies, although in some banks, including some from the OSII group,[3] it may be higher than the average in the entire sector.

It is worth emphasizing that although the costs incurred for the transition to a low-carbon economy will reduce GDP and global consumption, they can also stimulate the development of new industries and technologies, making the final impact of the green transition on GDP and consumption uncertain.

The expected research should concern the analysis of transition risk shocks and the main transmission channels, perhaps using more detailed micro data, but perhaps also through the prism of theoretical models. Research would be valuable, firstly, in the scope of a wider set of credit portfolios of banks from many countries,

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[2] The NB300 reporting package includes banks' reporting to the NBP, whose total commitment amounts to: ≥ PLN 500,000 for banks in the form of joint-stock companies, state-owned banks, branches of credit institutions, branches of foreign banks and non-affiliated cooperative banks that have obtained the consent of the PFSA to operate independently, and ≥ 100 thousand PLN for other banks, respectively. Statement complementary package NB300, (NB300, 2022).

[3] OSII banks are recognised by the PFSA as other systemically important institutions (*other systemically important institutions*). The list of OSII banks is published on the website: NBP (2023).

e.g., in the form of panel models of transition risks, on the other hand, revealing the differences between the banking sectors of individual countries.

Annex

Summary Statistics, using the observations Q4 2013 – Q2 2023

Table A.1.

Variable	Mean	Median	Minimum	Maximum
CPRR	362.88	367.25	287.14	414.94
Dirty	192.21	195.25	157.88	212.01
Black	8.4387	7.5896	4.5084	15.970
Brown	79.369	82.194	58.877	90.414
Green	170.68	174.07	129.26	204.37
Variable	Std. Dev.	C.V.	Skewness	Ex. kurtosis
CPRR	35.563	0.098002	-0.47263	-0.94217
Dirty	13.267	0.069023	-1.0464	0.36113
Black	3.0440	0.36071	0.97019	0.37596
Brown	8.9961	0.11335	-0.94281	-0.17412
Green	23.558	0.13802	-0.13584	-1.4202
Variable	5% Perc.	95% Perc.	IQ range	Missing obs.
CPRR	295.81	410.71	58.444	0
Dirty	161.51	209.93	13.032	0
Black	4.5780	15.714	3.9223	0
Brown	59.899	89.913	11.622	0
Green	134.31	203.22	47.912	0

Source(s): Own calculations used StataSE 16.

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Workshop "Addressing climate change data needs: the global debate and central banks' contribution"

Hosted by the Central Bank of the Republic of Türkiye with the support of the Irving Fisher Committee on Central Bank Statistics (IFC), the Bank of France and Deutsche Bundesbank İzmir, Türkiye, 6-7 May 2024

Climate risk in the Polish banking sector – analysis of dirty and green industries

Aneta Kosztowniak, NBP, Department od Systemic Risk and Macroprudential Policy

- This presentation should not be reported as representing the views of the National Bank of Poland.
- The views expressed are those of the authors and do not necessarily reflect those of the NBP.

Overview

- ☐ Introduction
- ☐ Climate Policy Relevant Sectors – an empirical approach
- ☐ Result for Poland
- ☐ Conclusion

1. Introduction

- The aim of the study is to estimate credit exposures and their changes in banks' portfolios in terms of sectors important for climate policy, which exposes them to the risk of transformation in Poland in 2013-2023.

- The research concerned the analysis of changes in the structure of the loan portfolio in terms of sectors relevant to climate change (CPRS) broken down by: groups (green, black, brown, and dirty), industries (fossil fuels, utility-electricity, production, manufacturing, transportation, and agriculture), and types of activity divided into sections.

- The CPRS methodology was applied (Battiston *et al.*, 2017-2022), which is used in EiOPA, ECB and EBA reports for EU countries.

1. Climate Policy Relevant Sectors (CPRS)

- **The methodology for determining CPRS**, i.e. industries sensitive to climate change, was developed m.in by S. Battiston and I. Monasterelo (2017-2022) and used in studies by EiOPA (2018), ECB (2019) and EBA (2020).

- CPRS provide a standardised and practical classification of activities (at NACE Rev2 level, 4-digit) on which revenues can have a positive or negative impact in a disorderly low-carbon transition, based on their energy technology (e.g. based on fossil fuels or renewable energy).

- For this reason, the CPRS classification is considered a benchmark for assessing the financial risks associated with climate change and has been used by several international financial institutions to assess investors' exposure to climate transition risks (e.g. ECB, EIOPA).

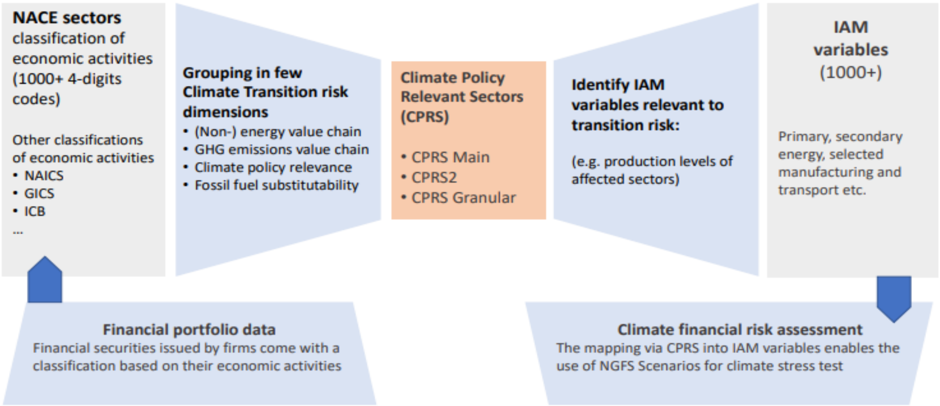
Table 1. List of sectors relevant for climate policy according to the NACE code classification

CPRS sector	NACE codes
1-fossil-fuel	05, 06, 08.92, 09.10, 19, 35.2, 46.71, 47.3, 49.5
2-utility|electricity	35.11, 35.12, 35.13
3- energy-intensive (industry)	07.1, 07.29, 08.9, 08.93, 08.99, 10.2, 10.41, 10.62, 10.81, 10.86, 11.01, 11.02, 11.04, 11.06, 13, 14, 15, 16.29, 17.11, 17.12, 17.24, 20.12, 20.13, 20.14, 20.15, 20.16, 20.17, 20.2, 20.42, 20.53, 20.59, 20.6, 21, 22.1, 23.1, 23.2, 23.3, 23.4, 23.5, 23.7, 23.91, 24.1, 24.2, 24.31, 24.4, 24.51, 24.53, 25.4, 25.7, 25.94, 25.99, 26, 27, 28, 32
4-buildings	23.6, 41.1, 41.2, 43.3, 43.9, 55, 68, 71.1
5-transportation	29, 30, 33.15, 33.16, 33.17, 42.1, 45, 49.1, 49.2, 49.3, 49.4, 50, 51, 52, 53, 77.1, 77.35
6-agriculture	01, 02, 03

Source: Battiston, S., Mandel, A., Monasterolo, I., Schütze, F., & Visentin, G. (2017). A Climate stress-test of the financial system. *Nature Climate Change*, *7*(4), 283–288; https://www.finexus.uzh.ch/en/projects/CPRS.html

2. Climate Policy Relevant Sectors (CPRS)

Fig. 1. Mapping economic activities into IAM variables via Climate Policy Relevant Sectors



NACE sectors classification of economic activities (1000+ 4-digits codes)

Other classifications of economic activities
- NAICS
- GICS
- ICB
...

Grouping in few Climate Transition risk dimensions
- (Non-) energy value chain
- GHG emissions value chain
- Climate policy relevance
- Fossil fuel substitutability

Climate Policy Relevant Sectors (CPRS)
- CPRS Main
- CPRS2
- CPRS Granular

Identify IAM variables relevant to transition risk:

(e.g. production levels of affected sectors)

IAM variables (1000+)

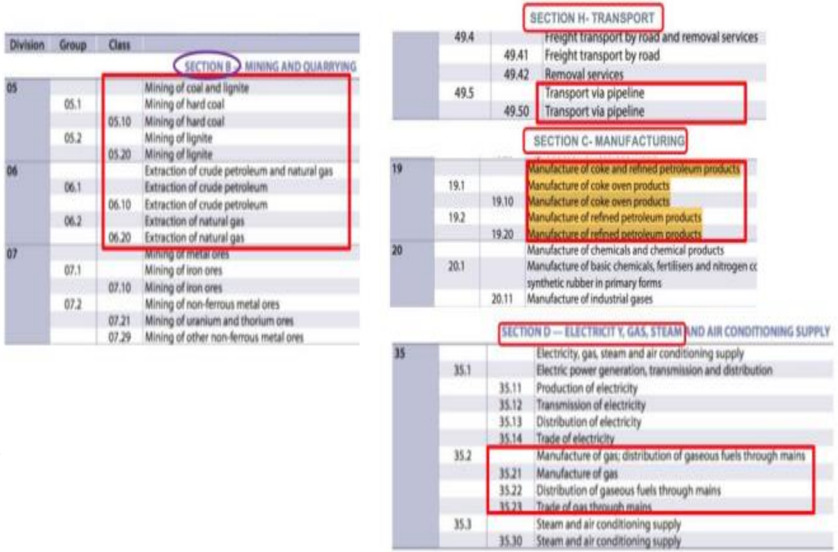
Primary, secondary energy, selected manufacturing and transport etc.

Financial portfolio data
Financial securities issued by firms come with a classification based on their economic activities

Climate financial risk assessment
The mapping via CPRS into IAM variables enables the use of NGFS Scenarios for climate stress test

Source: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4223606.

Fig. 2. Activities related to the NACE 2.



SECTION B – MINING AND QUARRYING

Division	Group	Class	
05			Mining of coal and lignite
	05.1		Mining of hard coal
		05.10	Mining of hard coal
	05.2		Mining of lignite
		05.20	Mining of lignite
06			Extraction of crude petroleum and natural gas
	06.1		Extraction of crude petroleum
		06.10	Extraction of crude petroleum
	06.2		Extraction of natural gas
		06.20	Extraction of natural gas
07			Mining of metal ores
	07.1		Mining of iron ores
		07.10	Mining of iron ores
	07.2		Mining of non-ferrous metal ores
		07.21	Mining of uranium and thorium ores
		07.29	Mining of other non-ferrous metal ores

SECTION H- TRANSPORT

	49.4		Freight transport by road and removal services
		49.41	Freight transport by road
		49.42	Removal services
	49.5		Transport via pipeline
		49.50	Transport via pipeline

SECTION C- MANUFACTURING

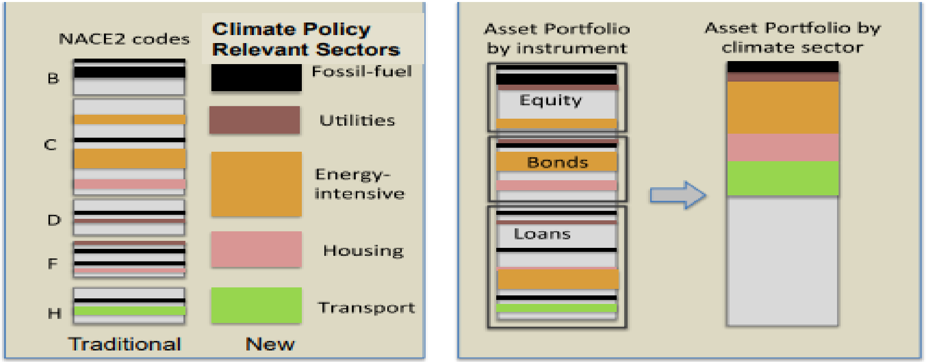
19			Manufacture of coke and refined petroleum products
	19.1		Manufacture of coke oven products
		19.10	Manufacture of coke oven products
	19.2		Manufacture of refined petroleum products
		19.20	Manufacture of refined petroleum products
20			Manufacture of chemicals and chemical products
	20.1		Manufacture of basic chemicals, fertilisers and nitrogen cc synthetic rubber in primary forms
		20.11	Manufacture of industrial gases

SECTION D — ELECTRICIT Y, GAS, STEAM AND AIR CONDITIONING SUPPLY

35			Electricity, gas, steam and air conditioning supply
	35.1		Electric power generation, transmission and distribution
		35.11	Production of electricity
		35.12	Transmission of electricity
		35.13	Distribution of electricity
		35.14	Trade of electricity
	35.2		Manufacture of gas; distribution of gaseous fuels through mains
		35.21	Manufacture of gas
		35.22	Distribution of gaseous fuels through mains
		35.23	Trade of gas through mains
	35.3		Steam and air conditioning supply
		35.30	Steam and air conditioning supply

Source: Eurostat, 2012

Fig. 3. Classification of the financial contracts and securities of an investor's portfolio into CPRS Main.



Source: Battiston et al. (2017)

3. Climate Policy Relevant Sectors (CPRS) – results for the banking sector in Poland

In Poland, in the years 2013-2023, the value of **CPRS exposures** increased by 45%, including:

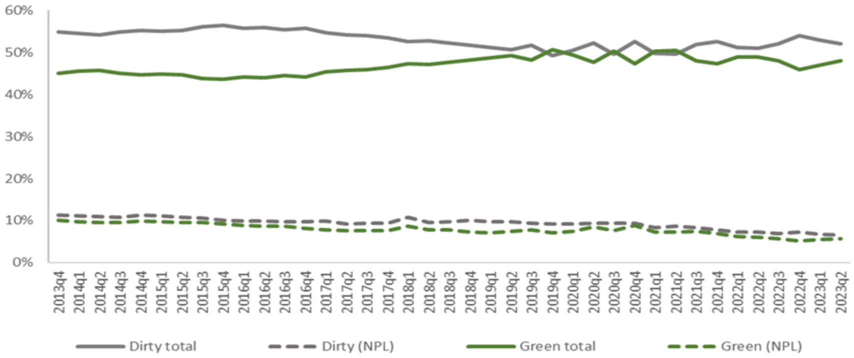
- dirty exposures by 34%,
- black exposures by 69%,
- brown exposures by 30%
- and green exposures by 57%.

On the other hand, the average share of dirty exposures in CPRS exposures was 53% vs. 47% share of green exposures.

Comparing dirty exposures to the exposures of **the entire banking sector**, their share fell from 55% in 2013 to 52% in 2023, and green exposures from 11% to 9%, respectively.

The share of dirty loans (NPLs) in the banking sector exposure fell from 11% to 9%, while the share of green loans (NPLs) fell from 10% to 8% (Fig. 4).

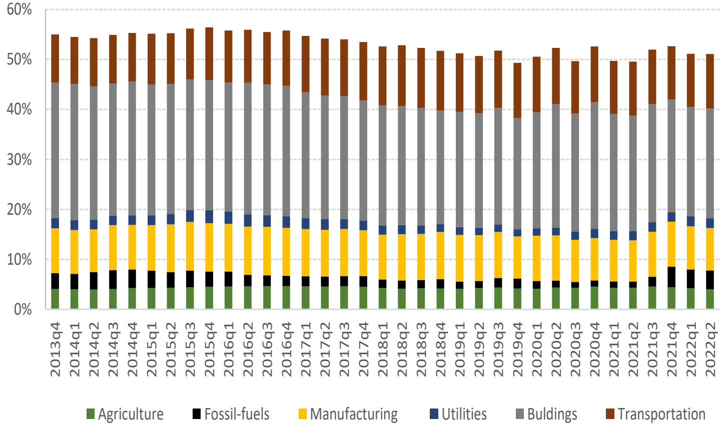
Fig. 4 Share of dirty and green industries in the banking sector exposure (%)



Source: Own study on NBP data.

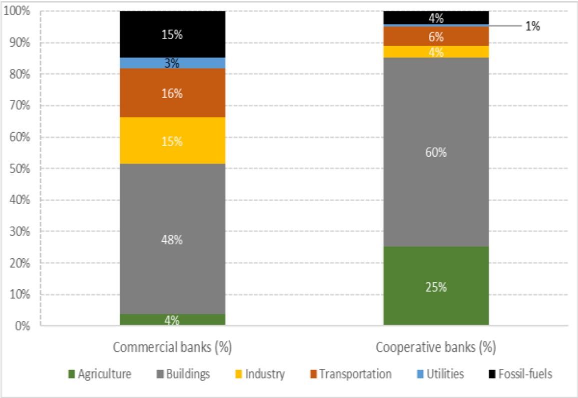
3. Climate Policy Relevant Sectors (CPRS) – results for the banking sector in Poland

Fig. 5 Shares of CPRS groups in the exposure of the banking sector (%)



- **Over 50%** of exposures of the **entire banking sector** are classified as **CPRS groups**.
- The largest share in this exhibition belongs to **the buildings industry (over 20%).**
- Nevertheless, in the analyzed period the share of this industry showed a decrease by 5 pp. (from 27% to 22%), compared to an increase of 1 pp. in the field of transportation (from 10% to 11%) or fossil fuels (from 3% to 4%).

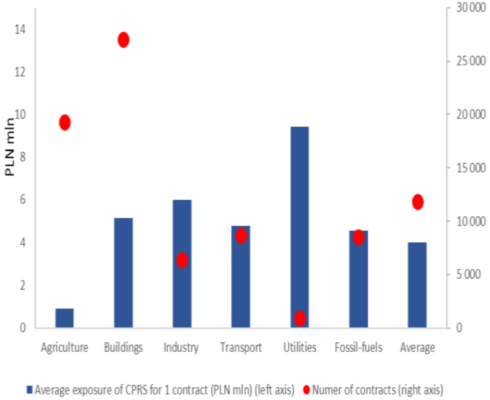
Fig. 6. Shares of individual CPRS groups in commercial and cooperative banks as of Q2 2022 (%)



Source: Own study on NBP data.

- In commercial banks, CPRS shares are more dispersed (diversified) than in cooperative banks.
- However, in commercial banks the share of dirty industries such as fossil-fuels or transportation and industries is higher than in cooperative banks.
- These shares are determined by the financing of enterprises, which is more balanced in commercial banks than in cooperative banks (with a predominance of buildings and agriculture).

Fig. 7 Average exposure by CPRS groups and number of contracts for Q2 2022 (PLN million, number)



- The concentration of bank receivables per CPRS group varies:
- Most contracts concern the buildings group, but their value corresponds to the average per contract.
- A smaller number of contracts, but for high amounts, concern the utilities group.

Conclusion

1. In Poland, in the years 2013-2023, the value of **CPRS exposures** increased by 45%.
2. Over 50% of exposures of the entire banking sector are classified as CPRS groups and nearly half of these exhibitions belong to the group of so-called dirty exposures, including mostly industry, buildings and transportation. Due to the intersectional connection, the these pillars of industries with the highest transformation risk among CPRS.
3. These CPRS groups divided on buildings (43%), transport (21%) and industry (17%) account for the largest share of this exposure, followed by agriculture (8%), fossil fuels (7%) and electricity (4%).
4. Dirty exposures to the exposures of **the entire banking sector**, their share fell from 55% in 2013 to 52% in 2023, and green exposures from 11% to 9%, respectively.
5. Commercial banks have a more diversified loan portfolio in terms of CRPS than cooperative banks.
6. Reassuming, buildings played a key role in shaping the exposure, due to its dominant share in CPRS groups (43%) and in the entire banking sector in Poland (over 20%).

Thank for your attention

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IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

The impact of temperature and precipitation on wheat production in Türkiye[1]

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Central Bank of the Republic of Türkiye

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

THE IMPACT OF TEMPERATURE AND PRECIPITATION ON WHEAT PRODUCTION IN TÜRKİYE

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Abstract

It is now a well-known fact that climate is changing globally at an unprecedented rate and agriculture sector is one of the most vulnerable sector to this change. Considered as a significant threat for food security, climate change and its impact on agricultural practices is one of the hottest topics in the recent economic literature. Climate change poses a significant threat also for the Turkish economy through agricultural production which is crucial with respect to its contribution to employment, exports and national income. With this regard, in this study, the impact of climate change on wheat production is investigated for Türkiye at province-level with unique, up-to-date and comprehensive dataset that is constructed by Central Bank of the Republic of Türkiye (CBRT) under the Early Warning System (EWS) Project. In the analysis, climate change is initially considered in a conventional way via temperature and precipitation measures, later considered with new alternative composite climate indicators. The results obtained from two different alternative climate measures indicate a significant reduction in wheat production in the short, medium and long-term. The impact is found to be increasing over time depending on various climate scenarios. We believe that our understanding regarding climate change-agricultural production relation will improve with the advancements of the data set, and this will support the development of more efficient policy recommendations.

1.1 Introduction

Climate change, defined as long-term changes in temperature and weather patterns, is one of the most important issues of this century. Unfortunately over the last decades, we frequently encounter news about droughts, increasing temperatures, decreasing precipitation as well as occurrence of extreme weather events and their adverse impact on our lives. It is now a well-known fact that climate is changing globally at an unprecedented rate and agriculture is one of the most vulnerable sector to this change. Considered as a significant threat to sustainability of agricultural practices, climate changes' impact on

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agricultural production has become one of the most prominent topic both for researchers and policymakers. Among agricultural products, with it's high nutritional value and good storage properties, wheat has been indispensable for world nutrition at all times and it has become essential for modern food production. Wheat has been a major source of protein for humans and covers 20% of their total protein needs (Shiferaw et al., 2013). As the main nutritional source especially for developing countries, such as Türkiye, wheat is considered as a staple food (Shiferaw et al., 2013).

Wheat which is the most produced, harvested and consumed crop across the world is particularly very sensitive to precipitation and temperature changes. Having a leading role in food security and livelihoods, impact of climate change on wheat production draws significant attention. There is a broad range of literature on the impacts of meteorological variables on wheat production especially in major wheat producing regions in Asia, Europe and Northern Africa. For China You et al. (2009), Zhai et al. (2017) and Zhang et al. (2022); for Pakistan Abbas (2022), Gul et al. (2022) and Chandio et al. (2021); for Somalia Warsame et al. (2021); for India Bhardwaj et al. (2022); for Asia Ozdemir (2021) and for selected low-middle income countries Kumar et al (2021) study the impact of climatic factors on wheat production.

As one of the major wheat producers in the world there are also numerous studies on Türkiye using different methodologies. Based on climate simulation models Ozdogan (2011) finds out that higher CO2 level and temperature and lower precipitation would reduce wheat yields between 5% to 35% in the Northwestern part of the country. Dellal et al. (2011) and Dellal and Unuvar (2019) using economic analysis and biophysical models indicate that climate change is expected to decrease yields in major crops up to 10.1% in 2050. The 2019 study extends the results and finds out that yield reductions will be 2% to 7% in 2020, 4% to 12% in 2050 and 5% to 20% in 2080. Chandio et al. (2020) examine the dynamic relationship between climate variables and crop yield in Türkiye between 1968-2014 using an ARDL model. A more recent study by Chandio et al. (2021) examines impact of climate change on wheat production by employing ARDL Model and Johansen and Juselius (JJC) cointegration test for 1980-2016 period. Estimation results reveal negative impact of CO2 emissions and temperature on wheat production in the short and long run and positive impact of precipitation on wheat production. Eruygur and Ozokcu (2022) using panel data approach analyzes the impact of meteorological variables on wheat yields in Türkiye and concludes that 8% reduction in wheat yields is expected based on the "average" scenario until 2100. Similarly, using panel data approach, Dogan and Karakas (2018) concludes that the impact of temperature and precipitation has significant impacts on agricultural production in the long-term. Their estimation results suggest that a 1% increase in temperature would cause a 0.19% and 0.50% reduction in wheat yields while a 1% increase in precipitation would increase wheat yields by 0.10% and 0.13% in drought-regions and non-drought regions, respectively.

Existing studies about the impact of climate change on wheat production using different data, methodology and time periods reveal contradictory and hence inconclusive results. As it was mentioned in Guiteras (2009) and Zhang et al. (2022), vulnerability of each region or country depends on their own adaptive capacity and unique circumstances. Therefore, country specific and regional analysis are critical in understanding the impact of climate change on agricultural production especially for developing countries in the regions already reached to a certain tolerance level with lower adaptive capacities.

Türkiye being located largely in Mediterranean geographical location where climatic conditions are quite temperate, diverse nature of the landscape and the existence of the mountains parallel to coasts result in significant differences in climatic conditions among its regions. While the coastal areas enjoy milder climates, the inland Anatolian plateau experiences extremes of hot summers and cold winters with limited rainfall (Sensoy et al., 2013). Its favorable climate and geographical conditions, rich soil sources and biological diversity makes Türkiye one of the leading countries in the world in the field of agriculture. Türkiye was ranked as the 12th largest wheat producer in the world (FAOSTAT, 2022). According to 2023 national statistics 22 million tonnes of wheat production constitutes 54.3% of total crop production in Türkiye (TurkStat, 2023). Wheat is the main product in the grain group and is produced almost every province as both spring and winter type. Wheat production is mostly concentrated in Central Anatolia (17%), Southeastern Anatolia (15%) and the Mediterranean (11%) regions (MOAF, 2022). A significant amount of wheat, especially winter wheat, is produced in West Marmara and West Black Sea regions.

Wheat is commonly a cool season crop ideally grown under the temperature between 21°C to 24°C. The crop does not like extreme weather conditions. If the temperature falls below 4°C during germination period, seeds potentially get harmed. If the temperature exceeds 35°C during maturation period, yields are expected to decrease. During the growth stages of wheat, when the grains start to fill out it requires additional sunlight. Temperature is more critical for wheat growth not requiring a lot of precipitation. However, extreme rainfall during late season may slow down the growth of the crop as well as the grain formation in wheat growing regions in the southern parts of the country. Overall, wheat development requires cold and moist weather during cultivation while warm weather and additional sunlight is necessary during harvesting. In general, meteorological conditions during spring, from March through June, is critical for wheat growth.

Regarding Türkiye's different climate conditions of diverse regions in this study, the impact of climate change on wheat production is investigated for Türkiye at province-level using a timely and comprehensive dataset. Initially, the impact of climate change is considered in a conventional manner with province-level temperature and precipitation variables. Then, alternative climate change indicator is constructed as a composite indicator for meteorological variables. The data used in the analysis come from micro-level dataset formed by Central Bank of the Republic of Türkiye (CBRT) under the Early Warning System (EWS) Project. In 2021, within the framework of the Food-EWS Project, data warehouse and analysis module have been established. This warehouse allows the analysis of data on food and agricultural product prices, critical for price stability, in a detailed and timely manner also enables the implementation of necessary precautionary measures. Using the advantages of this comprehensive micro-level dataset, the impact of major meteorological variables on wheat production is investigated by considering the differences in weather and production patterns across wheat growing regions of Türkiye. In addition to the analysis where temperature and precipitation variables are estimated separately, a composite indicator for meteorological variables is constructed and proposed as an alternative climate change variable that can be used as an explanatory variable in the related models.

1.2 Data and Methodology

In recent decades, strengthening sector polices for food security and supporting sustainable agricultural practices and estimating the impact of climate change more precisely has become extremely crucial. As it was mentioned in the previous section, existing studies reveal that the impact of climate change on agricultural production displays regional differences. In light of this information, impact of climate change on Türkiye's wheat production is examined by using up-to-date, comprehensive and regional micro-level dataset. The study utilizes a wide range of micro-level data from the Early Warning System Project of Central Bank of the Republic of Türkiye. As far as to our knowledge, data set used in this study is the most comprehensive among similar studies. Agricultural production and meteorological variables at province-level are of main interest of this study. In addition to production and meteorological data prices are also included as explanatory variables in the models. Time span and frequencies of the data are different. Province-level agricultural production data are annual, the meteorological data are daily and price data are monthly. The analysis covers 2000-2023 period. Details about the dataset is provided in Table 1.

Table 1. Data Sources Used under Early Warning System of CBRT

Data	Time Span	Frequency	Source
Production	1991-2023	Annual	Ministry of Agriculture and Forestry
Meteorological Data (Temperature & Precipitation)	1990-2024	Daily	Turkish State Meteorological Service
Wheat and Barley Prices	1980-2022	Monthly	TURKSTAT (TL/kg)
Agricultural PPI	1991-2024	Monthly	TURKSTAT (Index)
Fertilizer Prices	2000-2024	Monthly	Ministry of Agriculture and Forestry (Index)
Commodity Prices	2000-2024	Daily	International Grains Council (Index)
Climate Scenarios	2030-2050 / 2050-2070 / 2070-2100	Seasonal	IPCC Interactive Atlas (IPCC, Gutiérrez, et al., 2021) / (Bagcaci et al., 2021)

Meteorological variables, namely temperature and precipitation, are considered as the main indicators for climate change. In the baseline model, following existing studies in the literature, monthly average temperature and precipitation across provinces over time are used separately as explanatory variables.

Based on existing related literature the following empirical baseline model is constructed:

$$log(Prod_{i,t}) = \beta_0 + \beta_1 \, log(Prod_{i,t-1}) + \sum_{k=1}^{12} \mu_{ik} \; log(MP_{i,k,t}) + \sum_{k=1}^{12} \rho_{ik} \; log(MT_{i,k,t}) + \sum_{k=1}^{12} \theta_{ik} \; (log(MT_{i,k,t}))^2$$

$$+ \; \alpha_1 \Delta PD_{Wheat,i,t-1} + \alpha_2 \Delta PD_{Barley,i,t-1} + \alpha_3 \Delta P_{Fertilizer,t-1} + \alpha_4 \Delta P_{Commodity,t-1} + \gamma_i + \Omega_t + e_{i,t}$$

(Equation 1)

where $Prod_{i,t}$ refers to wheat production measured in million tons for province i at year t. $MP_{i,k,t}$ denotes mean precipitation measured in millimeters (mm) observed in province i at year t and month k and $MT_{i,k,t}$ is the mean temperature measured in Celsius degrees for province i at year t and month k. In order to capture non-linear relationships between temperature and wheat yield, the simplest non-linear functional form, the squared of the mean temperatures, $(log(MT_{i,k,t}))^2$ are added as explanatory variables into the baseline model. $\Delta PD_{Wheat,i}$ refers to deviation of annual change of crop price of wheat at province level from agricultural producer prices for representing domestic price condition. Similarly, $\Delta PD_{Barley,i}$ refers to deviation of annual change of crop price of barley, known to be a substitute for wheat, at province level from agricultural producer prices for Türkiye. $\Delta P_{Fertilizer}$ represents the annual change of fertilizer price which is calculated as a weighted average of different types of fertilizers used in wheat production. The corresponding weights are determined by expert judgement based on the fertilizer types used during the growth stages of wheat. $\Delta P_{Commodity}$ denotes the annual change of commodity price proxied by the International Grains Council's (IGC) Grains and Oilseeds Index (GOI). γ_i , Ω_t and $e_{i,t}$ denote province fixed effects, year fixed effects and error term, respectively.

Estimation results obtained from the baseline model, provided in the Appendix, suggest that precipitation and temperature have statistically significant impact on wheat production that are consistent with the information obtained from relevant reports and regional field experts (Table 10). The baseline model estimation results regarding precipitation suggest that positive impact of spring precipitation and negative impact of precipitation during October and November that coincide with the views obtained from different reports and expert interviews in which reveal that spring precipitation as well as precipitation during October and November are critical periods for wheat production in Türkiye.

The baseline estimation results suggest that temperature increase during winter has a positive impact on wheat production while spring and summer heats negatively impact production. The baseline estimation results reveal existence of non-linear relationships between temperature and wheat yields, controlling for precipitation, prices together with the province and time fixed effects.

Using general to specific modelling strategy based on the Akaike Information Criteria, reduced form baseline model given in Equation 2 is obtained for wheat production in Türkiye:

$$
\begin{aligned}
log(Prod_{i,t}) = \beta_0 + \beta_1 \, log\left(Prod_{i,t-1}\right) \\
&+ \beta_2 \, log\left(MP_{March_{i,t}}\right) + \beta_3 \, log\left(MP_{April_{i,t}}\right) + \beta_4 \, log\left(MP_{May_{i,t}}\right) + \beta_5 \, log\left(MP_{June_{i,t}}\right) \\
&+ \beta_6 \, log\left(MP_{October_{i,t}}\right) + \beta_7 \, log\left(MP_{November_{i,t}}\right) + \beta_8 \, log\left(MT_{February_{i,t}}\right) + \beta_9 \, log\left(MT_{March_{i,t}}\right) \\
&+ \beta_{10} \, log\left(MT_{April_{i,t}}\right) + \beta_{11} \, log\left(MT_{May_{i,t}}\right) + \beta_{12} \, log\left(MT_{June_{i,t}}\right) + \beta_{13} \, log\left(MT_{July_{i,t}}\right) \\
&+ \beta_{14} \left(log\left(MT_{April_{i,t}}\right)\right)^2 + \alpha_1 \Delta PD_{\substack{Wheat \\ ,i,t-1}} + \alpha_2 \Delta PD_{\substack{Barley \\ ,i,t-1}} + \alpha_3 \Delta P_{Fertilizer,t-1} + \alpha_4 \Delta P_{Commodity,t-1} + \gamma_i \\
&+ \Omega_t + e_{i,t}
\end{aligned}
$$

(Equation 2)

Our reduced form baseline model, the impacts of precipitation from March to June as well as October to November together with the temperature change starting from winter months to July were considered as critical months for wheat production. In addition, squared term for the mean temperature of April captures the non-linear impact of temperature on yield in the reduced form model.

Türkiye has a diverse climate across its different regions due to its topography and the literature suggest that the impact of changes in climate related variables on crop production are geographically uneven (Parry et al. 1992, Fischer et al. 2002 and Butt et al. 2006). In order to consider these facts, the analysis is more scrutinized by selecting the regions where the wheat is majorly grown and by considering the climate in that region. In this regard, we estimate the reduced form baseline model in Equation 2 by adding regional dummies for wheat growing regions:

$$
\begin{aligned}
log(Prod_{i,t}) = \beta_0 + \beta_1 \, log\left(Prod_{i,t-1}\right) \\
&+ \beta_2 \, log\left(MP_{March_{i,t}}\right) + \beta_3 \, log\left(MP_{April_{i,t}}\right) + \beta_4 \, log\left(MP_{May_{i,t}}\right) + \beta_5 \, log\left(MP_{June_{i,t}}\right) \\
&+ \beta_6 \, log\left(MP_{October_{i,t}}\right) + \beta_7 \, log\left(MP_{November_{i,t}}\right) + \beta_8 \, log\left(MT_{February_{i,t}}\right) + \beta_9 \, log\left(MT_{March_{i,t}}\right) \\
&+ \beta_{10} \, log\left(MT_{April_{i,t}}\right) + \beta_{11} \, log\left(MT_{May_{i,t}}\right) + \beta_{12} \, log\left(MT_{June_{i,t}}\right) + \beta_{13} \, log\left(MT_{July_{i,t}}\right) \\
&+ \beta_{14} \left(log\left(MT_{April_{i,t}}\right)\right)^2 + \alpha_1 \Delta PD_{\substack{Wheat \\ ,i,t-1}} + \alpha_2 \Delta PD_{\substack{Barley \\ ,i,t-1}} + \alpha_3 \Delta P_{Fertilizer,t-1} + \alpha_4 \Delta P_{Commodity,t-1} \\
&+ \text{¥}_1 \, log\left(MP_{March_{i,t}}\right) * D_r \\
&+ \text{¥}_2 log\left(MP_{April_{i,t}}\right) * D_r + \text{¥}_3 \, log\left(MP_{May_{i,t}}\right) * D_r + \text{¥}_4 \, log\left(MP_{June_{i,t}}\right) * + \text{¥}_5 \, log\left(MP_{October_{i,t}}\right) * D_r \\
&+ \text{¥}_6 \, log\left(MP_{November_{i,t}}\right) * D_{region} + \text{¥}_7 \, log\left(MT_{February_{i,t}}\right) * D_r + \text{¥}_8 \, log\left(MT_{March_{i,t}}\right) * D_r \\
&+ \text{¥}_9 \, log\left(MT_{April_{i,t}}\right) * D_r + \text{¥}_{10} \, log\left(MT_{May_{i,t}}\right) * D_r + \text{¥}_{11} \, log\left(MT_{June_{i,t}}\right) * D_r + \text{¥}_{12} \, log\left(MT_{July_{i,t}}\right) * D_r \\
&+ \gamma_i + \Omega_t + e_{i,t}
\end{aligned}
$$

(Equation 3)

where D_r is a dummy variable for seven wheat growing regions of Türkiye.[3] An additional model is estimated for “dry regions” in which West Marmara and Black Sea regions are left out due to their different climatic conditions. In this alternative version of the estimation, dummy variables for wheat growing regions (D_r) are replaced with dummies only for wheat growing regions with drier conditions (D_{dr}). The estimation results for these models are provided in Table 4.

As an alternative, instead of inclusion of monthly temperature and precipitation data separately as independent variables, using the reduced form baseline model estimation results together with the expert judgement, two composite climate change indictors are constructed and used as explanatory variables in the empirical model. To compile the individual impacts of a large set of variables in a single index composite indicators (CIs) are widely used as a policy tool in climate literature (Saltelli et al.,2006) where the advantages and disadvantages of using it is thoroughly discussed in OECD (2008). We construct an alternative proxy for climate conditions as a composite indicator of meteorological variables, namely temperature and precipitation $\left(PCP_{i,t}\right.$ and $\left.PCT_{i,t}\right)$. A CI is constructed to evaluate the overall performance of the model with multiple criteria formed in equation 2. Similar to Equation 2, the CI is used as an independent variable in the empirical model for wheat production:

$$\begin{aligned} log(Prod_{i,t}) = {} & \beta_0 + \beta_1\, log\left(Prod_{i,t-1}\right) \\ & + \beta_2\, log\left(PCP_{i,t}\right) + \beta_3\, log\left(PCT_{i,t}\right) + \alpha_1 \Delta PD_{\substack{Wheat\\,i,t-1}} + \alpha_2 \Delta PD_{\substack{Barley\\,i,t-1}} + \alpha_3 \Delta P_{Fertilizer,t-1} \\ & + \alpha_4 \Delta P_{Commodity,t-1} + \gamma_i + \Omega_t + e_{i,t} \end{aligned}$$

(Equation 4)

Constructed CIs $\left(PCP_{i,t}\right.$ and $\left.PCT_{i,t}\right)$ are based on Principal Component Analysis (PCA). A PCA is a method that is commonly used for large data sets, by transforming a large set of variables (in our case meteorological variables) into a compact one (climate indicators -$PCP_{i,t}$ and $PCT_{i,t}$) without losing much information (OECD, 2008).

1.3 Model Estimation Results

The estimation results for the reduced form baseline model of Equation 2 is presented in Table 2 which are in line with the field information gathered from the Ministry of Agriculture and Forestry as well as the literature. Estimation results in Table 2 reveal that precipitation during stem extension period, commonly March to May, positively impacts wheat production whereas precipitation during harvesting period, that is to say June, has negative impact. The observed impact of precipitation is limited possibly

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[3] Regions are selected at NUTS1 level. Wheat is mainly cultivated in the Aegean, West Anatolia, Mediterranean, Central Anatolia, Southeast Anatolia, West Marmara and West Black Sea regions of Türkiye.

due to irrigation systems in the wheat growing regions, yet, the impact of temperature is observed more significantly. The impact of temperature on production is predominant. Higher mean temperature from March, May and June is expected to decrease wheat production. Especially, temperature increases during harvesting period (spring), negatively affected the production of wheat. Estimated "β" coefficients of Equation 2 (sum of the coefficients $log(MT_{May})$ to $log(MT_{June})$) implies a 1% increase in mean temperature during May to June decreases wheat production by 1.7% (Table 2 (1)). Moreover, the squared term for mean temperature in April indicates that while temperature increase up to a certain level is beneficial for wheat growth, it starts harming the production after a threshold. The results are in line with the field information as well as the literature. According to Table 2, while precipitation during stem extension in spring positively impacts wheat production, additional precipitation during harvesting, June, negatively impacts production.

In addition, our regression coefficient estimates of the reduced form baseline model behave similarly when we add dummies for wheat growing regions (Equation 3). The estimation results of Equation 3 are presented in Table 2 (2) and (3). The restricted sample results suggest that the positive impact of increased precipitation is significant in March and the negative impact is observed earlier in the year. Moreover, when we restrict the sample to only dry regions excluding West Marmara and West Black Sea, the more restricted sample supports the similar results (Table 2 (3)).

Table 2. Model Estimation Results[4][5]

Variables	(1)	(2)	(3)
$log(Prod)$	0.580***	0.557***	0.581***
	(0.0221)	(0.0228)	(0.0225)
$log(MP_{March})$	0.0514***	0.102***	0.0305
	(0.0151)	(0.0337)	(0.0227)
$log(MP_{April})$	0.00447	-0.0733***	-0.0235
	(0.0131)	(0.0272)	(0.0177)
$log(MP_{May})$	0.00920	0.0433*	0.0355**
	(0.0114)	(0.0257)	(0.0170)
$log(MP_{June})$	-0.0309***	0.0212	0.0132
	(0.00891)	(0.0224)	(0.0165)
$log(MP_{October})$	-0.0118	0.0112	0.00671
	(0.00848)	(0.0183)	(0.0136)
$log(MP_{November})$	-0.0180*	-0.0113	-0.00149
	(0.00947)	(0.0160)	(0.0122)
$log(MT_{February})$	0.0506***	0.00963	0.0301
	(0.0174)	(0.0252)	(0.0211)
$log(MT_{March})$	-0.102***	-0.114**	-0.100**
	(0.0394)	(0.0476)	(0.0460)
$log(MT_{April})$	3.596***	3.396***	3.143***
	(0.861)	(0.877)	(0.879)
$log(MT_{May})$	-0.960***	-0.835***	-0.969***
	(0.215)	(0.279)	(0.238)
$log(MT_{June})$	-0.751**	-0.891**	-0.432
	(0.294)	(0.406)	(0.341)

---

[4] Reduced form baseline model is selected based on general to specific AKAIKE information criteria.

[5] Additional models using various control variables were tested for robustness showing similar results with the reduced form baseline model.

$log(MT_{July})$	-0.200	-0.376	0.0560
	(0.323)	(0.458)	(0.362)
$(log(MT_{April}))^{\wedge 2}$	-0.805***	-0.753***	-0.687***
	(0.184)	(0.191)	(0.190)
ΔPD_{Wheat}	0.00809	0.00869*	0.00868*
	(0.00506)	(0.00511)	(0.00505)
ΔPD_{Barley}	0.00350	0.00353*	0.00298
	(0.00214)	(0.00213)	(0.00212)
$\Delta P_{Commodity}$	0.991	0.770	1.101
	(0.758)	(0.756)	(0.761)
$\Delta P_{Fertilizer}$	-0.484	-0.405	-0.462
	(0.311)	(0.310)	(0.310)
$log(MP_{March})*D_r$		-0.0590	
		(0.0368)	
$log(MP_{April})*D_r$		0.0872***	
		(0.0286)	
$log(MP_{May})*D_r$		-0.0421	
		(0.0274)	
$log(MP_{June})*D_r$		-0.0602**	
		(0.0238)	
$log(MP_{October})*D_r$		-0.0274	
		(0.0188)	
$log(MP_{November})*D_r$		-0.00910	
		(0.0169)	
$log(MT_{February})*D_r$		0.0642**	
		(0.0293)	
$log(MT_{March})*D_r$		0.0358	
		(0.0482)	
$log(MT_{April})*D_r$		-0.0294	
		(0.143)	
$log(MT_{May})*D_r$		-0.145	
		(0.267)	
$log(MT_{June})*D_r$		0.397	
		(0.398)	
$log(MT_{July})*D_r$		0.154	
		(0.449)	
$log(MP_{March})*D_{dr}$			0.0224
			(0.0297)
$log(MP_{April})*D_{dr}$			0.0474**
			(0.0232)
$log(MP_{May})*D_{dr}$			-0.0512**
			(0.0217)
$log(MP_{June})*D_{dr}$			-0.0522***
			(0.0192)
$log(MP_{October})*D_{dr}$			-0.0211
			(0.0148)
$log(MP_{November})*D_{dr}$			-0.0287*
			(0.0148)
$log(MT_{February})*D_{dr}$			0.0649**
			(0.0282)
$log(MT_{March})*D_{dr}$			0.0209
			(0.0468)
$log(MT_{April})*D_{dr}$			-0.220
			(0.142)
$log(MT_{May})*D_{dr}$			-0.157
			(0.249)
$log(MT_{June})*D_{dr}$			-0.284
			(0.363)
$log(MT_{July})*D_{dr}$			-0.464
			(0.421)
Constant	8.406***	8.101***	10.25***

	(1.580)	(1.671)	(1.910)
Observations	1,330	1,330	1,330
Number of Province	76	76	76
Year FE & City FE	YES	YES	YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Alternatively, a composite indicator is constructed to evaluate the overall performance of the model formed in Equation 2. Constructing the CI, we use statistically significant variables in general to specific identification as well as field information gathered from related local institutions. Accordingly, the findings of PCA are in line with the findings of Table 2. In both estimations, the impact of precipitation tends to be positive while the impact of temperature is negative in wheat production. Moreover, PCA confirms the impact of temperature being larger compared to precipitation.

Table 3. Principal Component Analysis

Variables	(a)	(b)
log(Prod)	0.584***	0.586***
	(0.0217)	(0.0221)
PCP	0.0345***	0.0380***
	(0.00845)	(0.00991)
PCT	-0.0692***	-0.106***
	(0.00837)	(0.0150)
ΔPD_{Wheat}	0.00903***	0.00929*
	(0.00348)	(0.00513)
ΔPD_{Barley}	0.00462**	0.00327
	(0.00219)	(0.00218)
$\Delta P_{Commodity}$	-0.0188	1.510***
	(0.0573)	(0.497)
$\Delta P_{Fertilizer}$	-0.0381	-0.693***
	(0.0238)	(0.240)
Constant	4.953***	6.042***
	(0.258)	(0.366)
Observations	1,330	1,330
R-squared	0.416	
Number of Province	76	76
Year FE & Province FE		YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The estimation results suggest that weather conditions in spring significantly impact wheat production in Türkiye. Accordingly, an increase in mean temperature during spring causes a decline in wheat production. While precipitation in spring is highly crucial, continuous precipitation during summer potentially slows down crop development, delaying the maturity of wheat.

In Türkiye, wheat is grown in multiple regions with a wide range of climatic conditions. As the results of Equation 3 suggest, the impact of precipitation and temperature on wheat production varies when we add regional interaction terms. Therefore, we further extend our analysis at NUTS 1 level highlighting regional differences across different parts of the country. Table 4 provides separate regression outputs constraining the sample to only wheat producing regions. Each estimation result under Table 4 are the estimations of Equation 2 for different regions. It is estimated that a 1% change in mean temperature during April and May decrease wheat production in major wheat growing regions, namely, Central Anatolia, Mediterranean, Southeast Anatolia, West Marmara and West Black Sea by 1.4% (Table 4 (8)). When we restrict the sample to dry regions, the impact remains to be similar (Table 4 (6)). Among other regions, Mediterranean and Southeast Anatolia, accounting 33.5% of total wheat production[6], is found to be more sensitive to temperature increase (Table 4 (5)). It is important to note that the impact of temperature increase is expected earlier in these hotter regions in the south.

Similar to our initial methodology, principal component analysis is conducted for wheat growing regions. The findings are in line with the primary results supporting the negative impact of temperature increase on wheat production. Regardless of the regional restriction, principal component coefficients are found to be negative and significant (Table 5).

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[6] Agricultural Products Markets Report: July 2022. Ministry of Agriculture and Forestry.

Table 4. Regional Model Estimation Results

Variables	(1) Reduced form baseline model	(4) Aegean, West and Central Anatolia	(5) Mediterranean and Southeast Anatolia	(6) **Dry regions**	(7) West Marmara and Black Sea	(8) **All wheat growing regions**
$log(Prod)$	0.580***	0.448***	0.313***	0.311***	0.702***	0.403***
	(0.0221)	(0.0504)	(0.0538)	(0.0367)	(0.0433)	(0.0289)
$log(MP_{March})$	0.0514***	0.0280	0.00952	0.0319*	0.00571	0.0321**
	(0.0151)	(0.0236)	(0.0336)	(0.0185)	(0.0226)	(0.0140)
$log(MP_{April})$	0.00447	0.0715***	0.0517*	0.0491***	-0.0333*	0.0162
	(0.0131)	(0.0195)	(0.0291)	(0.0166)	(0.0187)	(0.0121)
$log(MP_{May})$	0.00920	-0.0252	-0.00743	-0.0180	0.0208	0.00358
	(0.0114)	(0.0181)	(0.0230)	(0.0144)	(0.0164)	(0.0106)
$log(MP_{June})$	-0.0309***	-0.0315**	-0.0451***	-0.0381***	-0.00979	-0.0401***
	(0.00891)	(0.0157)	(0.0145)	(0.00925)	(0.0182)	(0.00801)
$log(MP_{October})$	-0.0118	0.00820	-0.0236	-0.00727	0.00239	-0.0150*
	(0.00848)	(0.0106)	(0.0163)	(0.00916)	(0.0139)	(0.00781)
$log(MP_{November})$	-0.0180*	-0.0364***	0.00806	-0.00560	0.0155	-0.00621
	(0.00947)	(0.0141)	(0.0211)	(0.0113)	(0.0128)	(0.00903)
$log(MT_{February})$	0.0506***	0.0488**	0.0867	0.0591***	0.0236	0.0509***
	(0.0174)	(0.0211)	(0.0533)	(0.0225)	(0.0267)	(0.0180)
$log(MT_{March})$	-0.102***	0.0327	-0.153	-0.0275	-0.0974	-0.0561
	(0.0394)	(0.0474)	(0.152)	(0.0468)	(0.0972)	(0.0403)
$log(MT_{April})$	3.596***	-1.696	10.64***	5.384***	0.0177	4.688***
	(0.861)	(1.382)	(2.837)	(1.083)	(1.682)	(0.925)
$log(MT_{May})$	-0.960***	-1.381***	-0.435	-0.818***	-1.712***	-0.953***
	(0.215)	(0.315)	(0.508)	(0.273)	(0.314)	(0.213)
$log(MT_{June})$	-0.751**	-0.110	-0.421	-0.00598	1.079**	-0.198
	(0.294)	(0.394)	(0.857)	(0.386)	(0.450)	(0.293)
$log(MT_{July})$	-0.200	-0.630	1.661	-0.436	-0.333	-0.304
	(0.323)	(0.445)	(1.020)	(0.426)	(0.476)	(0.314)
$(log(MT_{April}))$^2	-0.805***	0.368	-2.360***	-1.250***	-0.0133	-1.064***
	(0.184)	(0.306)	(0.552)	(0.228)	(0.355)	(0.195)
ΔPD_{Wheat}	0.00809	-0.00830	0.0153	0.00459	0.00175	0.0104
	(0.00506)	(0.0105)	(0.0163)	(0.00982)	(0.00858)	(0.00658)
ΔPD_{Barley}	0.00350	-0.000376	0.00349	0.00818	-6.34e-07	0.00266
	(0.00214)	(0.00727)	(0.0102)	(0.00609)	(0.00156)	(0.00190)
$\Delta P_{Commodity}$	0.991	1.477	3.380*	2.401**	0.657	1.436*
	(0.758)	(1.264)	(1.854)	(0.980)	(1.111)	(0.737)
$\Delta P_{Fertilizer}$	-0.484	-0.308	-0.946	-0.557	-0.731*	-0.564*

	(0.311)	(0.494)	(0.775)	(0.400)	(0.435)	(0.302)
Constant	8.406***	15.13***	-4.182	8.124***	6.992***	8.219***
	(1.580)	(2.163)	(4.547)	(2.003)	(2.509)	(1.594)
Observations	1,330	342	327	669	312	981
Number of Province	76	19	17	36	15	51
Year FE & Province FE	YES	YES	YES	YES	YES	YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5. Regional Principal Component Indicators

Variables	(b) Reduced form baseline model	(c) Aegean, West and Central Anatolia	(d) Mediterranean and Southeast Anatolia	(e) **Dry regions**	(f) West Marmara and Black Sea	(g) **All wheat growing regions**
log(Prod)	0.586***	0.426***	0.314***	0.290***	0.694***	0.410***
	(0.0221)	(0.0510)	(0.0555)	(0.0382)	(0.0418)	(0.0296)
PCP	0.0380***	0.00847	0.0428*	0.0291**	0.00772	0.0217**
	(0.00991)	(0.0155)	(0.0257)	(0.0135)	(0.0140)	(0.00977)
PCT	-0.106***	-0.118***	-0.0803**	-0.0794***	-0.116***	-0.100***
	(0.0150)	(0.0257)	(0.0333)	(0.0206)	(0.0188)	(0.0149)
ΔPD_{Wheat}	0.00929*	-0.000027	0.0171	0.0122	-0.000684	0.0111
	(0.00513)	(0.0106)	(0.0176)	(0.0104)	(0.00851)	(0.00676)
ΔPD_{Barley}	0.00327	-0.00139	0.00224	0.00494	0.000350	0.00274
	(0.00218)	(0.00736)	(0.0110)	(0.00647)	(0.00155)	(0.00198)
$\Delta P_{Commodity}$	1.510***	1.522**	-0.966	-0.144	1.886***	0.728
	(0.497)	(0.714)	(0.960)	(0.622)	(0.608)	(0.488)
$\Delta P_{Fertilizer}$	-0.693***	-0.582*	0.650	0.218	-1.190***	-0.355
	(0.240)	(0.344)	(0.471)	(0.301)	(0.288)	(0.234)
Constant	6.042***	8.003***	8.584***	9.290***	5.019***	8.167***
	(0.366)	(0.675)	(0.872)	(0.569)	(0.609)	(0.447)
Observations	1,330	342	327	669	312	981
Number of Province	76	19	17	36	15	51
Year FE & Province FE	YES	YES	YES	YES	YES	YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

1.4 Climate Scenarios

In climate analysis, using climate scenarios is a common tool to make predictions. “A climate scenario is a plausible representation of future climate that has been constructed for explicit use in investigating the potential impacts of anthropogenic climate change” (IPCC, 2001). Regional assessments are crucial in climate analysis as the impact of climate change varies across different regions in the world. Improvements in data and modelling has revealed that adverse impacts of climate change are more substantial in some regions especially in lower latitude countries (Parry et al., 2004). Türkiye, being located in the Mediterranean basin, an arid to semi-arid region, is expected to be affected by the negative consequences of climate change significantly (IPCC, 2007).

Climate scenarios released by International Panel on Climate Change (IPCC) utilizing Global Circulation Models (GCMs) are widely accepted in climate literature. With the advancement of data, the regional performance of GCMs has improved significantly especially in simulating temperature and precipitation changes. The influential 2021 IPCC Report provides an Interactive Atlas offering regional information on projected changes in climate related variables, mainly mean temperature and precipitation change. The Interactive Atlas have advanced the understanding of regional climate variability through providing different climate related variables over time and across regions. The Atlas provides projections on the Mediterranean region, yet, the predicted temperature and precipitation change at province level is not available based on publicly accessible data of the IPCC.

A novel study by Bagcaci et al. (2021) extends the projections of the IPCC specifically for Türkiye using the same methodology as the Interactive Atlas. In their study, Bagcaci et al. (2021) consider the 2021 IPCC Report with baseline years 1995 to 2014 and estimate mean temperature and total precipitation over the short (2030–2050), medium (2050–2070) and long-term (2070–2100) across different regions of the country. Their predictions also distinguish between two major IPCC climate scenarios: high emissions scenario (SSP5-8.5) and low emissions scenario (SSP2-4.5). Their study is crucial for our analysis as it provides regional projections for each season of the year over a time span in line with the existing literature.

According to the estimations of Bagcaci et al. (2021), mean temperature projections are all positive and statistically significant under both high emissions scenario (HES) and low emissions scenario (LES) over the short, medium and long run. Southeastern and Eastern Anatolia, main wheat growing regions, are the most vulnerable regions to temperature changes under HES and LES (Table 7). Spring warmings are also estimated to be effective in major wheat growing regions with their impact reaching 1.1°C to 4°C depending on the region and time span. According to HES and LES temperature increase during summer is highly significant reaching a record high up to 6.5^0C under HES across many regions.

This increased temperature is alarming by itself, yet, it can cause additional drying in the region through evapotranspiration even if precipitation changes are not significant during the same period. Unlike temperature, estimation results for precipitation suggest that not all seasonal precipitation changes over time are statistically significant.[7] The most prominent precipitation reduction is expected in summer under LES and in autumn under HES over the long-term across all regions. In particular, spring precipitation changes are significant across most of the regions under HES. Under LES, a major reduction in precipitation is expected in Central Anatolia and Mediterranean in the short and medium term under LES (Table 6). In Southeastern Anatolia precipitation change is not significant under both scenarios in the short and medium term (Table 6). However, in the long-term, spring precipitation is significant under HES.

Overall, in the regions where wheat is mostly grown, a notable temperature increase is expected with the impact being higher under high emissions scenario. Especially, spring anomalies are to be expected in Southeast Anatolia, Mediterranean and Central Anatolia regions where drying levels are also higher. The estimations for mean temperature and precipitation change are in line with the literature confirming southern parts of the country being most vulnerable to climate change.

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[7] In Table 6, statistically significant value changes at the $p = 0.05$ level are marked in bold charachters.

Table 6. Estimated Precipitation Change for High Emissions Scenario (Low Emissions Scenario) (%)

		Marmara	**Black Sea**	**Eastern Anatolia**	**Aegean**	**Central Anatolia**	**Mediterranean**	**Southeastern Anatolia**	**Average**
2030-2050	**Spring**	0.4 (-3)	2.8 (2.1)	0.5 (-0.9)	-1.7 (-6.1)	-3.5 (**-6.2**)	-6.2 (**-10.6**)	-3.8 (-0.4)	-1.6 (-3.6)
	Summer	**-14.2** (-11.4)	**-10 (-12.4)**	-4.9 (**-10.5**)	-14.3 (-11.9)	-5.4 (-8.8)	-3.9 (-8.8)	5 (1)	-6.8 (-9)
	Autumn	-7.6 (-4.6)	-7.5 (**-9.5**)	-7.3 (-5.5)	-9.4 (-5.1)	-8.6 (-6.3)	**-11.6** (-2.5)	-0.9 (-2.4)	-7.6 (-5.1)
	Winter	**9.5** (1.3)	4.3 (1)	2.2 (-1)	4.8 (-0.5)	5.2 (-1)	1.6 (-3.6)	-3.6 (-3.3)	3.4 (-1)
2050-2070	**Spring**	2.5 (**-7.6**)	**4.2** (2.5)	4.6 (-1)	-0.5 (**-10.9**)	-2.3 (**-6.4**)	-5.8 (**-12.8**)	4 (-5.6)	1 (-6)
	Summer	**-30.7 (-22.3)**	**-20 (-10.6)**	-5.6 (**-15.8**)	**-27.2 (-22.3)**	-9.2 (-8.7)	-10.5 (-11.6)	11.3 (-8.1)	-13 (-14.2)
	Autumn	**-11.5** (-7)	**-9.1** (-4)	**-10.8** (1.9)	**-16.8** (-6.4)	**-10.7** (-6.6)	**-10.6** (-6.2)	-1.1 (8.4)	-10.1 (-2.8)
	Winter	1.4 (5.7)	2.8 (**7.4**)	0.3 (3.8)	**-6.8** (-1.2)	-2.7 (2.5)	**-8.2** (-4.2)	-8.8 (-3)	-3.1 (1.6)
2070-2100	**Spring**	**-13.3** (-0.5)	0.6 (**8.3**)	**-6** (2.4)	**-18** (-1.5)	**-11.7 (1.1)**	**-17.5** (-4.7)	**-13.9** (-5)	-11.4 (0)
	Summer	**-37.3 (-31.2)**	**-30.9 (-20.4)**	**-13.7 (-20.3)**	**-30.6 (-33.7)**	-9.4 (**-22.0**)	-9.3 (**-29.1**)	21.1 (-9)	-15.7 (-23.7)
	Autumn	**-27.2** (-7.1)	**-17.6 (-8.3)**	**-18.3** (-7.4)	**-29.6 (-12.3)**	**-25.4 (-16.4)**	**-25.5 (-17.3)**	**-18.3** (-3.8)	-23.1 (-10.4)
	Winter	5.8 (6.4)	**9.3 (8.5)**	4.9 (5.6)	**-9** (-0.7)	0.4 (2.3)	**-12.5** (-5.2)	-5.6 (0.6)	-1 (2.5)

Source: Bagcaci et. al. (2021)

Table 7. Estimated Temperature Change for High Emissions Scenario (Low Emissions Scenario) (ºC)

		Marmara	Black Sea	Eastern Anatolia	Aegean	Central Anatolia	Mediterranean	Southeastern Anatolia	Average
2030-2050	**Spring**	1.1 (0.9)	1.1 (0.8)	1.2 (1.0)	1.1 80.9)	1.1 (0.9)	1.2 (1.0)	1.2 (1.0)	1.1 (0.9)
	Summer	1.9 (1.6)	1.7 (1.5)	1.9 (1.7)	2 (1.7)	2 (1.7)	2 (1.7)	2 (1.7)	1.9 (1.7)
	Autumn	1.4 (1.1)	1.5 (1.2)	2 (1.6)	1.5 (1.2)	1.8 (1.4)	1.7 (1.4)	2 (1.6)	1.7 (1.4)
	Winter	0.8 (0.7)	0.8 (0.8)	1.3 (1.3)	0.8 (0.7)	0.9 (0.9)	0.9 (0.8)	1.2 (1.1)	1 (0.9)
2050-2070	**Spring**	2.1 (1.2)	2 (1.1)	2.6 (1.5)	2.2 (1.3)	2.3 (1.3)	2.5 (1.5)	2.7 (1.6)	2.3 (1.4)
	Summer	3 (2)	2.8 (1.9)	3.5 (2.2)	3.4 (2.1)	3.6 (2.2)	3.6 (2.3)	3.5 (2.3)	3.3 (2.1)
	Autumn	2.5 (1.5)	2.6 (1.5)	3.5 (2.1)	2.7 (1.6)	3.2 (1.8)	3.1 (1.9)	3.6 (2.2)	3 (1.8)
	Winter	1.7 (1)	1.9 (1)	2.9 (1.6)	1.7 (1)	2.1 (1)	1.9 (1.1)	2.5 (1.4)	2.1 (1.2)
2070-2100	**Spring**	3.4 (1.2)	3.1 (1.1)	3.9 (1.5)	3.6 (1.3)	3.6 (1.3)	4 (1.5)	4.2 (1.6)	3.7 (1.9)
	Summer	4.9 (2.7)	4.7 (2.5)	5.9 (3)	5.5 (2.9)	6 (3.1)	5.8 (3.1)	6 (3.1)	5.5 (2.9)
	Autumn	3.7 (1.9)	3.9 (1.9)	5.1 (2.7)	4.1 (2.1)	4.7 (2.4)	4.8 (2.5)	5.2 (2.8)	4.5 (2.3)
	Winter	2.8 (1.2)	2.9 (1.3)	4.2 (2.1)	2.8 (1.2)	3.1 (1.4)	3 (1.4)	3.7 (1.8)	3.2 (1.5)

Source: Bagcaci et. al. (2021)

1.5 Interpretation of Estimation Results

In Table 2, we presented estimation results to measure the impact of a percentage change in mean temperature and precipitation on wheat production in Türkiye. Accordingly, a 1% change in mean spring and summer temperatures would translate into 1.1% and 0.7% reduction in what production, respectively. Moreover, Table 7 projects that, based on the average temperature between 1995 and 2014, a 1.1°C, 2.3°C and 3.7°C temperature increase is expected in short, medium and long term under HES. Combining the estimation results of Table 2 with mean temperature forecasts of Table 7 would indicate that a significant amount of reduction in wheat production would be expected based on different scenarios due to increasing spring temperature (Table 8).

Table 8. Estimated Impact of Temperature Change on Wheat Production under High Emissions Scenario

		Projected Temperature Increase (°C)*	**Historical Average Temperature (1995-2014) (°C)****	**Projected Change (%)**	**Wheat*****	**Estimated Impact (%)**
2030-2050	**Spring**	1.1	12.1	9.1	-1.1	**-10.0**
	Summer	1.9	23.8	8.0	-0.7	**-5.6**
2050-2070	**Spring**	2.3	12.1	19.0	-1.1	**-20.9**
	Summer	3.3	23.8	13.9	-0.7	**-9.7**
2070-2100	**Spring**	3.7	12.1	30.6	-1.1	**-33.6**
	Summer	5.5	23.8	23.1	-0.7	**-16.2**

*(Bagcaci et al., 2021)

**Turkish State Meteorological Service

***Based on writers' calculations

A significant but less reduction in wheat production due to increasing temperature is projected under LES (Table 9). Moreover, the impact of a change in temperature during summer is found to be less compared to spring.

Table 9. Estimated Impact of Temperature Change on Wheat Production under Low Emissions Scenario

		Projected Temperature Increase (°C)*	**Historical Average Temperature (1995-2014) (°C)****	**Projected Change (%)**	**Wheat*****	**Estimated Impact (%)**
2030-2050	**Spring**	0.9	12.1	7.4	-1.1	**-8.2**
	Summer	1.7	23.8	7.1	-0.7	**-5.0**
2050-2070	**Spring**	1.4	12.1	11.6	-1.1	**-12.7**
	Summer	2.1	23.8	8.8	-0.7	**-6.2**
2070-2100	**Spring**	1.9	12.1	15.7	-1.1	**-17.3**
	Summer	2.9	23.8	12.2	-0.7	**-8.5**

*(Bagcaci et al., 2021)

**Turkish State Meteorological Service
***Based on writers' calculations

1.6 Conclusion

The detrimental effects of climate change on agriculture is undeniable. According to the IPCC, crop production is extremely vulnerable to climate change since production of major crops are mainly concentrated in several producing countries (IPCC, 2019). In this regard, the analysis aims to fill an important gap in the literature by quantifying the impact of climate change on wheat production in Türkiye, a major wheat producer.

Our model findings are in line with the existing literature. While precipitation in the development phase positively impacts production, the temperature increase has a negative impact during harvesting of the crop. Moreover, the results are more significant in the Central Anatolia, Mediterranean and Southeast Anatolia which are the major wheat growing regions of the country. According to the findings of the analysis, under both high and low emissions scenario, temperature increase especially during spring and summer months, would decrease wheat production significantly over the course of short, medium and long term. It is important to mention that the impact increases over time. For example, under high emissions scenario expected temperature increase during spring months is estimated to decrease wheat production by 10.0% in the short term. This number increases to 33.6% over the long term. Under the low emissions scenario, while the estimated reduction is less, it still increases over the long run.

The estimation results of our model present the alarming impact of meteorological variables on staple crop production. The analysis in this study is formed by a novel data set gathered under Food-EWS enabling us to generate relatively higher level of statistical validity through performing panel data analysis. We believe that with the availability and advancement of the data under Food-EWS, our model would improve and our results would be more scrutinized.

Appendix

Table 10. Baseline Model Estimation Results

Variables	Baseline Model
$log(Prod)_{i,t-1}$	0.631***
	(0.0274)
$log(MP)_{i,t,1}$	0.0347
	(0.0230)
$log(MP)_{i,t,2}$	-0.0305*
	(0.0176)
$log(MP)_{i,t,3}$	0.0598***
	(0.0208)
$log(MP)_{i,t,4}$	-0.00189
	(0.0172)
$log(MP)_{i,t,5}$	0.0380***
	(0.0143)
$log(MP)_{i,t,6}$	-0.0461***
	(0.0145)
$log(MP)_{i,t,7}$	-0.000505
	(0.00789)
$log(MP)_{i,t,8}$	0.00447
	(0.00748)
$log(MP)_{i,t,9}$	-0.0272***
	(0.00953)
$log(MP)_{i,t,10}$	-0.0102
	(0.0131)
$log(MP)_{i,t,11}$	-0.0115
	(0.0122)
$log(MP)_{i,t,12}$	-0.0346***
	(0.0132)
$log(MT)_{i,t,1}$	-0.0251
	(0.0249)
$log(MT)_{i,t,2}$	0.0697**
	(0.0292)
$log(MT)_{i,t,3}$	-0.354*
	(0.199)
$log(MT)_{i,t,4}$	3.321**
	(1.377)
$log(MT)_{i,t,5}$	-7.906*
	(4.306)
$log(MT)_{i,t,6}$	-3.592
	(6.974)
$log(MT)_{i,t,7}$	-4.448
	(10.95)
$log(MT)_{i,t,8}$	17.30*
	(10.28)
$log(MT)_{i,t,9}$	-4.125
	(6.424)
$log(MT)_{i,t,10}$	1.118
	(2.177)
$log(MT)_{i,t,11}$	-0.101
	(0.171)
$log(MT)_{i,t,12}$	0.0116
	(0.0292)
$log(MT)_{i,t,1}$^2	-0.0208
	(0.0133)
$log(MT)_{i,t,2}$^2	0.0266*
	(0.0140)
$log(MT)_{i,t,3}$^2	0.0908
	(0.0703)
$log(MT)_{i,t,4}$^2	-0.734**
	(0.292)
$log(MT)_{i,t,5}$^2	1.303*
	(0.768)
$log(MT)_{i,t,6}$^2	0.361
	(1.151)
$log(MT)_{i,t,7}$^2	0.509
	(1.728)
$log(MT)_{i,t,8}$^2	-2.611
	(1.620)
$log(MT)_{i,t,9}$^2	0.888

	(1.083)
$log(MT)_{i,t,\mathbf{10}}$**^2**	-0.154
	(0.417)
$log(MT)_{i,t,\mathbf{11}}$**^2**	-0.0106
	(0.0552)
$log(MT)_{i,t,\mathbf{12}}$**^2**	0.00118
	(0.0178)
$P_{Wheat,i,t-1}$	0.00463
	(0.00573)
$P_{Barley,i,t-1}$	0.00167
	(0.00222)
$P_{Commodity,t-1}$	0.699
	(1.306)
$P_{Fertilizer,t-1}$	-0.661
	(0.577)
Constant	4.896
	(20.93)
Observations	889
Number of Province	69
Year FE & Province FE	YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

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TÜRKİYE CUMHURİYET
MERKEZ BANKASI

The Impact of Precipitation and Temperature on Wheat Production in Türkiye

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Outline

(*) The contents of this study do not reflect the view of Central Bank of the Republic of Türkiye.

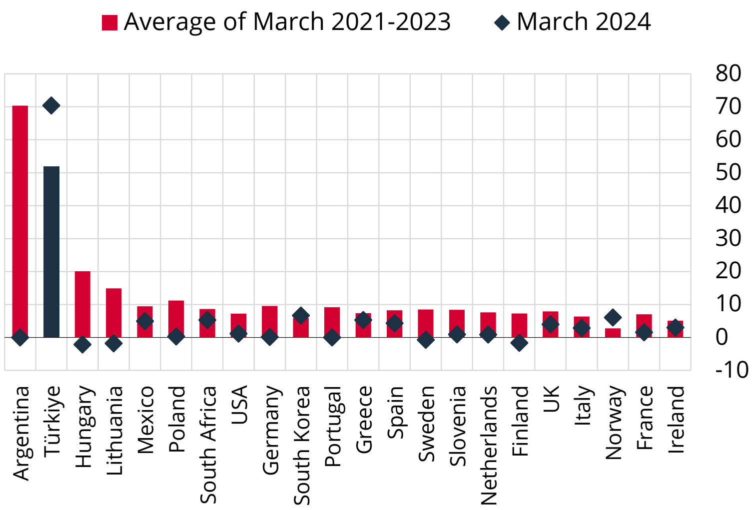
Purpose

- Attaining price stability is one of the main responsibilities of the CBRT. Inflation especially food inflation plays crucial role for the Turkish economy when high share of minimum waged households together with high share of food expenditures are considered.
- With the aim of monitoring food and agricultural products markets more closely in our country, the Food Committee was established in 9 December 2014.
- In 2021, to identify structural problems and develop solutions for price instability due to food inflation, CBRT- Food and Agricultural Product Markets Analysis Department was established and works closely with relevant institutions and organizations.
- One of the top priority tasks of our department is the construction of Early Warning System (EWS) which aims to provide policy makers timely information about risks on agriculture and food markets.
- This warehouse allows the analysis of data on food and agricultural product prices, critical for price stability, in a detailed and timely manner also enables the implementation of necessary precautionary measures.

Purpose

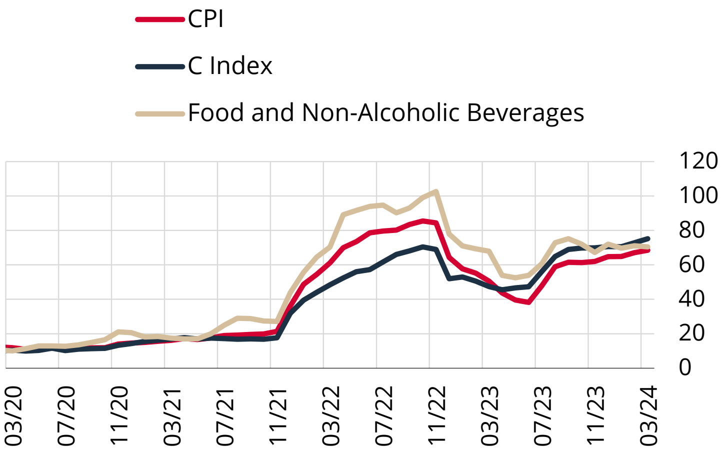
- The divergence between Turkish and international food price levels has been increasing.
- At the same time, Türkiye's food prices have been increasing faster and displaying higher volatility than overall prices in the domestic market.
- The behavior of domestic food prices, when compared to non-food prices, suggest that there are underlying domestic factors that are exerting upward pressure on food price levels and volatility.

Food and Non-Alcoholic Beverages Prices (Annual, %)



Source:
OECD,TURKSTAT

CPI, C Index, Food and Non-Alcoholic Beverages* (Annual, %)



Source: TURKSTAT
*C index: CPI excluding food and non-alcoholic beverages, energy, alcohol-tobacco and gold.

TÜRKİYE CUMHURİYET
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Purpose

- Agriculture is one of the most vulnerable sector to climate change.
- Climate change poses a significant threat for Turkish economy through agricultural production which is crucial with respect to its contribution to employment, exports and national income.
- Wheat, which is the most produced, harvested and consumed crop across the world is particularly very sensitive to precipitation and temperature changes.
- Türkiye was ranked as the 12th largest wheat producer in the world (FAOSTAT, 2022). According to 2023 national statistics 22 million tonnes of wheat production constitutes 54.3% of total crop production in Türkiye (TurkStat, 2023).
- The impact of climate change on wheat production is investigated for Türkiye at province-level with **unique, up-to-date and comprehensive dataset** that is constructed by CBRT under the Early Warning System (EWS) Project.
- The results indicate a significant reduction in wheat production in the short, medium and long-term. The impact is found to be increasing over time depending on various climate scenarios.

Data

The study utilizes a wide range of micro-level data from the Early Warning System Project of Central Bank of the Republic of Türkiye.

The analysis covers 2000-2023 period.

Data	Time Span	Frequency	Source
Production	1991-2023	Annual	Ministry of Agriculture and Forestry
Meteorological Data (Temperature & Precipitation)	1990-2024	Daily	Turkish State Meteorological Service
Wheat and Barley Prices	1980-2022	Monthly	TURKSTAT (TL/kg)
Agricultural PPI	1991-2024	Monthly	TURKSTAT (Index)
Fertilizer Prices	2000-2024	Monthly	Ministry of Agriculture and Forestry (Index)
Commodity Prices	2000-2024	Daily	International Grains Council (Index)
Climate Scenarios	2030-2050 / 2050-2070 / 2070-2100	Seasonal	IPCC Interactive Atlas (IPCC, Gutiérrez, et al., 2021) / (Bağçaci et al., 2021)

Methodology

Monthly average temperature and precipitation across provinces over time are used separately as explanatory variables.

All models are estimated with fixed effect panel regression.

1. Baseline Model:

$$\log(Prod_{i,t})$$
$$= \beta_0 + \beta_1\, log\left(Prod_{i,t-1}\right)$$
$$+ \sum_{k=1}^{11} \gamma_{ik}\quad log\left(MP_{i,k,t-1}\right) + \sum_{l=1}^{11} \gamma_{il}\quad log\left(MT_{i,l,t-1}\right) + \ \alpha_1 \Delta PD_{Wheat,i,t-1} + \ \alpha_2\, \Delta PD_{Barley,i,t-1} + \ \alpha_3\, \Delta P_{Fertilizer,t-1}$$
$$+ \ \alpha_4\, \Delta P_{Commodity,t-1} + \gamma_i + \Omega_t + e_{i,t}$$

2. Reduced Form Baseline Model:

$$\log(Prod_{i,t})$$
$$= \beta_0 + \beta_1\, log\left(Prod_{i,t-1}\right)$$
$$+ \beta_2\, log\left(MP_{March_{i,t}}\right) + \beta_3\, log\left(MP_{April_{i,t}}\right) + \beta_4\, log\left(MP_{May_{i,t}}\right) + \beta_5\, log\left(MP_{June_{i,t}}\right) + \beta_6\, log\left(MP_{October_{i,t}}\right) +$$
$$\beta_7\, log\left(MP_{November_{i,t}}\right) + \beta_8\, log\left(MT_{February_{i,t}}\right) + \beta_9\, log\left(MT_{March_{i,t}}\right)$$
$$+ \beta_{10}\, log\left(MT_{April_{i,t}}\right) \ + \beta_{11}\, log\left(MT_{May_{i,t}}\right) \ + \beta_{12}\, log\left(MT_{June_{i,t}}\right) \ + \beta_{13}\, log\left(MT_{July_{i,t}}\right)$$
$$+ \ \alpha_1 \Delta PaD_{\substack{Wheat\\ ,i,t-1}} + \ \alpha_2 \Delta PD_{\substack{Barley\\ ,i,t-1}} + \ \alpha_3 \Delta P_{Fertilizer,t-1} + \alpha_4\, \Delta P_{Commodity,t-1} + \gamma_i + \Omega_t + e_{i,t}$$

3. Model With Composite Climate Variables

$$\log(Prod_{i,t})$$
$$= \beta_0 + \beta_1\, log\left(Prod_{i,t-1}\right)$$
$$+ \beta_2\, log\left(PCP_{i,t}\right) + \beta_3\, log\left(PCT_{i,t}\right) + \ \alpha_1 \Delta PD_{\substack{Wheat\\ ,i,t-1}} + \ \alpha_2 \Delta PD_{\substack{Barley\\ ,i,t-1}} + \ \alpha_3 \Delta P_{Fertilizer,t-1} + \alpha_4\, \Delta P_{Commodity,t-1}$$
$$+ \gamma_i + \Omega_t + e_{i,t}$$

Estimation Results

Reduced Form Baseline Model:

VARIABLES	(1) Reduced form baseline model
$\log(Prod)$	0.577***
$log(MP_{March})$	0.0565***
$log(MP_{April})$	0.0167
$log(MP_{May})$	0.00457
$log(MP_{June})$	-0.0322***
$log(MP_{October})$	-0.0134
$log(MP_{November})$	-0.0224**
$log(MT_{February})$	0.0578***
$log(MT_{March})$	-0.100**
$log(MT_{April})$	-0.124
$log(MT_{May})$	-1.065***
$log(MT_{June})$	-0.692**
$log(MT_{July})$	-0.325
ΔPD_{Wheat}	0.00842*
ΔPD_{Barley}	0.00347
$\Delta P_{Commodity}$	0.266
$\Delta P_{Fertilizer}$	-0.247
Constant	12.89***
Observations	1,330
Number of Province	76
Year FE & Province FE	YES

Principal Component Analysis:

VARIABLES	(b) Reduced form baseline model
$log(Prod)$	0.586***
	(0.0221)
PCP	0.0380***
	(0.00991)
PCT	-0.106***
	(0.0150)
ΔPD_{Wheat}	0.00929*
	(0.00513)
ΔPD_{Barley}	0.00327
	(0.00218)
$\Delta P_{Commodity}$	1.510***
	(0.497)
$\Delta P_{Fertilizer}$	-0.693***
	(0.240)
Constant	6.042***
	(0.366)
Observations	1,330
Number of Province	76
Year FE & Province FE	YES

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Climate Scenarios

Climate scenarios released by IPCC utilizing Global Circulation Models are widely accepted in climate literature.

With the advancement of data, the regional performance of GCMs has improved significantly especially in simulating temperature and precipitation changes.

Estimated Temperature Change for High Emissions Scenario (Low Emissions Scenario) (ºC)

		Marmara	Black Sea	Eastern Anatolia	Aegean	Central Anatolia	Mediterranean	Southeastern Anatolia	Average
2030-2050	**Spring**	1.1 (0.9)	1.1 (0.8)	1.2 (1.0)	1.1 80.9)	1.1 (0.9)	1.2 (1.0)	1.2 (1.0)	**1.1 (0.9)**
	Summer	1.9 (1.6)	1.7 (1.5)	1.9 (1.7)	2 (1.7)	2 (1.7)	2 (1.7)	2 (1.7)	**1.9 (1.7)**
	Autumn	1.4 (1.1)	1.5 (1.2)	2 (1.6)	1.5 (1.2)	1.8 (1.4)	1.7 (1.4)	2 (1.6)	**1.7 (1.4)**
	Winter	0.8 (0.7)	0.8 (0.8)	1.3 (1.3)	0.8 (0.7)	0.9 (0.9)	0.9 (0.8)	1.2 (1.1)	**1 (0.9)**
2050-2070	**Spring**	2.1 (1.2)	2 (1.1)	2.6 (1.5)	2.2 (1.3)	2.3 (1.3)	2.5 (1.5)	2.7 (1.6)	**2.3 (1.4)**
	Summer	3 (2)	2.8 (1.9)	3.5 (2.2)	3.4 (2.1)	3.6 (2.2)	3.6 (2.3)	3.5 (2.3)	**3.3 (2.1)**
	Autumn	2.5 (1.5)	2.6 (1.5)	3.5 (2.1)	2.7 (1.6)	3.2 (1.8)	3.1 (1.9)	3.6 (2.2)	**3 (1.8)**
	Winter	1.7 (1)	1.9 (1)	2.9 (1.6)	1.7 (1)	2.1 (1)	1.9 (1.1)	2.5 (1.4)	**2.1 (1.2)**
2070-2100	**Spring**	3.4 (1.2)	3.1 (1.1)	3.9 (1.5)	3.6 (1.3)	3.6 (1.3)	4 (1.5)	4.2 (1.6)	**3.7 (1.9)**
	Summer	4.9 (2.7)	4.7 (2.5)	5.9 (3)	5.5 (2.9)	6 (3.1)	5.8 (3.1)	6 (3.1)	**5.5 (2.9)**
	Autumn	3.7 (1.9)	3.9 (1.9)	5.1 (2.7)	4.1 (2.1)	4.7 (2.4)	4.8 (2.5)	5.2 (2.8)	**4.5 (2.3)**
	Winter	2.8 (1.2)	2.9 (1.3)	4.2 (2.1)	2.8 (1.2)	3.1 (1.4)	3 (1.4)	3.7 (1.8)	**3.2 (1.5)**

Source: Bagcaci et. al. (2021)

Conclusion

Almost 11% to 36% reduction in wheat production would be expected based on different scenarios due to increasing spring temperature in Türkiye.

Estimated Impact of Temperature Change on Wheat Production under High Emissions Scenario

		Projected Temperature Increase (°C)*	Historical Average Temperature (1995-2014) (°C)**	Projected Change (%)	Wheat***	Estimated Impact (%)
2030-2050	**Spring**	1.1	12.1	9.1	-1.2	**-10.6**
	Summer	1.9	23.8	8.0	-0.7	**-5.5**
2050-2070	**Spring**	2.3	12.1	19.0	-1.2	**-22.2**
	Summer	3.3	23.8	13.9	-0.7	**-9.6**
2070-2100	**Spring**	3.7	12.1	30.6	-1.2	**-35.8**
	Summer	5.5	23.8	23.1	-0.7	**-15.9**

Estimated Impact of Temperature Change on Wheat Production under Low Emissions Scenario

		Projected Temperature Increase (°C)*	Historical Average Temperature (1995-2014) (°C)**	Projected Change (%)	Wheat***	Estimated Impact (%)
2030-2050	**Spring**	0.9	12.1	7.4	-1.2	**-8.7**
	Summer	1.7	23.8	7.1	-0.7	**-4.9**
2050-2070	**Spring**	1.4	12.1	11.6	-1.2	**-13.5**
	Summer	2.1	23.8	8.8	-0.7	**-6.1**
2070-2100	**Spring**	1.9	12.1	15.7	-1.2	**-18.4**
	Summer	2.9	23.8	12.2	-0.7	**-8.4**

*(Bagcaci et al., 2021)
**Turkish State Meteorological Service
***Based on writers' calculations

Conclusion

- Under both high and low emissions scenario, temperature increase especially during spring and summer months, would decrease wheat production significantly over the course of short, medium and long term.
- The estimation results of our model present the alarming impact of meteorological variables on staple crop production.
- The analysis in this study is formed by a novel data set gathered under Food-EWS of CBRT enabling us to generate relatively higher level of statistical validity through performing panel data analysis.
- We believe that with the availability and advancement of the data under Food-EWS, our model would improve and our results would be more scrutinized.
    - More timely and higher frequency production data can help to make reliable and healthy analysis about the climate impact on economic activity.
    - In addition to temperature and precipitation, in order to be able to evaluate climate risk thoroughly, humidity data needed.

TÜRKİYE CUMHURİYET
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IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

Assessing physical risk impact of climate change: a focus on Chile[1]

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

ESTUDIOS ECONÓMICOS ESTADÍSTICOS

Assessing Physical Risk Impact of Climate Change: A Focus on Chile

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Assessing Physical Risk Impact of Climate Change: A Focus on Chile[1]

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Resumen

El cambio climático plantea desafíos importantes para las economías de todo el mundo, incluido Chile, donde los efectos adversos ya son evidentes y se espera que empeoren. Para evaluar el impacto financiero del cambio climático, comprender la exposición de los agentes a los eventos naturales es crucial, aunque desafiante debido a la escasez de datos. Este artículo se centra en evaluar la exposición a riesgos físicos en Chile, utilizando un enfoque novedoso que combina datos de ventas administrativas a nivel micro, información de deuda a nivel de empresa y escenarios de riesgo físico a nivel municipal. El conjunto de datos cubre todas las transacciones de facturas a nivel de empresa en Chile, lo que permite un cálculo preciso de las exposiciones al riesgo físico. Este enfoque granular proporciona conocimientos sin precedentes sobre los impactos potenciales del cambio climático en los sectores económicos, agentes y regiones. Existe una alta concentración de ventas y deuda bancaria en municipios con altos riesgos físicos. Aproximadamente la mitad de las ventas y la deuda se encuentran en municipios que podrían enfrentar episodios de calor extremo en el futuro; este número disminuye al 15% cuando se trata de riesgo de incendio urbano. Este estudio contribuye a cerrar brechas de datos en la investigación relacionada con el clima, ofreciendo una evaluación integral de la exposición a riesgos físicos en los 345 municipios de Chile. Los resultados resaltan el diverso panorama económico de Chile y arrojan luz sobre los desafíos únicos del país, incluida la seguridad del agua, el calor extremo, los incendios urbanos, la generación hidroeléctrica y la mortalidad por calor, enfatizando la necesidad de intervenciones específicas para mejorar la resiliencia económica.

Abstract

Climate change poses significant challenges to economies worldwide, including Chile, where adverse effects are already evident and expected to worsen. To assess the financial impact of climate change, understanding agents' exposure to natural events is crucial yet challenging due to data scarcity. This paper focuses on evaluating exposure to physical risks in Chile, utilizing a novel approach that combines micro-level administrative sales data, firm-level debt information, and physical risk scenarios at the municipality level[2]. The dataset covers all invoice transactions at the firm level in Chile, enabling precise computation of physical risk exposures. This granular approach provides unprecedented insights into climate change's potential impacts on economic sectors, agents, and regions. There is a high concentration of sales and banking debt in municipalities with high physical risks. About half of sales and debt are in municipalities that might face extreme heat episodes in the future, this number decreases to 15% when dealing with urban fire risk. The study contributes to closing data gaps in climate-related research, offering a comprehensive evaluation of physical risk exposures in all 345 municipalities in Chile. Results highlight the diverse economic landscape of Chile and sheds light on the country's unique challenges, including water safety, extreme heat, urban fires, hydroelectric generation, and heat mortality, emphasizing the need for targeted interventions to enhance economic resilience.

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[1] The views expressed are those of the author and do not necessarily reflect the views of the Central Bank of Chile or its board members. Corresponding author fcordova@bcentral.cl

[2] Municipality in Chile corresponds to local governments, that is, institutional units whose fiscal, legislative, and executive authority extends over the smallest geographical areas distinguished for administrative and political purposes.

1. Introduction

Climate change has far-reaching implications for economies across the world, Chile is no exception. Anthropogenic climate change is already causing significant adverse effects, which will deepen in the coming decades under practically any scenario, and which will propagate and amplify risks in the economy (BCBS,2021). A first step towards assessing the financial impact of climate change is to quantify the exposure of agents to the occurrence of adverse natural events, which is a challenge given the shortage of available data (BCBS, 2020). Our paper delves into the task of evaluating the financial repercussions of climate change, with a specific focus on physical risks for Chile. Quantifying agents' exposures to adverse natural events can be a challenge, particularly given the scarcity of granular enough data. To tackle this, we utilize a novel source of information comprised of micro-level administrative sales data obtained from the Chilean tax authority, when combined with firm-level debt, and physical risk NGFS scenarios at the municipality level, it allows for the computation of granular exposures to this type of events. The administrative sales dataset covers the entirety of invoice transactions at the firm level in Chile, allowing for the identification of both sellers and buyers and including all the other characteristics of the transaction. The utilization of granular data permits a precise computation of physical risk exposures across Chile, providing an unprecedented depth of insight into the potential impacts of climate change on various economic sectors, agents, and regions.

Our research connects with the growing strand of literature in climate change impact assessment (NGFS, 2022 and Aurouet et al., 2023). While previous studies have already developed frameworks for assessing physical climate risk, our research distinguishes itself by using a granular micro-level approach that is based on transaction data that includes geographical location of seller and buyer, attaining a fine resolution in the evaluation of physical risks. The unique contribution of our research lies in its application of tax micro-data, providing a novel perspective on the intricate interplay between climate risks and economic activities. Our study sheds light on the unique challenges faced by Chile, a country marked by a diverse geography and a wide array of climatic threats. Our results, coupled with the identification of critical risk factors impacting different economic sectors, serve as a valuable foundation for tailored risk mitigation strategies.

This paper contributes to closing the data gaps in climate-related research. Limited data availability has long been a challenge in the study of climate impacts. Our dataset encompasses the entire country, covering all 345 municipalities in Chile. This exhaustive coverage allows for a comprehensive evaluation of physical risk exposures. The dataset contains the universe of transactions with invoices among firms, providing a robust foundation for our analysis. This enhances the reliability and applicability of our findings, offering insights into the diverse economic landscape of Chile in the face of climate change. This innovative use of administrative data not only increases the precision of our analysis but also sets a precedent for overcoming data gaps in climate research.

The main climatic threats to Chile, given its geography, are coastal deterioration, increased flooding, temperature increases and prolonged droughts (IPCC, 2022). The Northern and Central macro-zones have a high relative exposure to physical risks of coastal deterioration (especially in the Central macro-zone), floods and drought, while the Southern and Metropolitan Region (RM) macro-zones have a much lower exposure to these elements. In particular, the exposure of agricultural properties and business use is higher than the risk in residential housing. Thus, the population of all the properties in Chile faces an exposure of 38.6% to climate change (Cortina and Madeira, 2023).

Thus, in Chile, the northern macro-zones, the metropolitan region (MR) and the center of the country appear to be more exposed to the decrease in the availability of water resources and increases in ambient temperatures. In terms of the climate indicators available in ARClim and CIE, and according to IPCC (2022), the most critical risk factors for the national territory would be urban domestic water security, changes in the electrical grid due to a decrease in water resources, variation in labor productivity due to thermal stress, and increases in maximum daily temperature. This is where our study will focus.

Chile is a highly concentrated country in terms of population settlements and productive activities. According to Córdova et al. (2022), the North, Central and MR macro-zones concentrate 88% of the population, 86% of the firms, 95% of their annual sales, and 90% of the country's GDP. This implies that the direct exposure of households and businesses to the most pressing physical risks for Chile is high, which could exacerbate operating, reinsurance, and credit and market risks. Given this concentration of economic activities in the most exposed macro-zones, if materialized, the impact of physical risks could be significant. Given the concentration of economic activities in the center of the country, together with the vulnerability of the area to an intensification of adverse climatic events, the direct exposure to physical hazards observed would be high. For example, 87% of bank loans are concentrated in regions located in the extreme-risk area for at least one of the dimensions examined, where 59% correspond to commercial loans, 31% to mortgage loans, and 10% to consumer loans. A similar geographic distribution is found in the sales and location of companies throughout Chile, with significant accumulations in the Central and MR macro-zones.

In this paper, by combining the administrative sales and debt data with the physical risk scenarios at the municipality level, we were able to compute granular exposures to adverse natural events for each firm. A pivotal aspect of the methodology is the identification of the firms of supply and use of the goods or services traded, derived directly from the electronic invoices. This level of detail extends beyond the traditional focus on legal company address, offering a more accurate reflection of economic activity as it occurs across firms. After estimating our exposure index, the water safety risk in the central and southern areas dissipates due to the crossing with sales and debt.

Our analysis reveals a notable concentration of billing and debt in municipalities within the metropolitan region, indicating potential economic vulnerabilities to climate change impacts in these areas. Additionally, the physical risk map highlights that municipalities in the central zone of Chile face the highest likelihood of increased water insecurity and extreme heat, with implications for sectors reliant on stable water sources and vulnerable to heat stress. In the northern zone, the municipality of Antofagasta stands out, likely due to the prevalent mining activity in the area, intensifying its exposure to physical risks.

In terms of extreme heat, the exposure rate intensifies in several municipalities. Although the urban fire risks in general are low, when combined with the concentration of sales and debt, the combined exposure index shows an overall deterioration at the national level. Something similar can be seen with Hydroelectric Generation and Heat Mortality indexes. It is worth noting that this exercise does not consider the full range of effects, since it does not consider feedback between sectors, nor future dynamics of reaction to policies.

In summary, our preliminary results provide relevant insights into the potential consequences of climate change on various economic sectors in Chile. Our paper not only introduces a novel approach employing sales micro-level data but also contributes to the broader literature by integrating NGFS climate scenarios and provides insights into the specific challenges faced by Chile. By offering a comprehensive and nuanced assessment of climate-related financial risks and closing data gaps, our study serves as a resource for policymakers, financial institutions, and researchers navigating the complex intersection of climate change and economic resilience.

As we move forward, the preliminary results pave the way for a more in-depth exploration of climate-related financial risks in Chile. The ongoing analysis aims to refine these initial findings, providing a comprehensive understanding of the potential economic impacts and facilitating informed decision-making in the face of a changing climate.

The paper is structured as follows, Section 2 discusses our links with related literature, Section 3 details the data we used for computing exposures, Section 4 describes the methodology for computing exposures, Section 5 summarizes results and Section 6 concludes.

2. Connections with literature

According to UNEP-FI (2018a, 2018b), borrowers' financial health may be at risk due to rising temperatures, droughts, and floods. However, the impact of these climate-related risks on credit risk can vary based on the sector, geography, and reliance on hydropower (NCFA and GIZ, 2017). Therefore, it is crucial to use detailed information to better understand the exposure of these risks (BCBS, 2020; BoE, 2022). Unfortunately, it is challenging to accurately assess firms' exposure to climate risks due to the lack of standardized information about the location of corporate assets and value chain emissions. The heterogeneity of debtors and banks across different regions justifies a more detailed analysis to study the impact of transmission channels on firms, households, and governments with other types of debts (BCBS, 2021).

This paper presents three main contributions. Firstly, we utilize administrative sales data from all Chilean firms at the municipality level. Many studies have focused on listed equities and publicly traded bonds as these securities have readily available data. Consequently, there has been a lack of research on climate exposure of smaller firms.

To determine the optimal location for sales, a thorough assessment of the Chilean territory, considering various elevations, topography, and sensitivities, is essential. Additionally, most physical risk analyses only focus on direct physical damages to properties, infrastructure, and agricultural assets without considering the impact of climate events on factors that affect a company's overall operating environment (NGFS, 2020b). To complement the exposure of assets, we use a company's sales as an indicator to calculate its physical risk exposure.

This document encourages banks to develop and advance their tools for further evaluating their exposure to climate-related risks. Although climate risks can lead to credit, market, liquidity, operational risk exposures, or even bank balance sheet losses, they are not usually considered when assessing credit risk. With the BIS (2021) indicating that climate risks can translate into various forms of financial risks, this assessment of the exposure of Chilean firms to climate risks is a crucial first step in attaining a deeper understanding and more sophisticated tools that will allow for better evaluation of credit risk.

Why is it relevant to assess companies' vulnerability to physical risks?

It has been well documented that extreme weather events can severely impact banks' balance sheets, potentially leading to systemic consequences (ECB, 2019; ECB 2021; NGFS 2020a). The situation is worsened because physical risks may increase rapidly under certain conditions (IPCC, 2018; NGFS, 2020a).

Climate risks can result in traditional financial risks, such as credit and market risks for investors and banks, as well as risks to underwriting and reserving for insurance companies (BIS, 2021; Scott et al., 2017) [3] [4]. Banks can face physical risks depending on the location of the assets they finance or use as collateral. Similarly, climate impacts can affect corporations beyond just the physical exposure of their facilities or branches. This includes disruptions to their supply chains and distribution networks, which can lead to increased operating costs and decreased sales. It can also impact their customers and markets, causing interruptions in the normal development of their operations (EBRD and GCECA, 2018).

Exposure to climate risk may increase credit risk for debtors, reducing their ability to repay debt and banks' ability to recover in case of default (BCBS, 2021; NGFS, 2020b)[5]. This is why financial institutions should consider climate risk when providing loans and incorporate this monitoring in all stages of the loan life (ECB, 2020). Precisely determine how climate risks affect the probability of default (PD) and loss given default (LGD) in sectors or geographies vulnerable to physical risk. The impact may differ significantly across industries and geographic areas.

In addition to traditional financial risks, the ECB (2023) and NGFS (2020b) also highlight fiscal costs. Climate change can potentially impact a country's sovereign risk in several ways. Firstly, it can lead to weak economic activity and damage to infrastructure, which in turn can reduce GDP growth. Secondly, population migration can result from climate change, which can negatively affect a country's economy. Moreover, periods of low growth may require fiscal resources for reconstruction, which can divert money that could be used for research and development (ECB, 2023). According to Buhr et al. (2018), developing countries face increased debt costs due to exposure to climate risk. The study reveals that, on average, the cost of debt has increased by 117 basis points, resulting in an additional $40 billion in interest payments on government debt over the past ten years. The International Monetary Fund (IMF) conducted a study in 2020 to analyze the ten most significant disasters between 1970 and 2018. The study found that emerging markets suffered damage ranging from 2.9% to 10.1% of their gross domestic product (GDP), while advanced

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[3] In NGFS (2020b) are detailed 24 categories and subcategories of environmental risks. Each may result in financial risks such as credit (default) risk, market risk (valuation loss), and liquidity risk, as well as operational risk in financial institutions. There are therefore numerous scenarios for environmental risks to transmit to financial risks.

[4] In BoE (2015) it is possible to find a detailed report on the impact of climate change on the insurance sector. The report identifies three risk factors (physical, transition and liability risks) and explores the nature of the risk, the possible impacts on the liability and/or asset side of insurance firms' balance sheets, and the actions firms are taking to mitigate them.

[5] Market risk has also been studied. Market risk is exacerbated if institutions hold assets exposed to multiple climate risks in their portfolios and are forced to sell assets at heavily discounted prices (fire-sales) (ECB, 2022).

economies experienced damages equivalent to 1% to 3.2%. These reductions in GDP may impact how banks assess credit risk at the country level.

Increases in human mortality and decline in labor productivity are other crucial costs related to climate change. These costs are projected to be the primary causes of reductions in output. A study conducted by Carleton and Hsiang (2016) quantifies the impact of climate change on economies. It proves that rising temperatures adversely affect mortality, morbidity, agricultural yields, labor supply, and productivity. Another study by Hsiang et al. 2017 found that the most significant direct cost in the US for global mean surface temperature changes above 2.5°C is the burden of excess mortality, followed by changes in labor supply, energy demand, and agricultural production.

How are physical risks transmitted to the financial sector?

Physical risks can be either acute or chronic (NGFS, 2019a). Acute risks are associated with one-time or sudden climatic events, such as heatwaves, forest fires, disruptions in rainfall patterns, and different types of storms and floods. On the other hand, chronic risks are associated with long-term changes in weather patterns, such as rising sea levels, the planet's average temperature, and the acidification of the oceans. Studies show that these risks can have a detrimental impact on the profitability, sales, and productivity of companies.

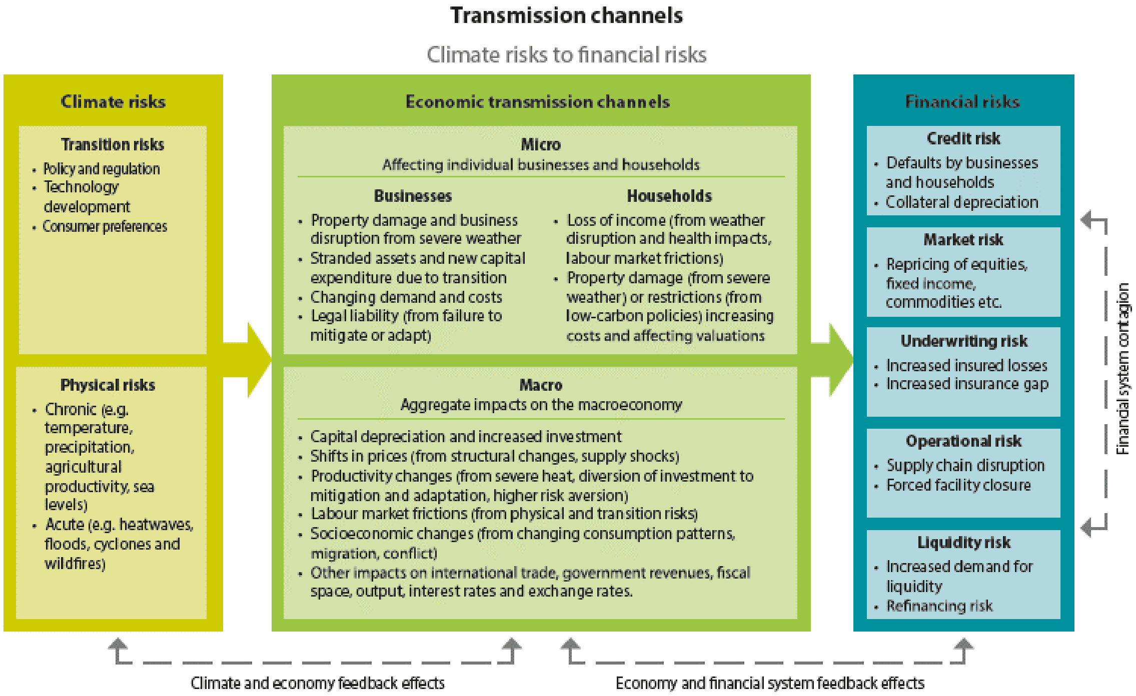
Physical risks are transmitted to the economy and financial system through micro and macroeconomic channels (Hubert et al. 2018; NGFS 2020a; NGFS 2020b; NGFS 2023). Transmission channels are the pathways that describe how climate risk drivers affect banks directly and indirectly through their assets, counterparties, and the economy in which they operate. Research indicates that the effects of these risk drivers on banks are noticeable through conventional risk categories (BCBS, 2021; NGFS, 2023), as illustrated in Figure 1.

Microeconomic channels can have an impact on both homes and businesses.

- Households may experience a loss of income due to disruptions in economic activity caused by climate change. In addition, weather disruptions can impact health, including decreased labor productivity, mortality, and morbidity resulting from changes in temperature extremes. Furthermore, households can also face physical damage or loss of valuation due to asset destruction caused by events such as floods or windstorms.

- Businesses may experience a loss in revenue due to direct damage or supply chain disruptions, as well as a reduction in agricultural yields or labor productivity. Additionally, companies may face higher costs from investing in adaptation. Real estate and other infrastructure are particularly vulnerable to specific hazards, such as flooding in coastal areas, which can result in a decline in the collateral values of borrowers.

Figure 1



Source: NGFS (2023)

Macroeconomic channels have an aggregate effect on the economy. Among the main channels are productivity, migration, reconstruction and replacement of infrastructure, capital replacement, investment, structural changes in the markets, socio-economic changes, etc. (NGFS, 2020a). Given the microeconomic orientation of this document, we will not go into further detail. However, interested readers can refer to NGFS (2019b), NGFS (2023), and ECB (2023).

Climate risks translate into traditional financial risks. The main one that interests us is credit risk. This risk arises from direct exposures of financial institutions to affected firms through lending or asset holdings as collateral. Physical risks directly affect firm revenues and operating expenses (Alogoskoufis et al., 2021). Natural catastrophes generate physical capital losses, which might eventually require additional investments, exerting upward pressure on leverage. At the same time, revenues would decrease as the physical capital losses would result in a decline in production capacity and productivity (NGFS, 2019b). It can also be mentioned that supply-chain links or lower demand and higher unemployment can occur because of a more generalized economic downturn.

The impact of physical risk will also depend on the geographical location. Significant differences exist in the distribution of the economic effects of physical risks across regions and sectors. This variation is driven by differences in the gross exposure to physical risks and the level of resilience and adaptation (action taken to prevent or minimize damage). Countries with less economic diversification, climate-resilient public infrastructure, capital market flexibility, and lower adaptation capacity will be at greater risk. Some sectors could be at greater risk, too, depending on their regional footprint. Granular data are also needed to conduct bottom-up, quantitative analysis of the macro-financial impacts of climate-related risks (NGFS, 2019).

Finally, the nature of the financial risks will also depend on the price and availability of insurance. If losses are insured, they can directly affect insured and reinsurance firms through higher claims. If losses are not insured, the burden can fall on households, corporations, and governments. This can impair asset values, reduce the value of investments held by financial institutions, and increase credit risk for banks and investors (NGFS, 2023).

Measuring exposures to physical risks in Chile

Hernández and Madeira (2021) study the impact of precipitation and temperatures on GDP using region-industry panel data for Chile from 1985-2017. They found no effect of precipitation changes on GDP, but the results confirm a negative impact of higher summer temperatures on agriculture, silviculture, and fishing. Using similar information but in a different time window, Reszczynski (2024) studies the relationship between climate change and GDP through a regional-industrial panel for Chile between the first quarter of 1997 and the fourth quarter of 2019. She finds that an increase in temperature has a negative impact and is significant in economic activity for most industries in Chile's GDP. Also, she finds that a drop in precipitation negatively affects activity but only in the agricultural-forestry industry. These two studies reveal the heterogeneity in the impacts that climate change can generate on the Chilean economy.

Madeira (2022) presents a comprehensive review of several studies related to the future impact and effects estimated of climate change during the twenty-first century for Chile. The results suggest - with substantial uncertainty around these estimates - that Chile will likely suffer mild effects on GDP growth, labor productivity, and mortality costs. However, it could also experience significant water stress and scarcity due to low precipitation, fire hazards, and air pollution. It is also expected to significantly increase migration towards Chile from poorer neighboring countries that may be strongly affected by climate change.

Córdova et al. (2022) show that the impact of physical risks could be significant given the concentration of economic activities in the most exposed macro-zones. Using a mix of micro and aggregated data, they find that the northern macro-zones, the Metropolitan Region (RM), and the country's center appear to be more exposed to the decrease in the availability of water resources and increases in ambient temperatures[6]. This situation worsens if the North, Central, and RM macro-zones concentrate 88% of the population, 86% of the firms, 95% of their annual sales, and 90% of the country’s GDP. This implies that the direct exposure of households and businesses to Chile's most pressing physical risks is high, which could exacerbate operating, reinsurance, credit, and market risks. For example, 87% of bank loans are concentrated in regions located in the extreme-risk area for at least one of the dimensions examined, where 59% correspond to commercial loans, 31% to mortgage loans, and 10% to consumer loans. A similar geographic distribution is found in the sales and location of companies throughout Chile, with significant accumulations in the Central and RM macro-zones. Using this document, in the present paper, we refine the exposure calculation using microdata at the community level.

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[6] According to IPCC (2022), the most critical risk factors for the national territory would be urban domestic water security, changes in the electrical grid due to a decrease in water resources, variation in labor productivity due to thermal stress, and increases in maximum daily temperature.

Cortina and Madeira (2023) perform a quantification exercise of real estate properties exposed to climate risks using microdata to compute territorial exposure to physical hazards. For this purpose, the properties listed in the Real Estate Cadaster (georeferenced by district) are associated with climate exposure indicators referring to the loss of labor productivity in the event of heatwaves, fires, floods, drought, and coastal deterioration. It has been found that over 30% of property valuation in Chile is exposed to climate risks up to 2050 (under the assumption that current policies are maintained). The Northern and Central macro-zones have high relative exposure to physical risks of coastal deterioration (especially in the Central macro-zone), floods, and drought. In contrast, the Southern and RM macro-zones have much lower exposure to these elements. In particular, the exposure of agricultural properties and business use is higher than the risk in residential housing.

Beltran et al. (2023) summarize the results from several studies that quantify the impacts of climate change in Chile, emphasizing both the macroeconomic and sectoral effects of higher temperatures and other climate events. The review highlighted the need to expand the analytical efforts to quantify the impacts of climate change in Chile along three main dimensions: geo-referencing of physical and financial assets, characterization of the transmission channels through which climate shocks can spread throughout the economy, and accounting for the fact that climate events are not stationary.

Measuring exposures to climate physical risks: a focus on the work of central banks[7]

Several central banks have tried to measure their financial system's exposure to climate risks, focusing mainly on banks and insurance companies. For example, De Nederlandsche Bank (2017) examines the consequences of climate change for insurers and the impact of large-scale flooding on the Dutch financial sector. They conclude that the most significant economic losses from climate disasters could occur due to flooding caused by rising sea levels. This is because the affected assets are not fully insured and are only partly compensated by the government. There is a small probability of such an event occurring but with a significant impact. In this scenario, losses could reach 60 billion euros.

The European Central Bank (2021) estimates the banking system's exposure to climate risk. Using a sample of 1.1 million firms, they conclude that many firms are exposed to climate risk in different geographic areas. Floods are relevant in central and northern Europe, where around 7% of firms are exposed to this risk. In southern Europe, 18% of firms are exposed to heatwaves, water stress, or fires. Regarding lending, around 30% of the European banking system is exposed to non-financial firms with a high or increasing risk of at least one physical risk.

Banco de España (2021) uses the Orderly Transition scenario and the Hot House World scenario to evaluate the impact of physical risks on the banking sector, following the recommendations of the NGFS. At the beginning of the projection, the transition costs exceed the physical costs, so the firms' credit risk of default is somewhat higher in the Orderly scenario. However, this situation is reversed in the long term due to materializing physical risks, so the risk of default is more significant in the Hot House World scenario. In 2070, the probability of default for households was 0.57pp higher in

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[7] Given the extensive international literature, we have decided to focus on studies carried out by central banks. Like our work, these studies are characterized by covering many firms with an emphasis on financial stability.

the Hot House World scenario compared to the Orderly Transition scenario, with this difference increasing to 1.11pp for firms. The report indicates that even though these differences in the two scenarios may seem marginal, they are relevant since they show a permanent deterioration in the quality of the portfolio. This has a relevant impact when this deterioration accumulates throughout the loan's life.

Danmarks NationalBank (2021) shows that flood risk could affect a significant part of its financial institutions. This is due to the properties used as collateral for loans, which could be flooded and are in the same geographic area. These exposures account for kr. 41 billion today, which could increase to kr. 198 billion by the end of this century. The report indicates that financial institutions should incorporate this climate and geographic concentration risk into their portfolio management.

Banco de Portugal (2023) uses the Net-zero 2050, Delayed Transition, and Current Policies climate scenarios to carry out the climate risk analysis of the banking system. This work has a high degree of granularity in the information, including (i) GHG emissions, (ii) exposure to physical risk events, considering the geographical location, and (iii) the firm's financial situation. The banks' exposure is measured through the loans provided. Exposure to climate risk is mainly explained by water, heat, and fire stress. The exposure of firms to flood risk is significant, reaching 38% of total loans. On the contrary, exposure related to sea level rise, hurricanes, or typhoons is low.

The results of the 2021 Climate Biennial Exploratory Scenario (CBES, Bank of England (2022)) show the financial risks posed by climate change for the largest UK banks and insurers. In this exercise, three scenarios are proposed, of which they highlight the NAA (No Additional Action) scenario due to the impact generated by physical risks. Under this scenario, essential costs are identified for banks and insurers during the projection horizon. This is because heightened physical risks lead to higher losses on loans and insurance and lower returns on financial assets. Impairment rates projected by banks were just over 50% higher than normal levels but with high uncertainty. Banks appeared less equipped to assess the impact of physical risk, particularly those arising from corporate vulnerabilities. The aggregate results show that, for life and general insurers, the NAA scenario would likely have a more significant impact than either of the transition scenarios, even within the 30-year window of the exercise.

3. Data[8] [9]

a. Administrative sales data [10]

The administrative sales data obtained from the Chilean tax authority cover the entirety of invoice transactions at the firm level in Chile for 2022, allowing for the identification of both sellers and buyers, and their geographical location. Obtained from electronic invoices (EI), this dataset presents a groundbreaking approach to capturing the economic pulse at the municipality level. This data allows us to explore transactions of goods and services between companies, emphasizing the specific locations of these transactions rather than the broader regional scope traditionally reported. By leveraging the granularity of electronic invoicing data, the dataset illuminates the intricate web of economic activity within and between firms, offering insights into the flow of goods and services across the fabric of the local economy.

This approach considers internal sales exclusively, sidelining international transactions to focus squarely on the domestic economic landscape. Importantly, the analysis does not differentiate between the ultimate use of the goods sold, encompassing both intermediate inputs like raw materials and capital goods such as machinery and vehicles. This broad inclusion criterion ensures a comprehensive overview of the goods and services flowing through firms.

A pivotal aspect of the methodology is the identification of the firms of supply and use of the goods or services traded, derived directly from the electronic invoices. This level of detail extends beyond the traditional focus on legal company address, offering a more accurate reflection of economic activity as it occurs across firms.

With the aim of facilitating the presentation, the following table presents a summary of the information at the regional level for December 2022[11]. It shows the number of sellers and buyers, the volume of transactions within and between regions, and the total sales in millions of USD for both intra-regional and inter-regional exchanges.

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[8] *This study was developed within the scope of the research agenda conducted by the Central Bank of Chile (CBC) in economic and financial affairs of its competence. The CBC has access to anonymized information from various public and private entities, by virtue of collaboration agreements signed with these institutions.*

[9] *To secure the privacy of workers and firms, the CBC mandates that the development, extraction and publication of the results should not allow the identification, directly or indirectly, of natural or legal persons. Officials of the Central Bank of Chile processed the disaggregated data. All the analysis was implemented by the authors and did not involve nor compromise the SII and the CMF.*

[10] *The information contained in the databases of the Chilean IRS is of a tax nature originating in self-declarations of taxpayers presented to the Service; therefore, the veracity of the data is not the responsibility of the Service.*

[11] To fulfill the objectives of government and administration, the country is divided into sixteen smaller territorial units called Regions. The regions are divided, in turn, into provinces and these are finally divided into municipalities (source: División Política-Administrativa — (bcn.cl)).

Table 1. Intra-Regional and Inter-Regional economic transactions overview

Region*	**Sellers** *(in thousands)*	**Buyers**** *(in thousands)*	**Number of Electronic invoices issued** *(in thousands)*			**Total sales** *(in millions of USD)*		
			Intraregional	Interregional	Total	Intraregional	Interregional	Total
Arica y Parinacota (4)	5,5	19,0	144	40	184	58	52	111
Tarapacá (7)	8,1	38,5	266	86	352	186	145	330
Antofagasta (9)	16,3	54,2	568	189	758	428	907	1.335
Atacama (9)	7,4	25,7	236	82	318	146	185	331
Coquimbo (15)	19,2	72,2	631	204	836	286	323	609
Valparaíso (38)	46,3	196,2	1.582	664	2.246	840	1.942	2.782
Metropolitana (52)	236,4	892,8	13.901	5.903	19.803	22.907	6.038	28.944
O'Higgins (33)	27,0	94,9	749	289	1.038	767	785	1.553
Maule (30)	32,9	107,2	1.018	514	1.531	763	603	1.366
Ñuble (21)	12,2	45,8	389	211	599	178	270	448
Biobío (33)	39,1	138,1	1.299	437	1.736	854	1.060	1.915
La Araucanía (32)	25,4	85,6	862	324	1.186	444	395	839
Los Ríos (12)	11,9	40,6	310	152	462	155	231	386
Los Lagos (30)	30,4	95,9	1.196	333	1.529	1.012	525	1.537
Aysén (10)	4,7	14,2	133	28	161	48	35	83
Magallanes (11)	6,6	19,6	247	36	283	137	101	238
National level	526,4	1751,2	23.531	9.492	33.023	29.208	13.598	42.807

* Next to each region, within parentheses, the number of municipalities comprising it is indicated.

** The number of buyers includes natural persons, who do not issue electronic invoices.

***1USD=875,66$ (source: Base de Datos Estadísticos (BDE))

Table 2 provides a detailed view of the transactional dynamics of two enterprise categories for December 2022. It illustrates how sales volumes, and the distribution of electronic invoices vary by company size and transaction type. This detailed categorization helps to highlight the significant roles played by Micro, Small, and Medium Enterprises (MSMEs) and large enterprises in shaping the economic landscape, providing a clear depiction of their contributions across regions.

Table 2. Enterprises by business size

Enterprises	**Annual sales**	**Sellers**	**Buyers***	**Number of Electronic invoices issued** ***(In thousands)***			**Total sales** ***(In millions of USD)***		
	(USD)	*(In thousands)*	*(In thousands)*	MSME	Large	Total	MSME	Large	Total
MSME	Up to 4 million	513,4	1.735,50	9.122	2.295	11.417	5.481	5.793	11.274
Large	4 million or more	13,1	15,7	16.252	5.354	21.606	6.891	24.641	31.532
National level		526,4	1.751,20	25.374	7.649	33.023	12.372	30.434	42.807

* Micro, Small, and Medium Enterprises (MSME)

**1USD=875,66$ (source: Base de Datos Estadísticos (BDE))

This innovative approach to analyzing economic activity through electronic invoices at the municipality level provides a new perspective on the local economic landscape. By mapping the flow of goods and services with such specificity, it enhances our understanding of local economies and offers valuable insights for policymakers, businesses, and researchers. The project's use of technology to explore the microcosm of economic activity marks a new era of economic analysis, highlighting the local nuances of trade and commerce and offering a richer, more detailed portrait of the country's economic activity.

It should be noted that in our analysis and as a robustness exercise we will use two sales measures. The one we just described and the total sales of the firm. The latter also include exports and sales made through receipts.

b. Physical Risks in Chile

ARClim, the Climate Risk Atlas for Chile, it's a project of the Ministry of the Environment of the Government of Chile, developed by the Climate and Resilience Research Center (CR2) and the Center for Global Change (CCG-Catholic University of Chile) with the collaboration of other national and international institutions. ARCLim was supported by the Global Risk Assessment and Management Program for Climate Change Adaptation (Loss and Damage) commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ). The objective of this project is to collaborate with the Ministry of Environment of the Government of Chile, contributing to the strengthening of national capabilities in the face of the challenges of climate change in the country.

The ARClim project developed risk maps related to climate change for Chile, incorporating historical climate projections (period 1980-2010) and future (30-year multidecadal period, centered on 2050, under a scenario of high greenhouse gas emissions, RCP8.5). The maps communicate information on Threats, Exposure, Sensitivity and Risk of the selected national systems, at the community level.

The evaluated climate risk represents an indicator of the magnitude of damage that could be expected in the face of a change in climatic conditions. Each map is the result of the combination of the climate threat (T), exposure (E) and sensitivity (S) of the municipality. These three variables (T, E, S) are combined to determine the risk due to climate change. In Annex 1.1 there are the maps (impact chains) with de Estimating Risk (R) organized into five physical risks.

- Water Safety: This map represents the variation in negative impacts on the health of the urban population of each municipality, between the historical period and the future due to the change in the incidence of meteorological droughts and potential evotranspiration. The map is a graphic visualization of the risk index for each municipality. The index does not represent the probability of impacts occurring, but only which municipalities show willingness to suffer adverse impacts associated with urban domestic water insecurity under historical and/or future climatic, social, and institutional conditions. The index has a range between 0 and 1 and takes higher values (generating a darker color on the map) in communes in which a high incidence of urban domestic water insecurity conditions is recorded, a significant proportion of the urban population resides in which high conditions of demographic, household, health and territorial services sensitivity are observed, along with reduced social and institutional capacities to respond or adapt to these impacts.

  In this map it can be identified that the municipalities where the risk of water insecurity would increase the most correspond to those of the Valparaíso and Metropolitan regions of Santiago. Furthermore, in the Libertador Bernardo O'Higgins and Maule regions, the risk increases to very high for some municipalities distributed heterogeneously within the regions. On the other hand, a high risk is identified in some communes in the Coquimbo Region, mainly the coastal ones and in certain communes in the Bio-Bio and Los Ríos regions. A moderate increase in the risk of urban domestic water insecurity was shown by the Atacama and Araucanía regions and from Los Lagos to the south of the country. Finally, in the extreme north and south of the country, a risk reduction from low to very low was identified.

- Extreme Heat: This map represents the variation in the risk of health impacts because of heat waves, between the historical period and the future. The change in risk only considers the change in the threat (increase in heat waves), under conditions of future exposure and historical sensitivity and resilience. The index does not represent the probability that impacts will occur, but only which communes show willingness to suffer adverse impacts associated with heat waves under historical and future climatic, social, and institutional conditions. The index has a range between 0 and 1 and takes higher values (generating a darker color on the map) in communes in which a high incidence of heat wave conditions is recorded, a significant proportion of the population resides (urban or rural) and in which high conditions of territorial and/or population sensitivity are observed, together with reduced social and institutional capacities to respond to and mitigate these impacts.

  As can be seen in the map, the greatest increases in risk are recorded in the central-southern and southern areas, and especially marked in the Metropolitan Region For the rest, a slightly more uniform risk distribution is observed with municipalities with slightly high risk (“orange”) both in the north-central-RM zone and low (“green”) in the south zone.

- Urban Fires: The Impact Chain analyzes the risk of fire in urban settlements in all the communities of the country. Considers the variation in the incidence of temperatures above 30ºC, the urban population that is projected to reside in the country's municipalities in 2035, the percentage of homes with an “unrecoverable” and “recoverable” materiality index, and the communal rate of number of companies of firefighters per 100,000 inhabitants. From the physical risk map, some exposure can be observed in municipalities in the central area of the country and some more exposed in the northern area. However, in general the exposure to this risk is low.

- Hydroelectric Generation: The maps represent the impact chain and the risk of increased marginal costs of the electrical system associated with the decrease in water resources of the country's main hydroelectric generation plants because of climate change. The index takes high values in communities with high connected electricity consumption where their electricity supply needs to compensate for electricity generation using other more expensive resources. On the map it can be identified that the municipalities where the risk of water insecurity would increase the most are in the central zone and in the metropolitan region. Furthermore, in the regions immediately to the south, the risk increases to very high for some communes distributed heterogeneously within the regions. On the other hand, a high risk is identified in some coastal communes in the lower north. A moderate increase in the risk of urban domestic water insecurity was shown in the northern and southern regions of the country. Finally, in the extreme north and south a risk reduction from low to very low was identified.

- Heat Mortality: The risk is characterized as the increase in population mortality due to the change in temperature from the base period (1980-2010) to the future period (2050, as an average of the projected temperature for the years 2035-2064). The map shows communal premature mortality, which corresponds to the number of deaths from non-accidental causes expected by the year 2050, considering an increase in temperature due to climate change. This map shows that the exposed municipalities are in the central and northern areas of the country (orange and red colors).

c. Administrative debt records:

The administrative debt records come from the "Debtors System" file of the Financial Market Commission as of December 2022. Collapsed information is available per debtor for direct debts related to commercial credits transactions that a particular debtor has with the banking system[12]. This information corresponds to the universe of firms with legal personality in Chile.

In general, as expected considering the business model of banks, sales and debt show high spatial correlation (**Figure 2.1**). In terms of physical risks, most of debt and sales are usually located in municipalities where water safety risk is high (**Figure 2.2**). However, when it comes to extreme heat, there is a more even distribution across geographical areas (**Figure 2.3**). Related to the previous aspect, the risk of heat mortality is higher in areas that concentrate more debt and sales, as a reflection of the concentration of added value in the Metropolitan Region (**Figure 2.4**). Regarding urban fires, they have a low prevalence as physical prospective risk, most municipalities with high sales and debt are located away from these areas (**Figure 2.5**). About hydroelectric generation, one major source of electricity in Chile where near a quarter of the total is linked to this technology, most municipalities are in areas with low risk of increases in the marginal cost of generation (**Figure 2.6**).

As a first exercise we split all 345 municipalities equally into three groups (terciles) under each of the five physical risks we are considering, namely: water safety, extreme heat events, urban fires, heat mortality and hydroelectric generation difficulties. These terciles define thresholds for each risk dimension, so we label these regions as low, medium, and high risk. Results are in **Tables 2a and 2b**, based on the location of the seller and buyer, respectively. We find that for water safety risks about 74% of the sales are associated to sellers located in high-risk areas, this share climbs to 77% when calculated using the location of the buyer, so there does not seem to be much diversification of this particular risk from the sellers' point of view. Concentration is lower when it comes to urban fire risks, for both sales and debt, either from the point of view of the buyer or seller, this share amount to about 15%. These results point to high concentration is some dimensions of physical risks and to high heterogeneity across risks. Also, they suggest that there is room for diversification for sellers, in terms of the physical risks faced by their buyers.

The administrative sales records show a significant concentration of billing in municipalities in the metropolitan region, where it is possible to observe a significant concentration of municipalities in darker colors (Annex 1.1.2). While in the north, one municipality in particular, Antofagasta, stands out highly probably due to mining activity in the area (Annex 1.1.1). A similar situation can be observed in

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[12] More information about the characteristics of the debtor file used, see the "Debtor System" manual, section D10 file, available at: https://www.cmfchile.cl

terms of debt concentration.

4. Methodology

Through these indicators we can identify those municipalities most likely to suffer the impacts of droughts, wave heaths, fires, and hydroelectric dependence and indirectly through the administrative records of sales and debt those companies most exposed. As mentioned in BCBS (2021) droughts may pose a greater risk to the financial health of borrowers affecting firms in terms of production, supply chains and lower demand.

To compute physical risk exposures at the municipality level, we began by collecting micro-level administrative sales data. Next, we integrated this administrative sales data with firm-level debt data information. This integration allowed us to link sales data to specific firms and their debt profiles.

We then utilized physical risk scenarios developed by the ARClim at the municipality level. The future climate is not a prediction, but a projection based on a scenario of intense greenhouse gas emissions (NGFS RCP8.5)[13]. These scenarios provide estimates of the likelihood and severity of adverse natural events, such as floods, droughts, and extreme temperatures, occurring in each municipality.

By combining the administrative sales data and debt with the physical risk scenarios at the municipality level, we were able to compute granular exposures to adverse natural events for each firm. This involved assessing the probability and potential impact of each event on the firm's operations, revenues, and financial health.

Finally, we analyzed the computed exposures to identify patterns in physical risk across different regions in Chile. This analysis provided insights into the potential impacts of climate change on the economy and guided the development of risk mitigation strategies.

To compute the exposure to physical risk by municipality we define:

$$e_{it} = ln\,(r_{it} * f_{it})$$

Where r_{it} is a dimension of physical risk for municipality i in the period t, f_{it} is a real or financial characteristic and e_{it} is the exposure. Both r_{it} and f_{it} are rescaled to lie within the unit interval.

5. Results

Physical Risks and Financial variables

Water Safety – Sales (administrative/total) – *Debt (Annex 1.2.1 – 1.2.1.2)*
After estimating our exposure index, the high physical risk in the central and southern areas dissipates

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[13] Representative Concentration Pathways (RCPs). This high-emissions scenario if frequently referred to as "business as usual", suggesting that is a likely outcome if society does not make concerted efforts to cut greenhouse gas emissions. Compared to the total set of RCPs, RCP8.5 corresponds to the pathway with the highest greenhouse gas emissions.

due to the crossing with sales and debt. The Metropolitan Region maintains its high exposure due to both indicators (physical and financial). While in the north, one commune in particular, Antofagasta, is clearly intensifying, highly likely to mining activity in the area.

Extreme Heat – Sales (administrative/total) *– Debt (Annex 1.2.2)*
The exposure rate intensifies in several municipalities. In the northern area it is observed that several go from low to intermediate risk (green to yellow) and those from intermediate risk to slightly high risk (yellow to orange). In the central zone, the upper-intermediate municipalities intensify their index, mainly in the metropolitan region. In the southern zone, several low-risk communes increase to intermediate (green to yellow). In summary, the sales and debt of Chilean firms are exposed to the physical risk of extreme heat in the northern and central zone.

Urban Fires – Sales (administrative/total) *– Debt (Annex 1.2.3)*
Although the physical risk in general is low (Annex 1.1), when combined with the concentration of sales and debt, the combined exposure index shows an overall deterioration at the national level.

Hydroelectric Generation – Sales (administrative/total) *– Debt (Annex 1.2.4)*
The concentration of sales and debt explains a general deterioration in the risk index, especially in the central and northern areas of the country.

Heat Mortality – Sales (administrative/total) *– Debt (Annex 1.2.5)*
The index shows that in the central zone the municipalities reduce their exposure, something similar can be seen in the northern zone. However, here it is possible to observe that darker colors tend to predominate, which would indicate greater exposure of the firms' sales and debt to this physical risk.

6. Final remarks

Climate change poses significant challenges to economies worldwide, including Chile. Our study focuses on evaluating the financial repercussions of climate change, specifically addressing physical risks in Chile. By utilizing a unique dataset comprised of micro-level administrative sales data from the Chilean tax authority, combined with firm-level debt and physical risk scenarios developed by ARClim based on NGFS scenarios at the municipality level, we were able to compute granular exposures to adverse natural events for each firm.

Our analysis reveals a notable concentration of billing and debt in municipalities within the metropolitan region, indicating potential economic vulnerabilities to climate change impacts in these areas. Additionally, the physical risk map highlights that municipalities in the central zone of Chile face the highest likelihood of increased water insecurity and extreme heat, with implications for sectors reliant on stable water sources and vulnerable to heat stress.

The exposure index shows that while some municipalities reduce their exposure when considering sales and debt, the Metropolitan Region maintains its high exposure due to both physical and financial indicators. In the northern zone, the municipality of Antofagasta stands out, likely due to the prevalent mining activity in the area, intensifying its exposure to physical risks.

Our results are robust to using different sources of sales data, such as microdata for invoices and official administrative tax records, enhancing the reliability and applicability of our findings.

Further analysis is needed to explore if banks have reacted and changed their exposure to certain zones more affected by physical risk. This work is still in progress and will provide additional insights into the financial sector's response to climate change impacts in Chile.

Overall, our study will provide valuable insights into the potential consequences of climate change on various economic sectors in Chile. By offering a comprehensive and nuanced assessment of climate-related financial risks and closing data gaps, our study serves as a resource for policymakers, financial institutions, and researchers navigating the complex intersection of climate change and economic resilience.

As we move forward, further analysis and refinement of these initial findings will provide a deeper understanding of the potential economic impacts of climate change in Chile, facilitating informed decision-making and the development of targeted risk mitigation strategies.

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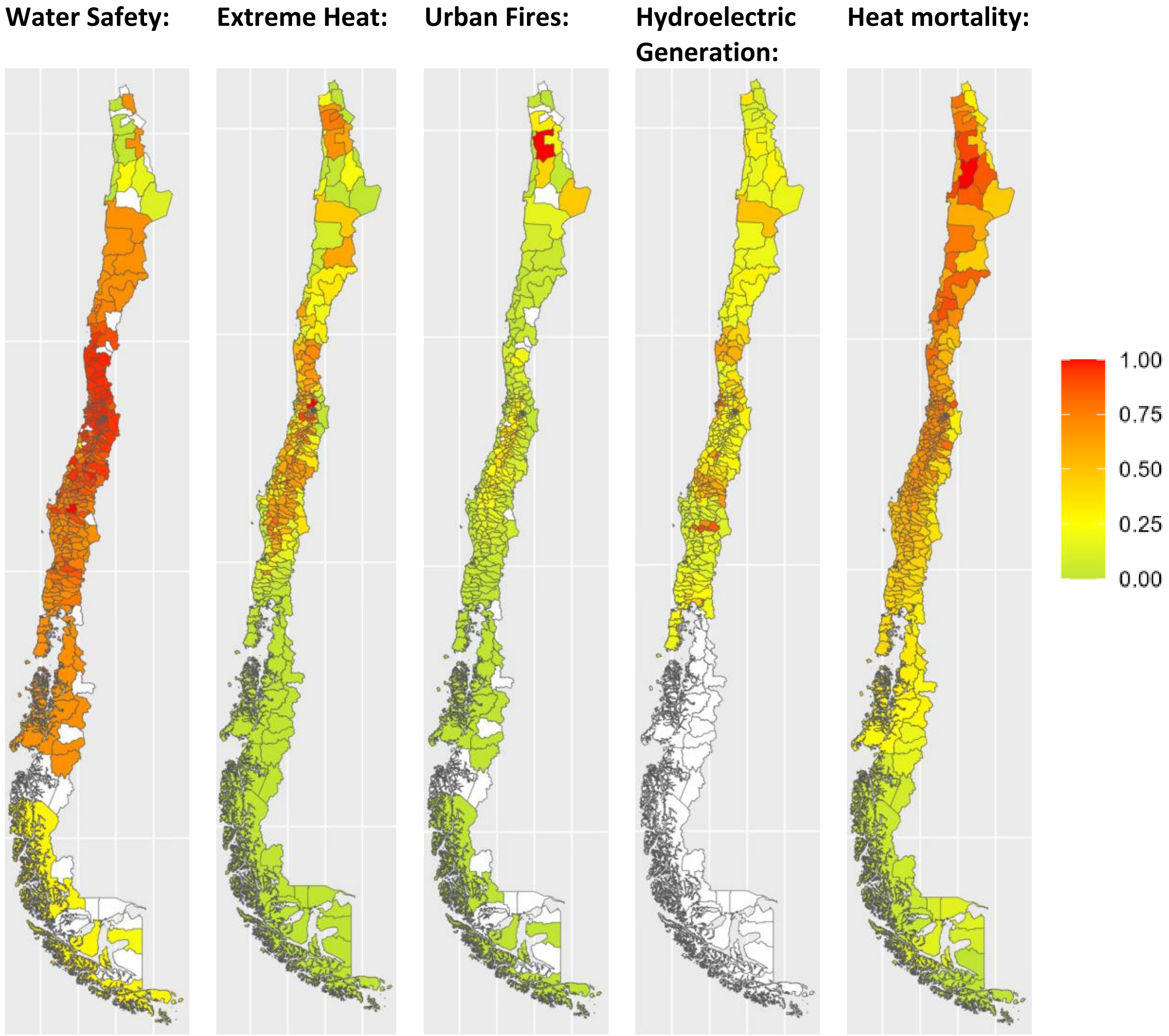
Annexes

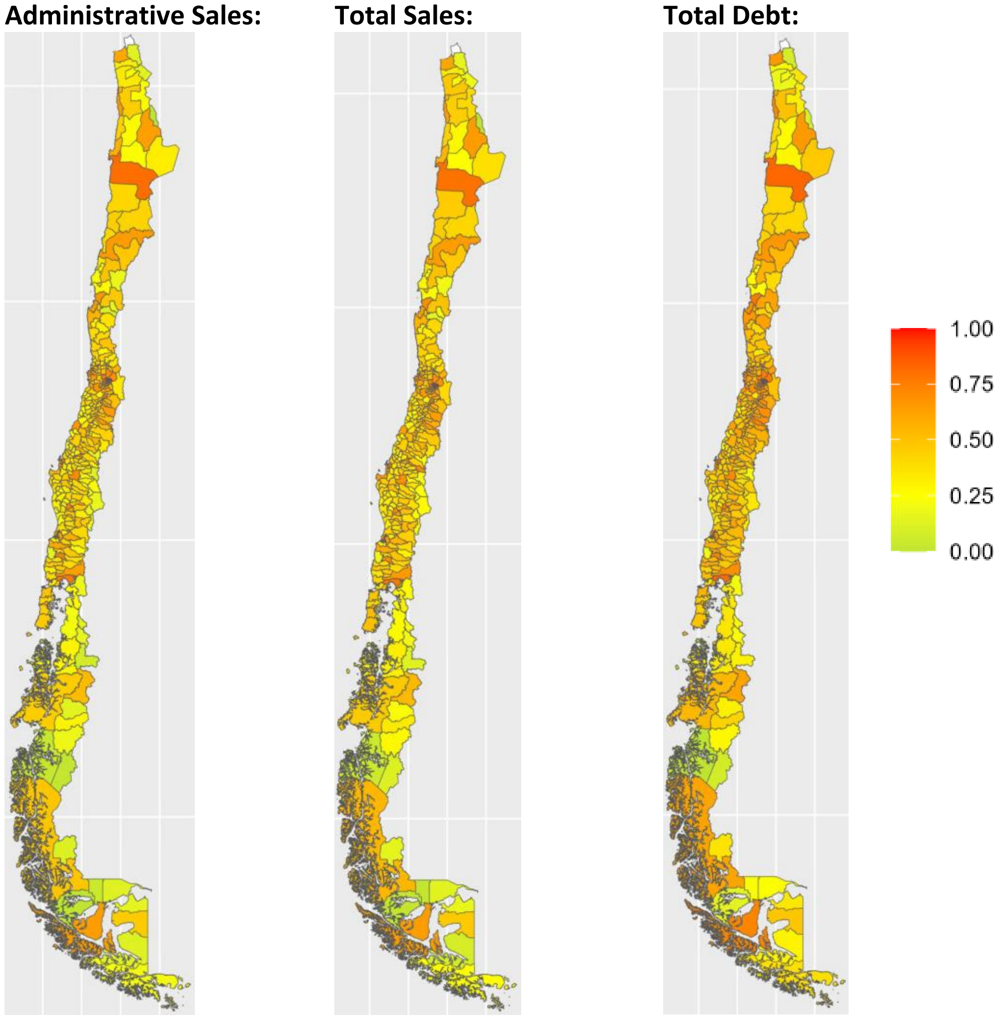
1.1 Physical Risks in Chile



Source: Central Bank of Chile based on ARClim data.

1.1 Financial variables

1.1.1 Chile

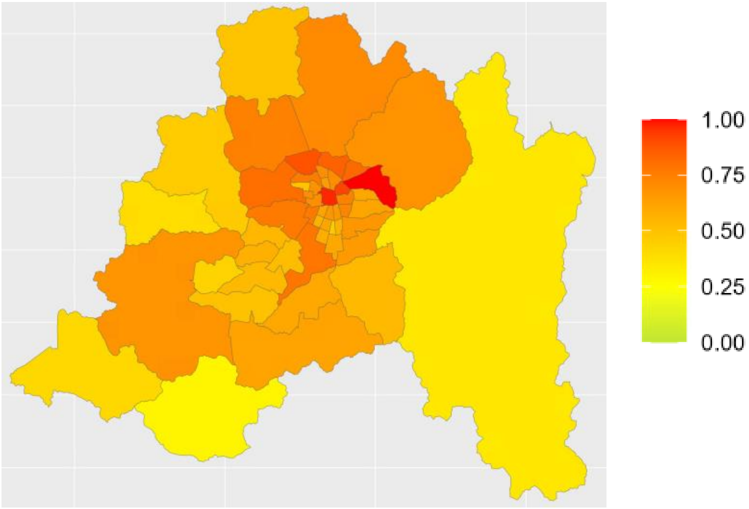


Administrative Sales: **Total Sales:** **Total Debt:**

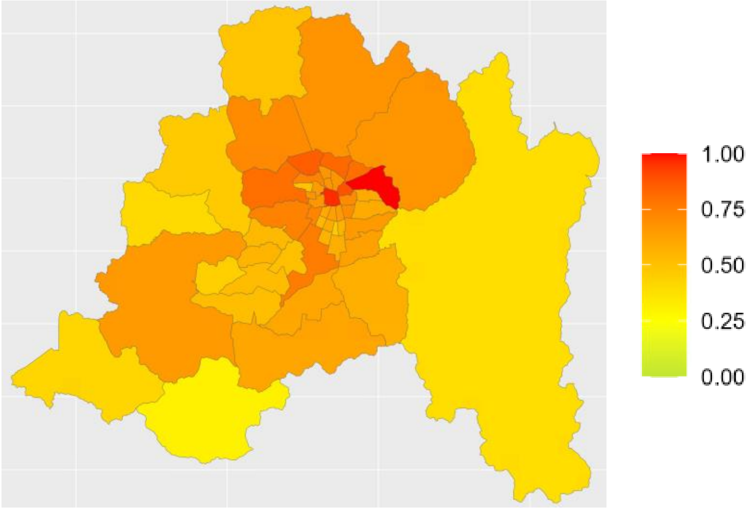
Source: Central Bank of Chile based on SII (Chilean tax authority) data.

1.1.2 Metropolitan area

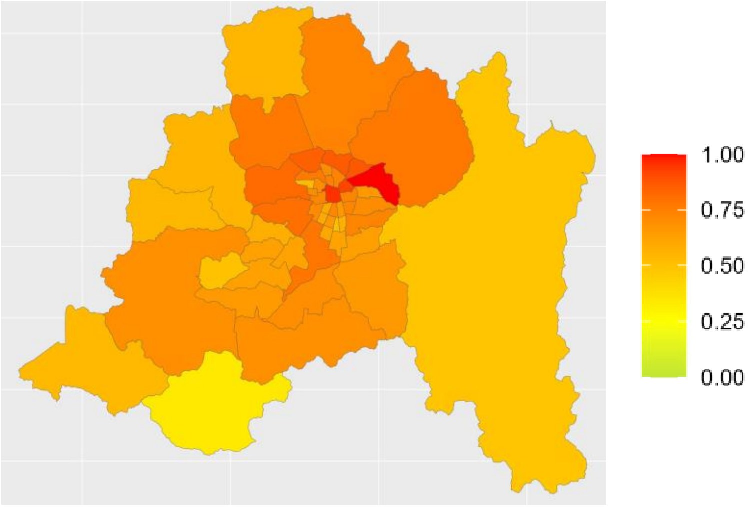
Administrative Sales:



Total Sales:



Total Debt:

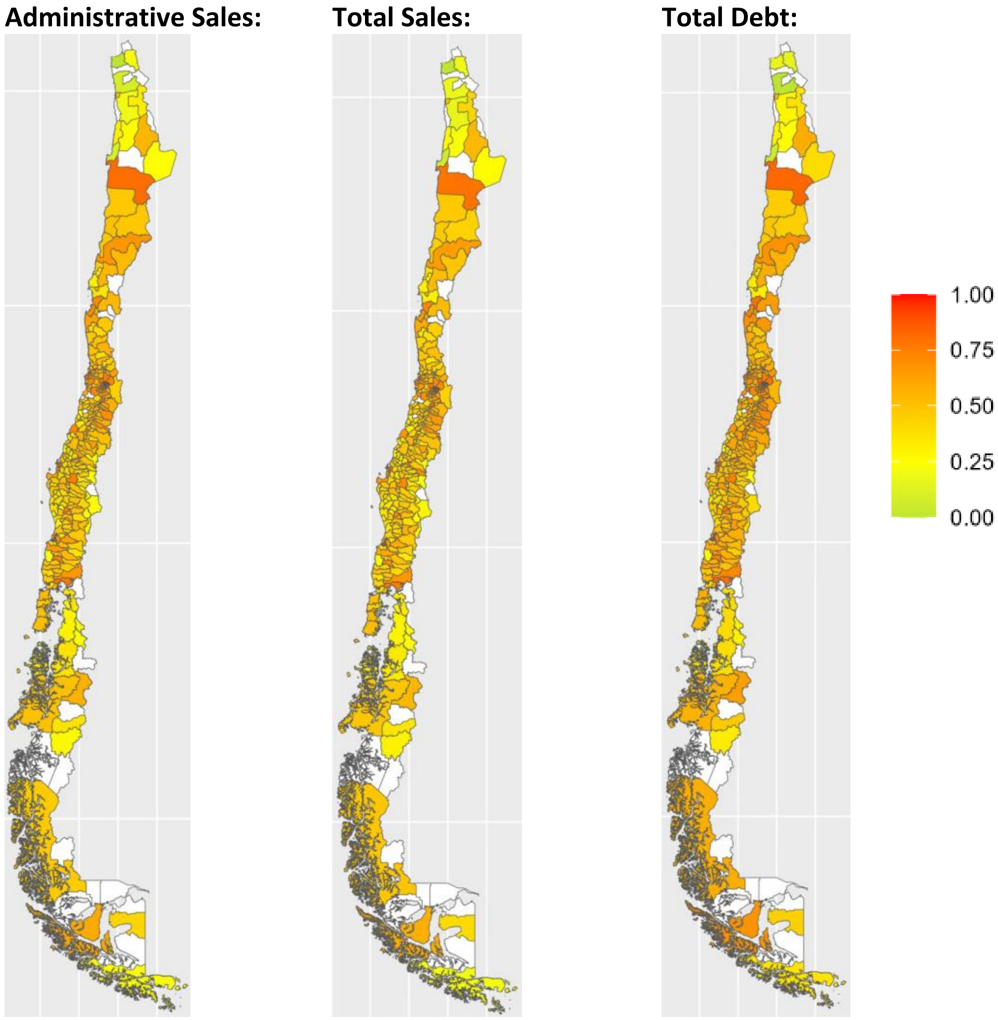


Source: Central Bank of Chile based on SII (Chilean tax authority) data.

1.2 Physical Risks – Financial variables

1.2.1 Water Safety

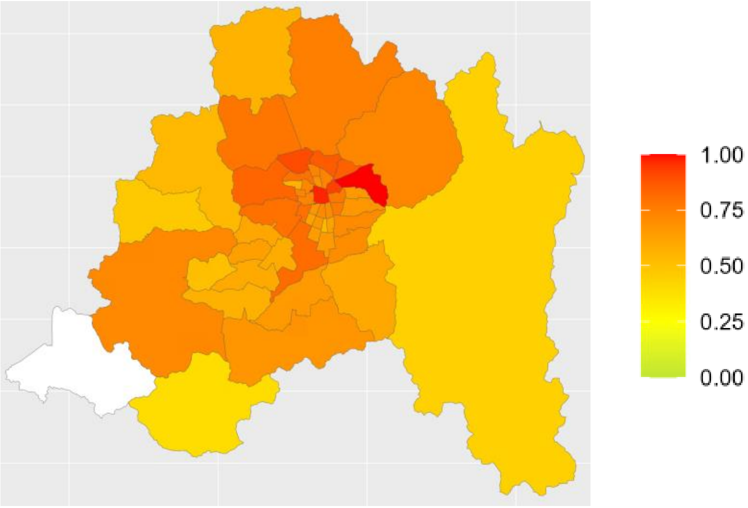
1.2.1.1 Chile



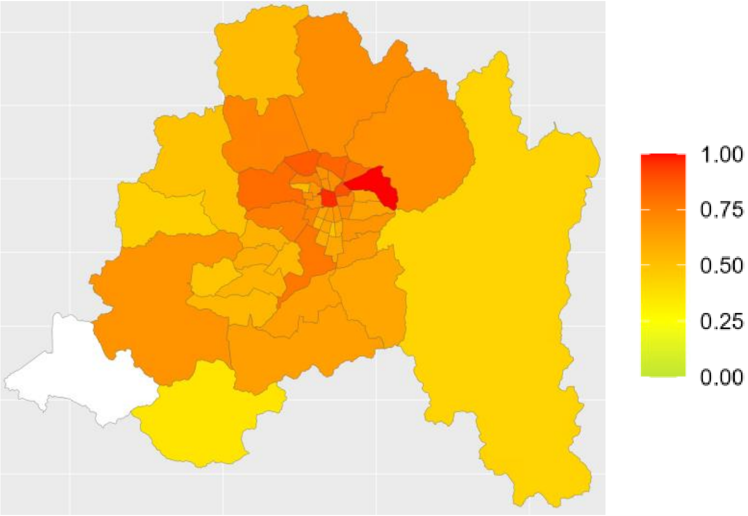
Source: Central Bank of Chile based on SII (Chilean tax authority) and ARClim data.

1.2.1.2 Metropolitan area

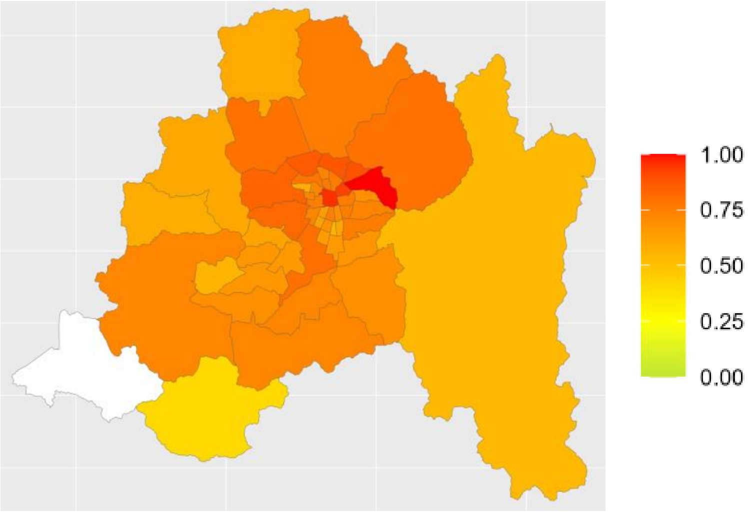
Administrative Sales:



Total Sales:

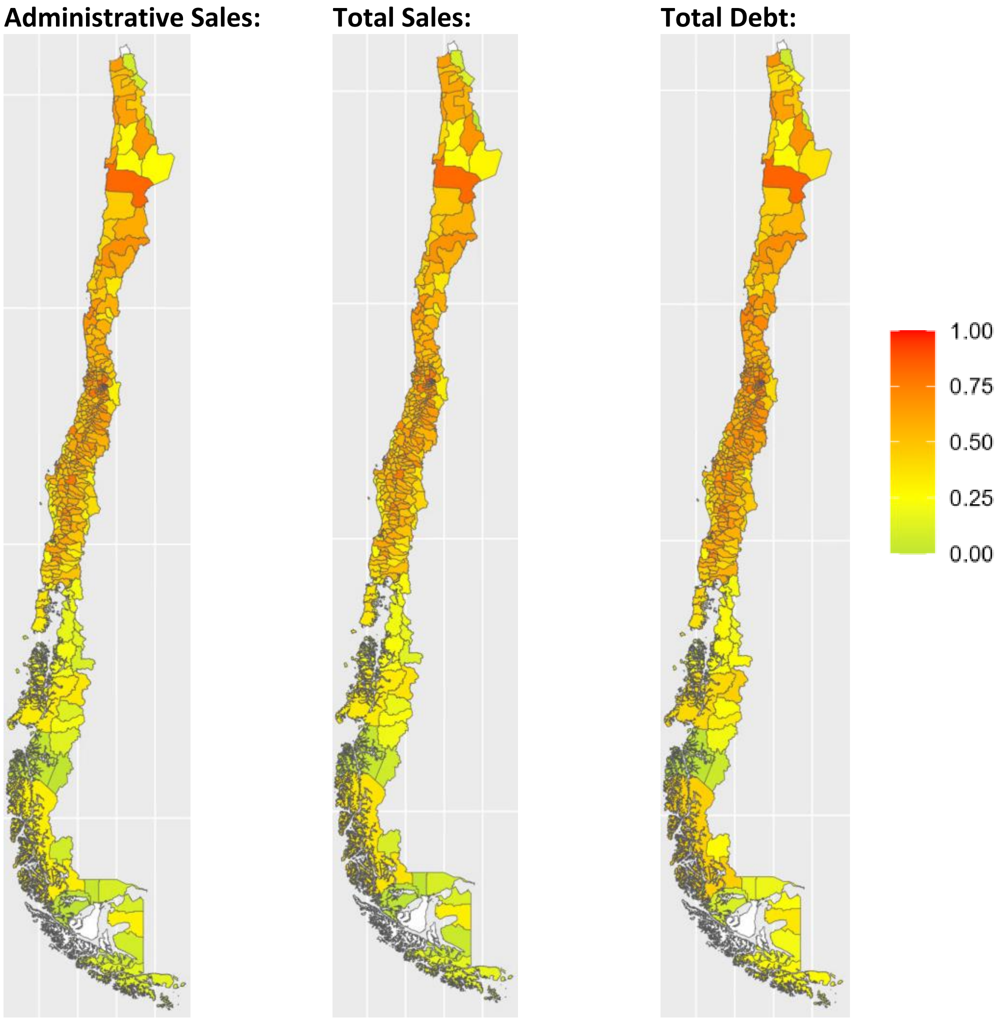


Total Debt:



Source: Central Bank of Chile based on SII (Chilean tax authority) and ARClim data.

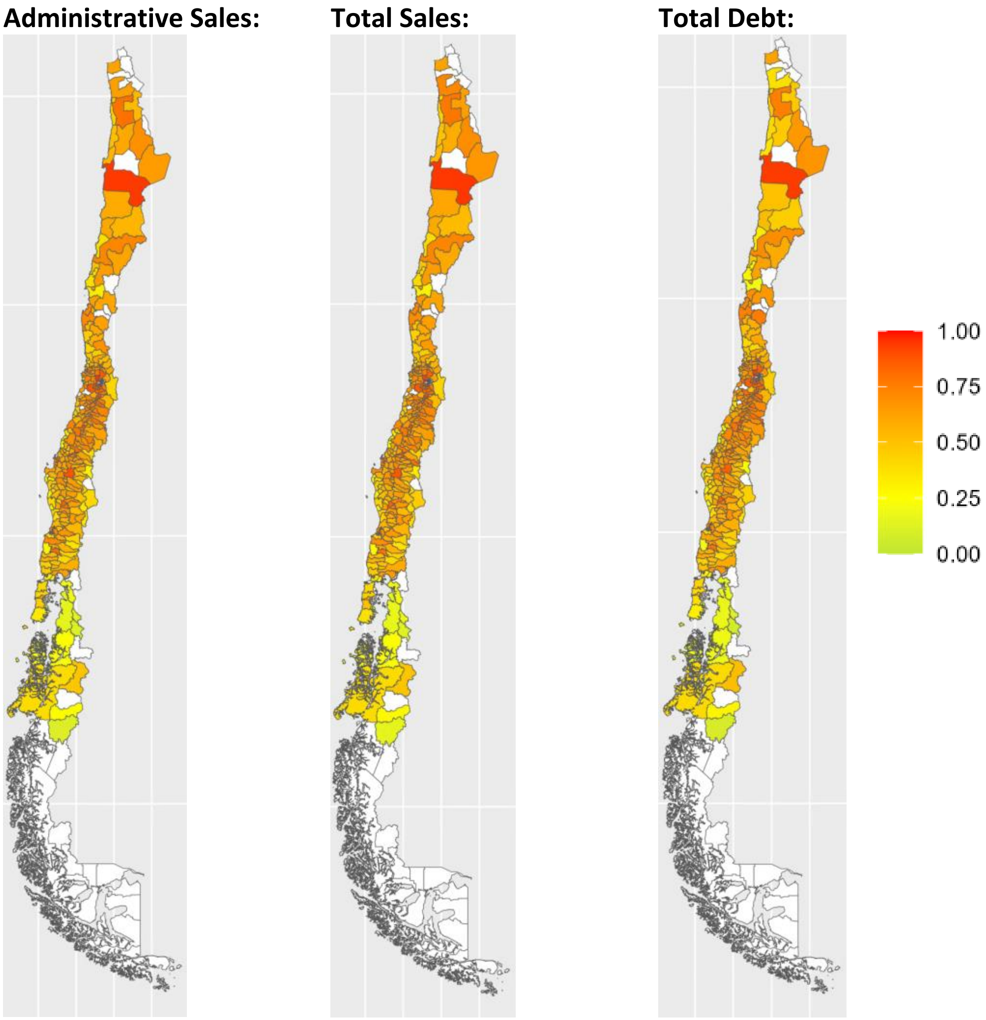
1.2.2 Extreme Heat



Administrative Sales: **Total Sales:** **Total Debt:**

Source: Central Bank of Chile based on SII (Chilean tax authority) and ARClim data.

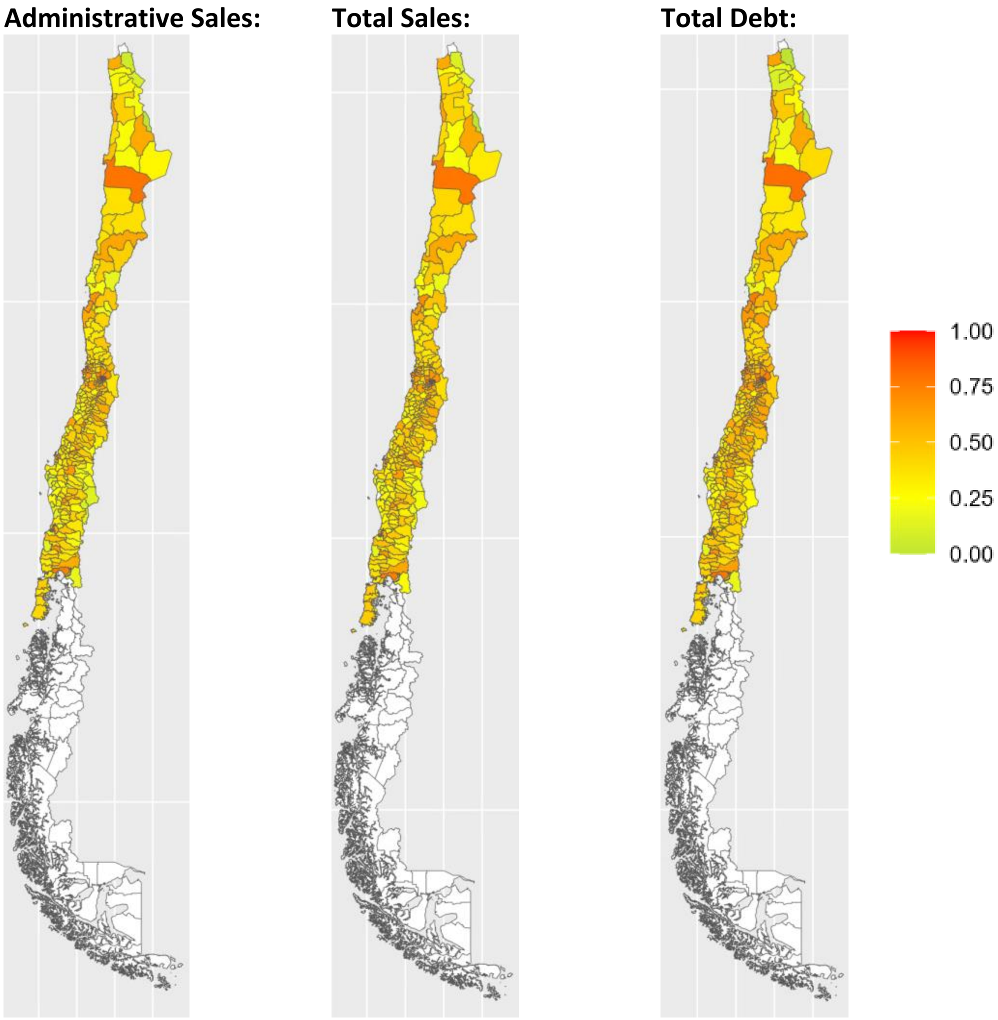
1.2.3 Urban Fires



Administrative Sales: **Total Sales:** **Total Debt:**

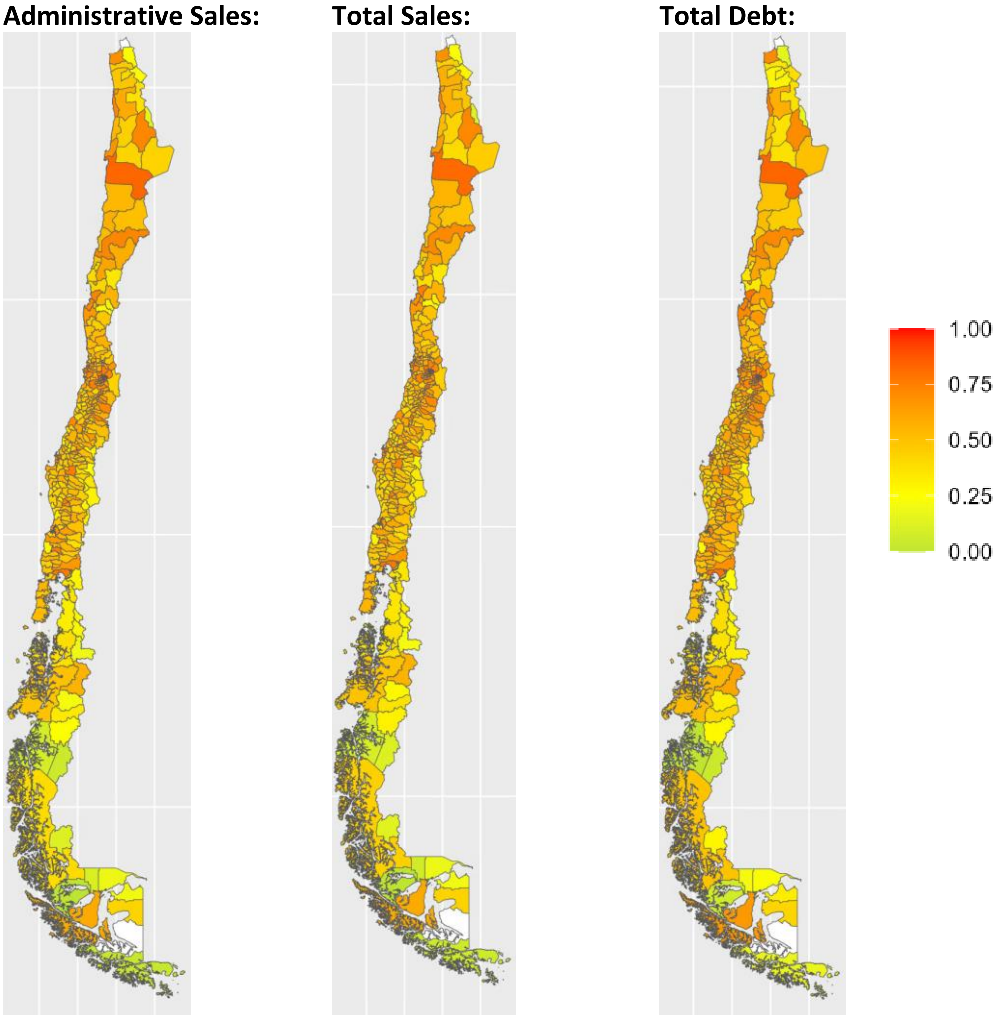
Source: Central Bank of Chile based on SII (Chilean tax authority) and ARClim data.

1.2.4 Hydroelectric Generation



Source: Central Bank of Chile based on SII (Chilean tax authority) and ARClim data.

1.2.5 Heat mortality.



Source: Central Bank of Chile based on SII (Chilean tax authority) and ARClim data.

Figure 2.1

Debt vs Administrative Sales
Sales and debt are highly correlated at the micro-level, such correlation is clearer as sales increase.

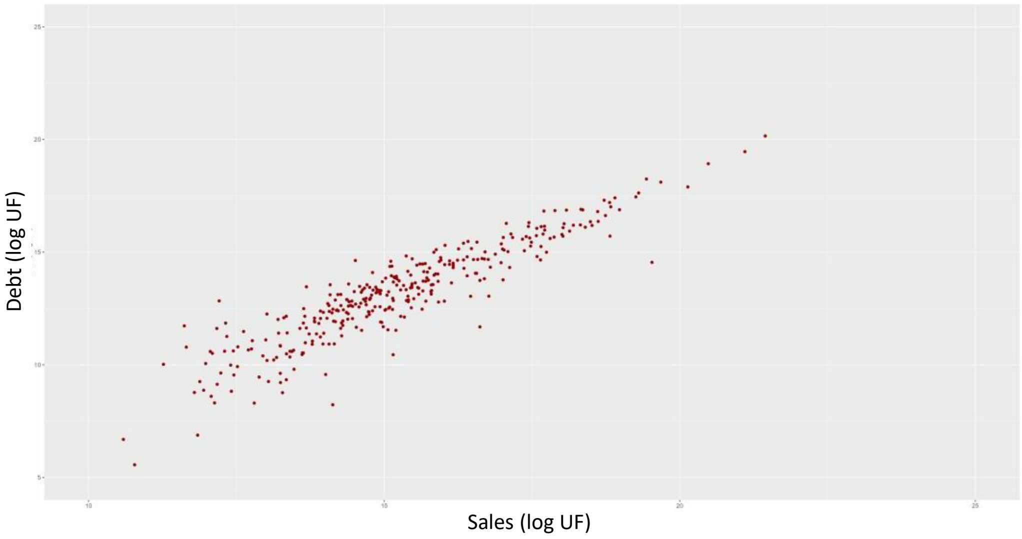


Figure 2.2

Water Safety
Most of the debt and sales are in municipalities where the water safety risk is high.

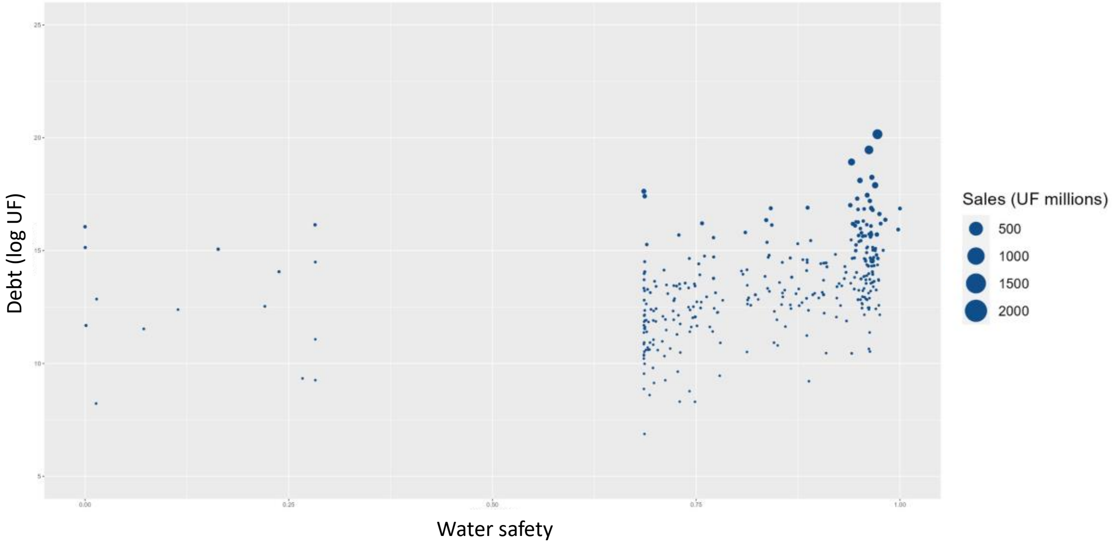


Figure 2.3

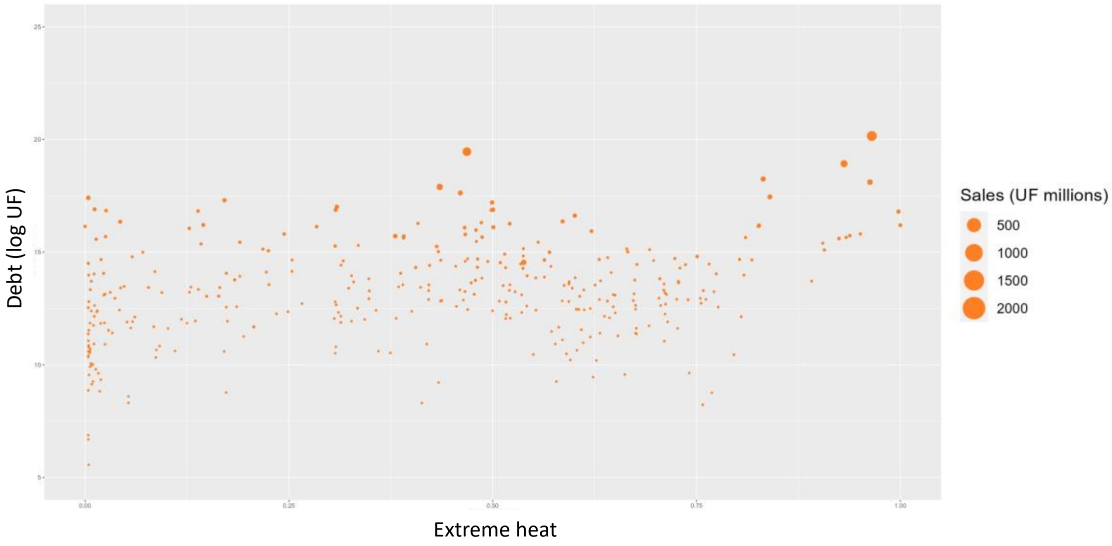


Figure 2.4

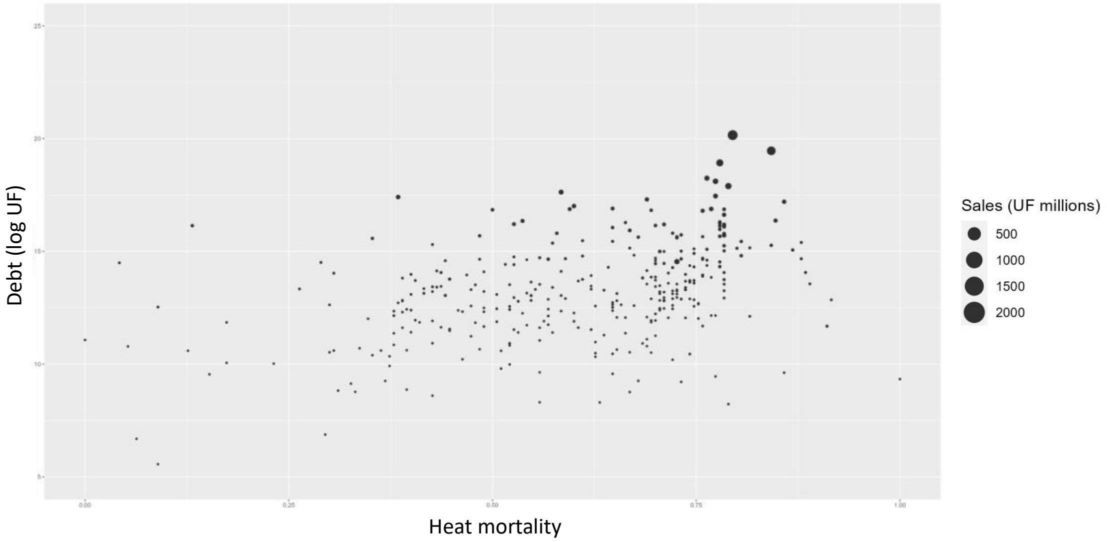


Figure 2.5

Urban Fires
Urban fires have low prevalence as prospecti

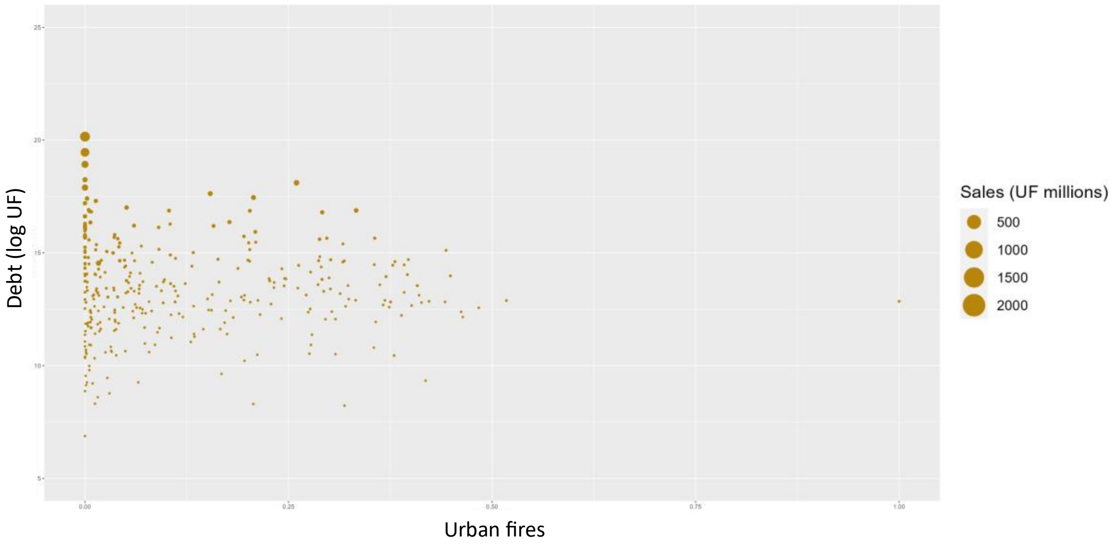


Figure 2.6

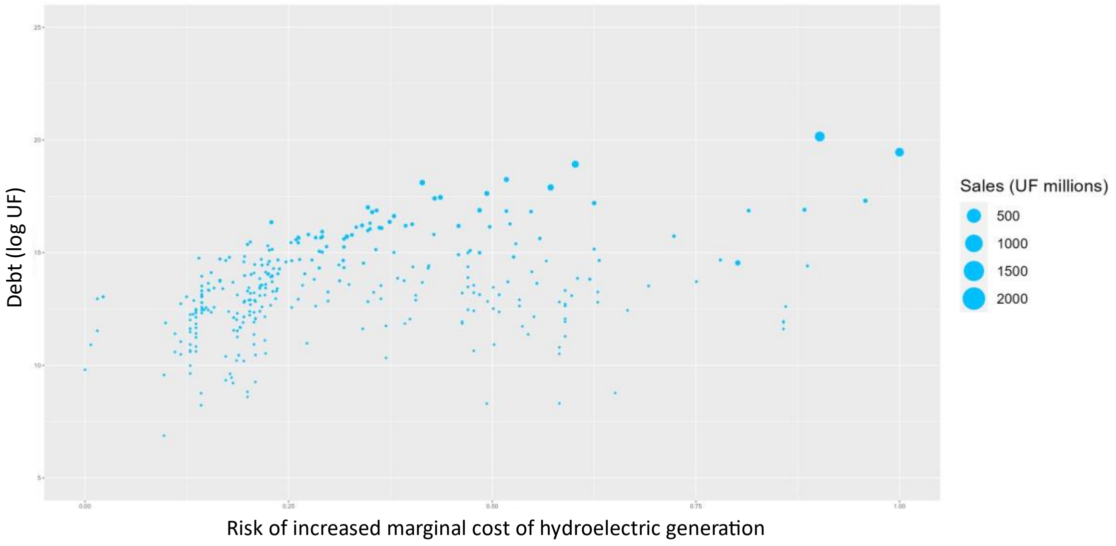


Table 2a – Distribution of debt and sales by physical risk across municipalities using the location of the seller.

Adm. Sales (percent)	Water Safety	Extreme Heat	Urban Fires	Heat Mortality	Hydroelectric Generation
Low risk	8.0	11.7	70.9	6.6	3.4
Medium risk	18.4	42.4	13.5	15.7	19.6
High risk	73.5	46.0	15.6	77.7	77.0

Debt (percent)	Water Safety	Extreme Heat	Urban Fires	Heat Mortality	Hydroelectric Generation
Low risk	7.2	11.6	73.8	6.6	2.2
Medium risk	18.2	34.5	11.5	15.6	15.3
High risk	74.6	53.9	14.8	77.8	82.5

Table 2b – Distribution of debt and sales by physical risk across municipalities using the location of the buyer.

Adm. Sales (percent)	Water Safety	Extreme Heat	Urban Fires	Heat Mortality	Hydroelectric Generation
Low risk	10.6	14.7	70.8	8.7	4.0
Medium risk	16.7	38.2	13.9	15.9	20.1
High risk	72.7	47.1	15.4	75.5	76.0

Debt (percent)	Water Safety	Extreme Heat	Urban Fires	Heat Mortality	Hydroelectric Generation
Low risk	7.1	12.0	76.6	6.4	2.1
Medium risk	16.4	28.4	10.2	14.0	14.7
High risk	76.5	59.6	13.2	79.7	83.2

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Geolocation Data Challenges for Physical and Financial Risks from Climate Change

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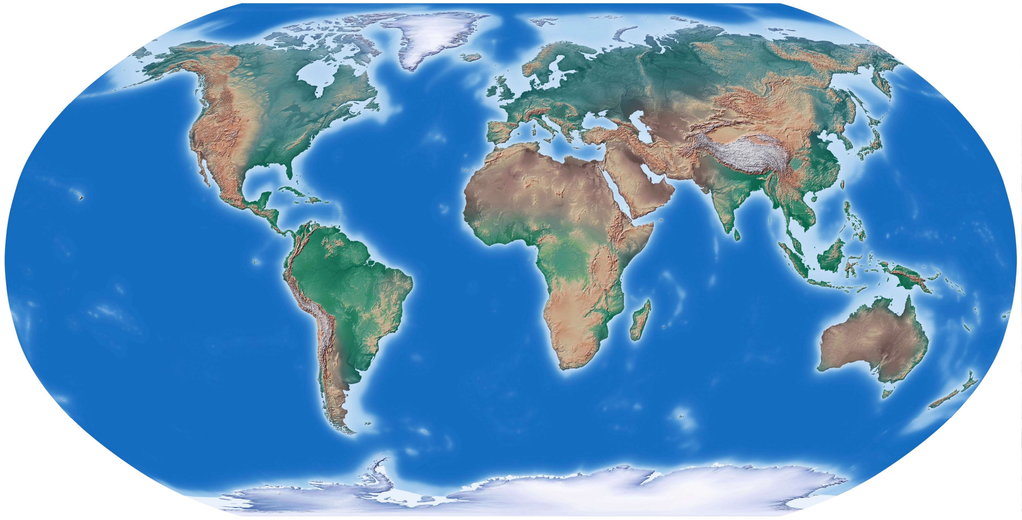
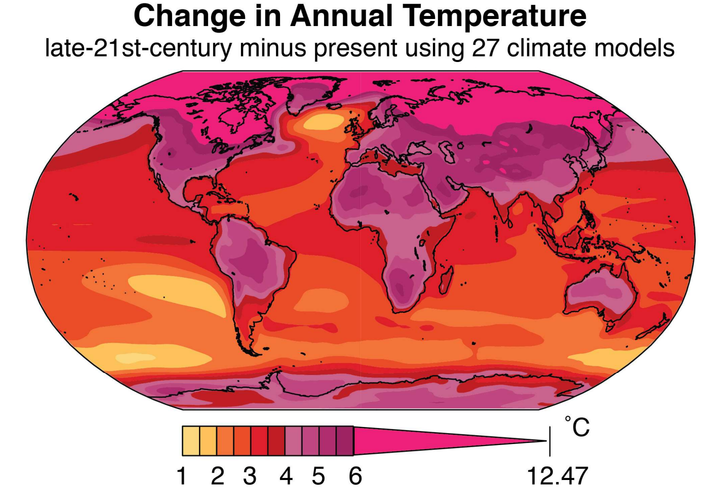
May 2024 – Izmir

CBRT-IFC Workshop
"Addressing Climate Change Data Needs: The Global Debate and Central Banks' Contribution"

Sovereign states as identified by Gleditsch and Ward (2007). Only countries that are independent today are shown in the map. Current country borders are used across time.

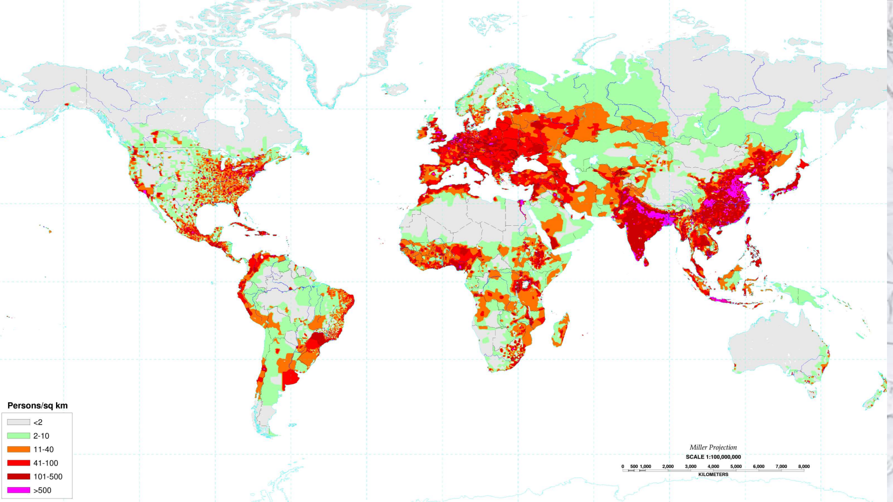
How we economists see our world





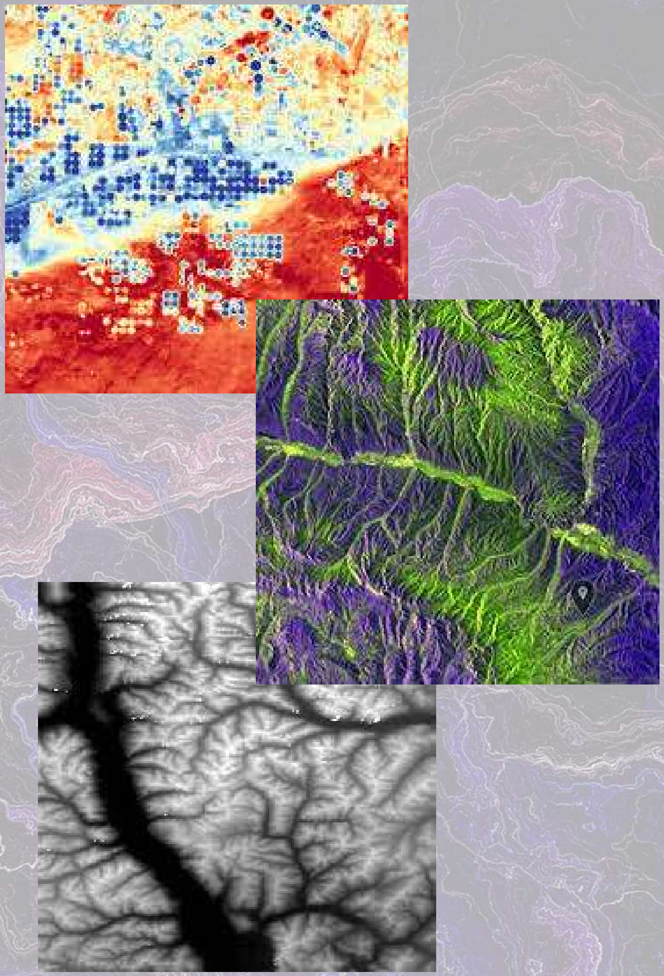
Change in Annual Temperature

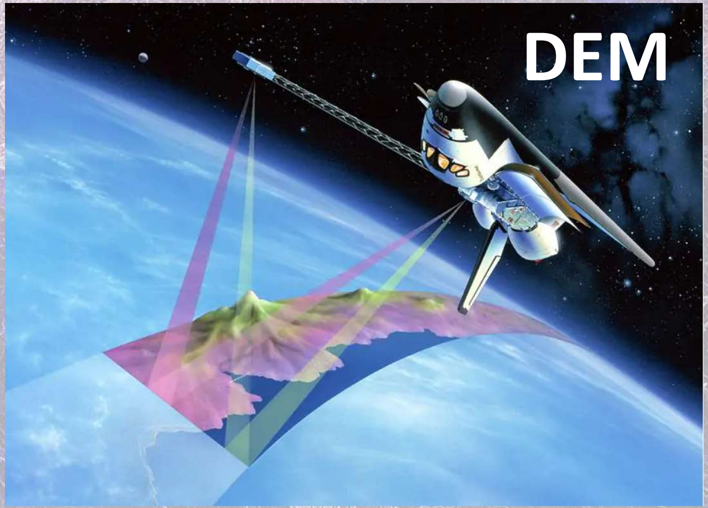
late-21st-century minus present using 27 climate models



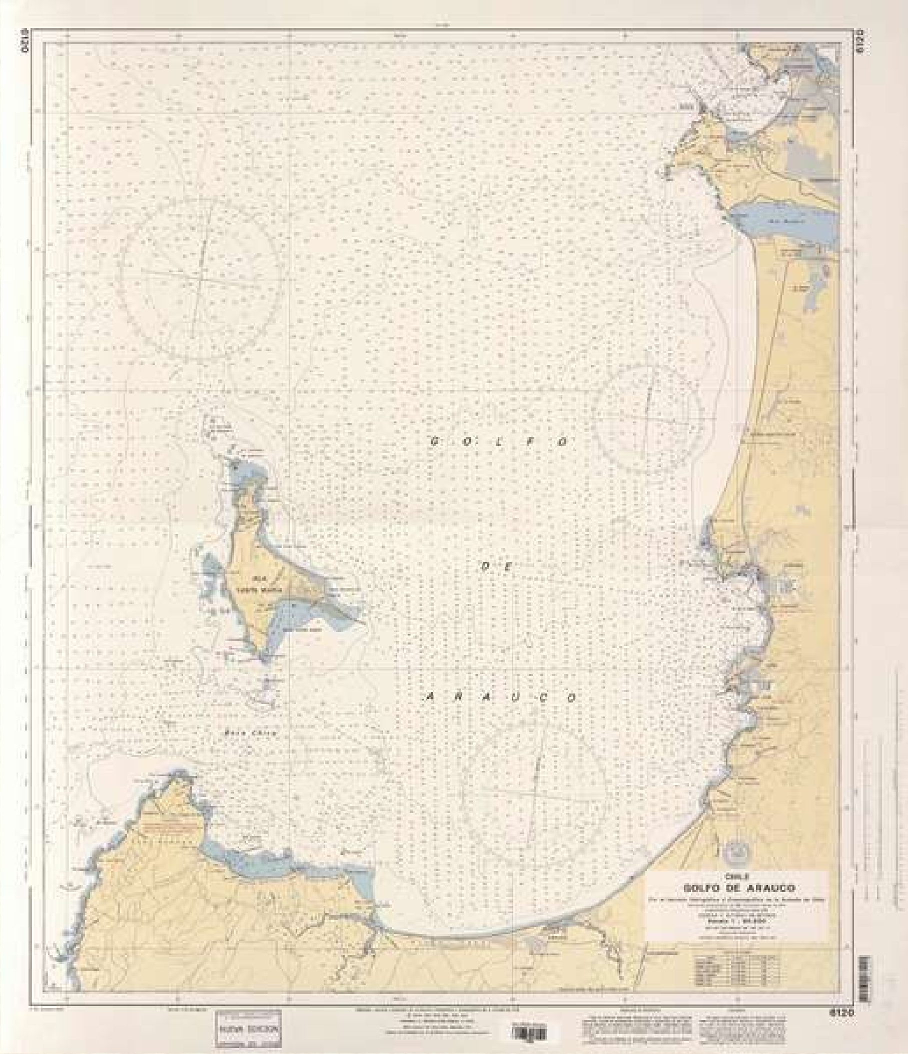
How we should see our world

We can see our world today





Land Use Land Cover Pilot @ Banco Central de Chile



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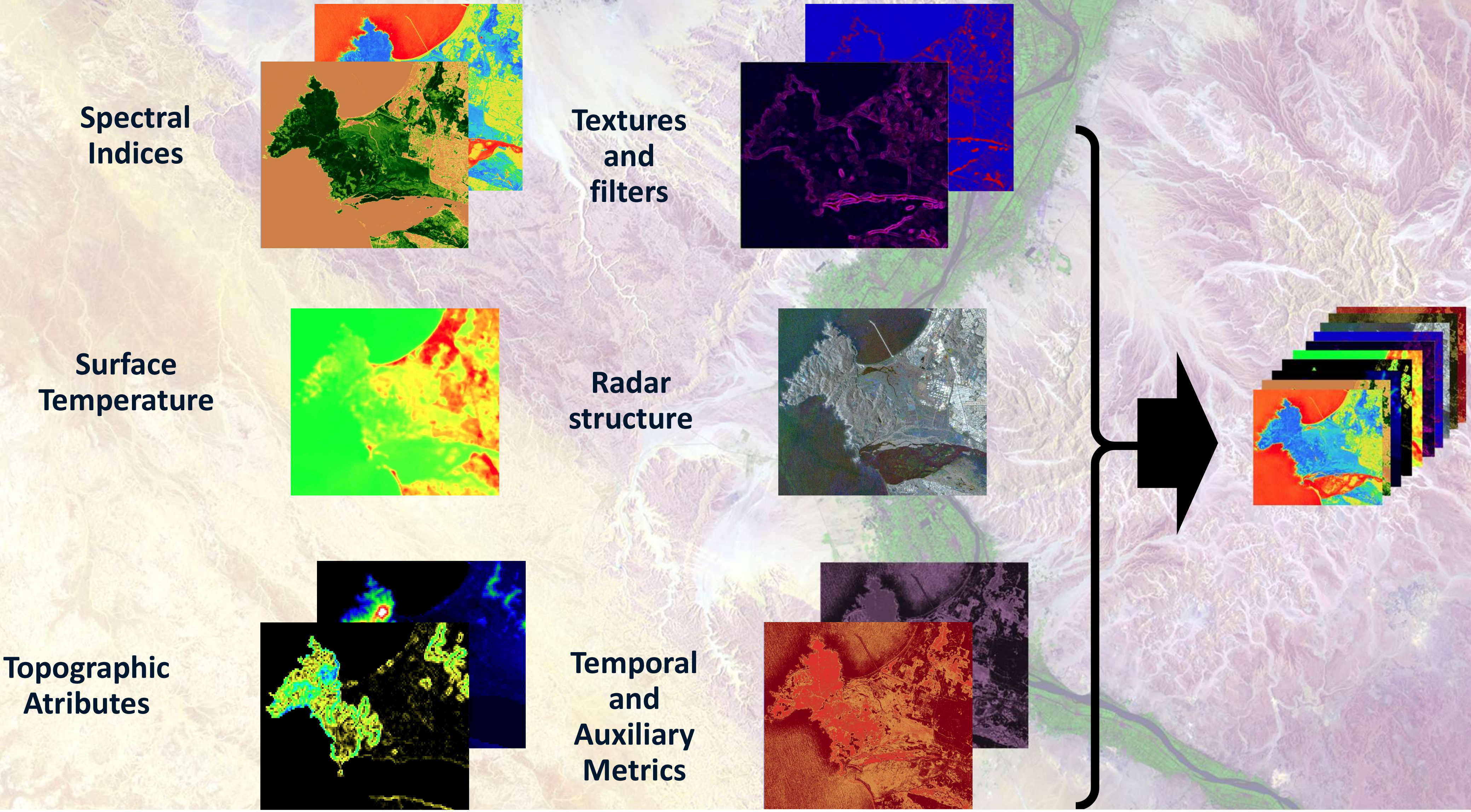

Spectral Indices

Textures and filters

Surface Temperature

Radar structure

Topographic Atributes

Temporal and Auxiliary Metrics

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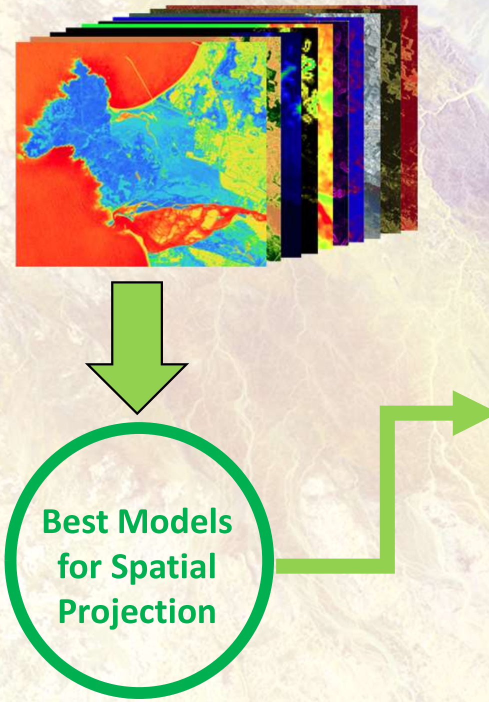
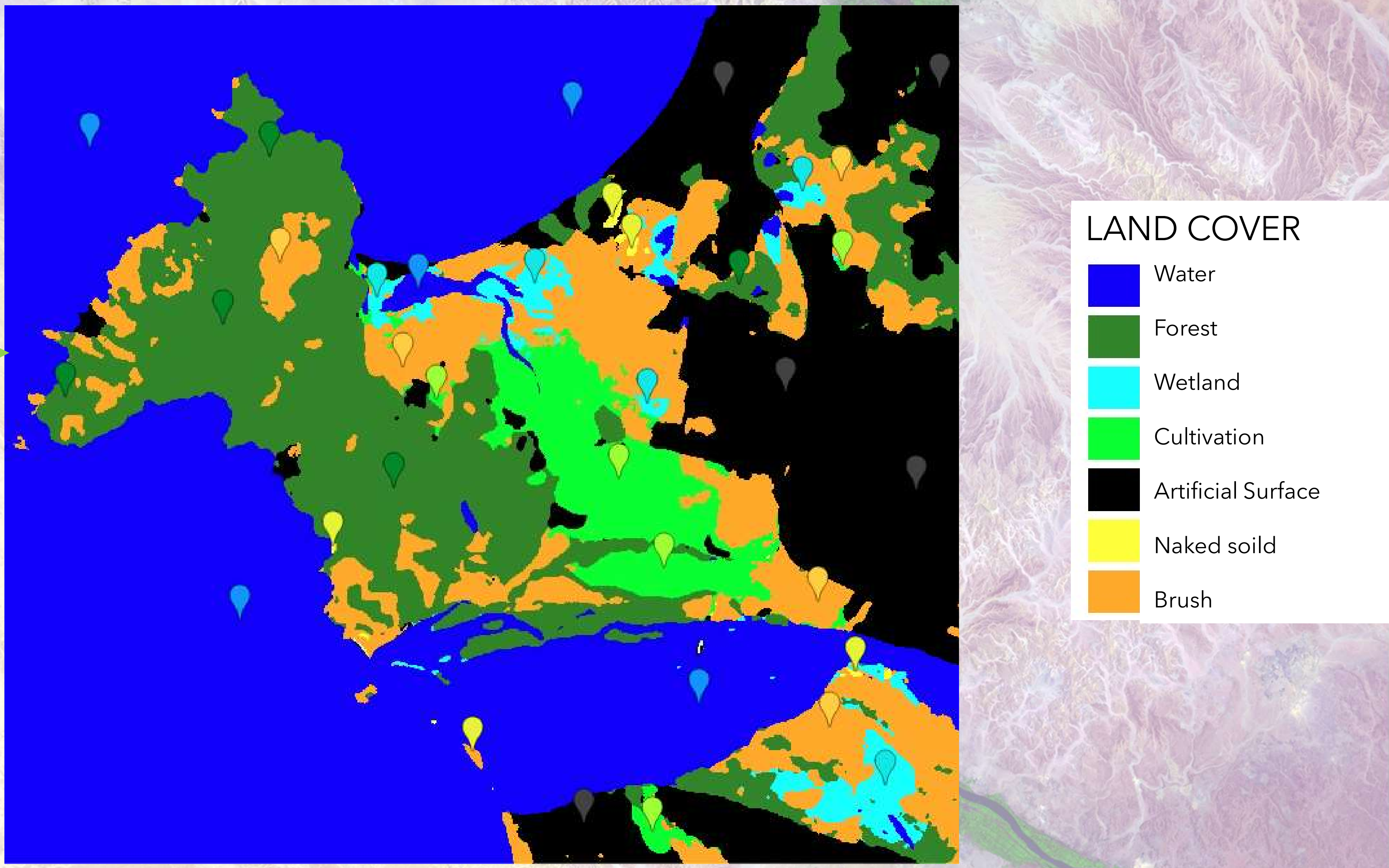


Best Models for Spatial Projection



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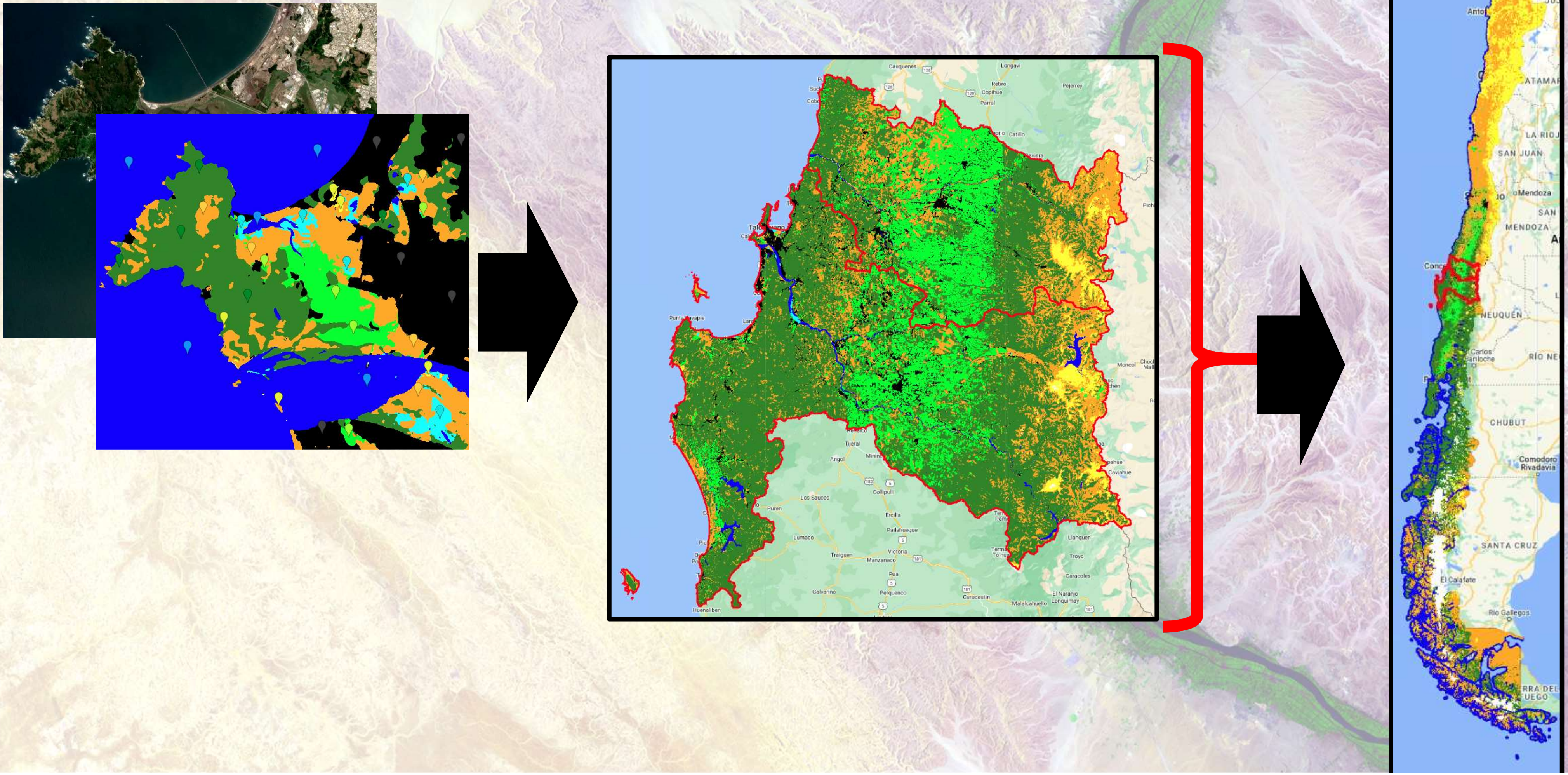
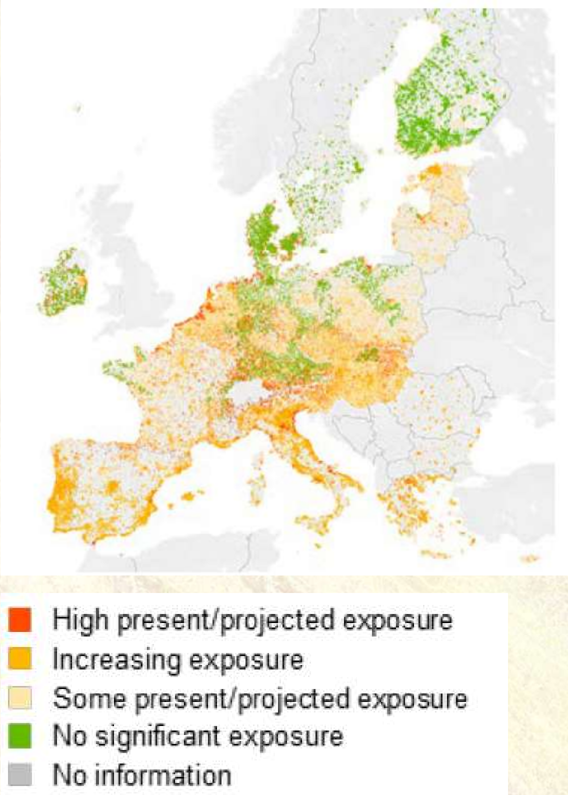


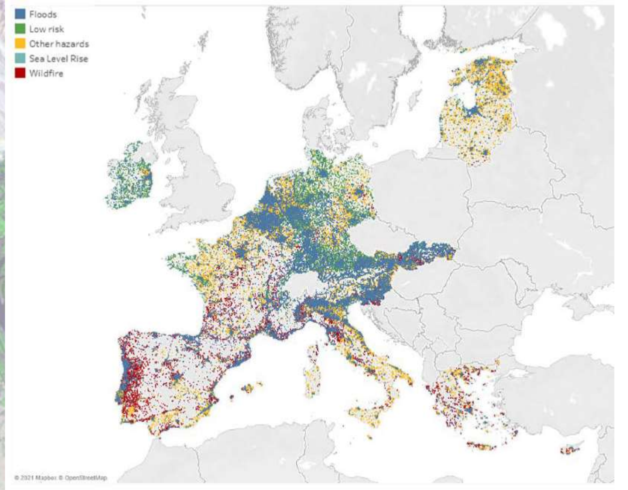
Physical Risk Exposures to Climate Risk

Corporate exposure to physical risk drivers (maximum risk level of each firm)



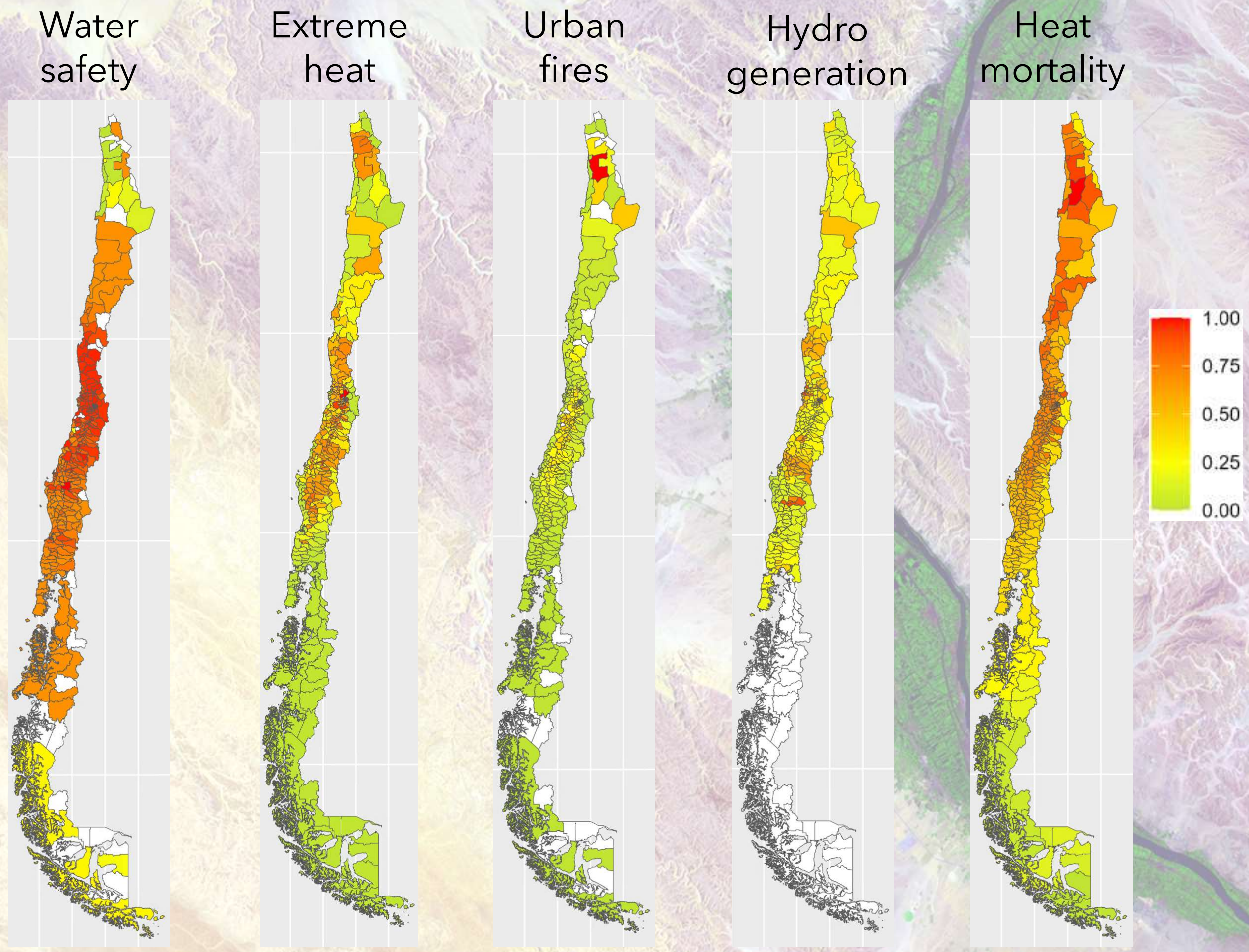
Source: Financial Stability Review. May 2021. European Central Bank

Physical risk: intensity and sources across European regions (maximum risk level of each firm)



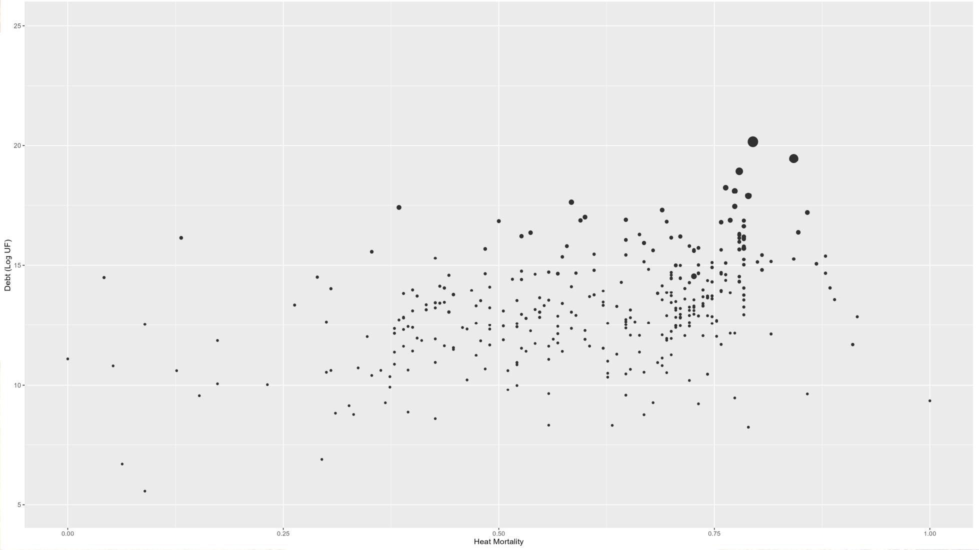
Source: Alogoskoufis et al. 2021

Physical Risk Exposures to Climate Risk

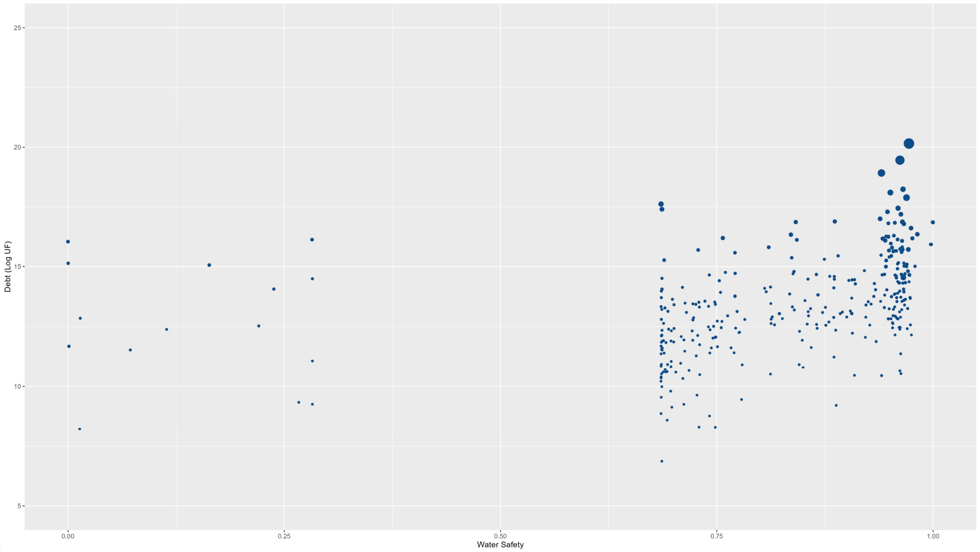


Relevance to Financial Stability

Debt (log)



Heat Mortality Risk



Water Safety Risk

Each dot is a municipality in Chile. Size is proportional to local sales. Heat Mortality and Water Safety Risks are higher in municipalities relatively large and holding more bank assets.

Incoming Challenges for the Community of Central Banks

Statistical areas in central banks will play key role

- More autonomy
- Statistics are less politically contentious at the starting point
- Requires expertise into other social and natural sciences
- Geolocation data gathering will demand ingenuity and innovation

The international dimension demands a coordinated response

- Risks and measurements do not care about political borders
- Global initiatives such as DGI3 need to be disseminated to the global community beyond G20
- BIS/IFC and IMF can be catalysts to these efforts

Policy implications will require broader engagement

- Policy implications go well beyond what can be implemented by traditional monetary/financial policies
- A proper governance in these areas will be critical to preserve the credibility of central Banks´ statistical function

THANK YOU

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May 2024 – Izmir

CBRT-IFC Workshop
"Addressing Climate Change Data Needs: The Global Debate and Central Banks' Contribution"

IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

Asset-level assessment of climate physical risk matters for adaptation finance[1]

S Battiston,
University of Zurich

Giacomo Bressan,
Vienna University of Economics and Business,

Anja Duranovic and Irene Monasterolo,
Utrecht University

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

Asset-level assessment of climate physical risk matters for adaptation finance

Giacomo Bressan (WU), Anja Đuranović (Utrecht University), Irene Monasterolo (Utrecht University), **Stefano Battiston (UNIVE, UZH)**

Climate Change Data Workshop - May 2024, Izmir

Motivation and contribution

Motivation

- Main **knowledge gaps** remain in climate physical risk assessment, hindering **capital reallocation** (Kreibiehl et al., 2022) low-carbon transition (Battiston et al., 2021)
- **Delayed action** on adaptation and mitigation leads to higher climate risks and failure to close the **adaptation gap** (UNEP, 2021)

Contributions of this paper

- A transparent **methodology**: from asset-level physical risk to financial valuation of securities
- Risk emerges from **interplay** of acute and chronic impacts on assets, assets' location and role in firm's revenues
- **Results**: neglecting asset-level dimension and tail risks can lead to underestimation of losses and non-coherent investment decisions

Literature and knowledge gaps

- **Asset-level data** (e.g. production plants): non standardized, proprietary; no consolidation (financial, climate, extrafin. info)
- **Plants' ownership** information: not standardized, difficult to reconstruct chain of ownership due to complexity of ownership networks (Garcia-Bernardo et al., 2017)
- **(Mis)pricing**: contrasting evidence, mostly for past disasters (Beirne et al., 2021, Giglio et al., 2021, Garbarino and Guin, 2021, Nguyen et al., 2022)
- Addressing these challenges is key to identify **policy responses** (Hallegatte et al., 2020), **financing needs** (GCA, 2021) and **instruments** (Mullan and Ranger, 2022) to fill the adaptation gap

CITE OUR PAPER!

G. Bressan, A. Duranovic, I. Monasterolo, and S. Battiston, Asset-level assessment of climate physical risk matters for adaptation finance, early ssrn 4062275 (2022), forthcoming (2024) on **Nature Communications**.

Are physical risks priced? Examples from the literature

- Several studies investigated **market pricing** of physical risks:
    - (Acharya et al., 2022) find that **heath stress** is most relevant for municipal bonds, non-investment grade bonds, and equity starting 2013-2015 (physical risk data **427**[1] and **SEAGLAS**[2])
    - (Gostlow, 2021) finds that **hurricanes** command a positive risk premium and **heath stress** a negative risk premium (data: **427**)
    - (Nguyen et al., 2022) document a positive sea-level risk premium for mortgages (data: **NOAA**[3])
- **Disagreement** due to data **limitations**: aggregate physical risk scores (eg. MSCI 427) diverge even within the same measurement method (Hain et al., 2022)!
- Most studies are **backward looking** (past data) but future climate will be much different: need to work with scenarios

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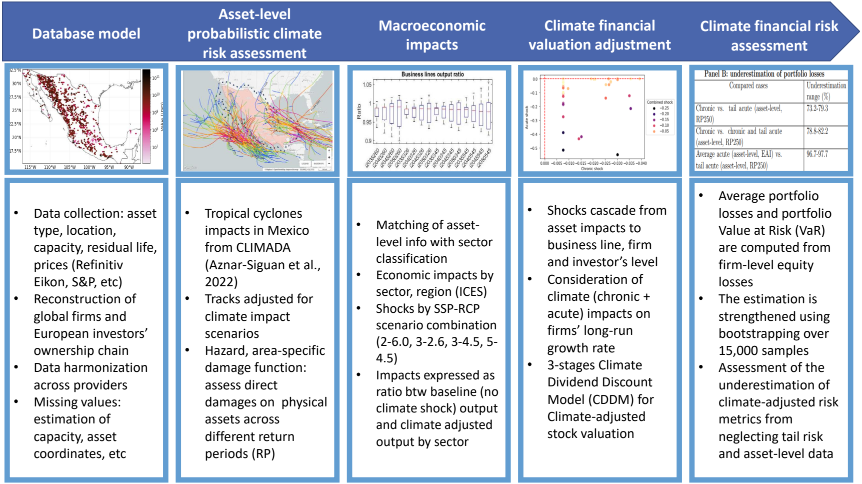
[1] https://www.moodys.com/web/en/us/capabilities/esg.html

[2] (Hsiang et al., 2017)

[3] https://www.noaa.gov/

Methodological framework



Database model

- Data collection: asset type, location, capacity, residual life, prices (Refinitiv Eikon, S&P, etc)
- Reconstruction of global firms and European investors' ownership chain
- Data harmonization across providers
- Missing values: estimation of capacity, asset coordinates, etc

Asset-level probabilistic climate risk assessment

- Tropical cyclones impacts in Mexico from CLIMADA (Aznar-Siguan et al., 2022)
- Tracks adjusted for climate impact scenarios
- Hazard, area-specific damage function: assess direct damages on physical assets across different return periods (RP)

Macroeconomic impacts

- Matching of asset-level info with sector classification
- Economic impacts by sector, region (ICES)
- Shocks by SSP-RCP scenario combination (2-6.0, 3-2.6, 3-4.5, 5-4.5)
- Impacts expressed as ratio btw baseline (no climate shock) output and climate adjusted output by sector

Climate financial valuation adjustment

- Shocks cascade from asset impacts to business line, firm and investor's level
- Consideration of climate (chronic + acute) impacts on firms' long-run growth rate
- 3-stages Climate Dividend Discount Model (CDDM) for Climate-adjusted stock valuation

Climate financial risk assessment

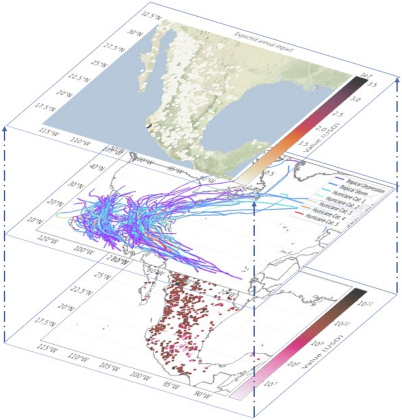
Panel B: underestimation of portfolio losses

Compared cases	Underestimation range (%)
Chronic vs. tail acute (asset-level, RP250)	73.2-79.3
Chronic vs. chronic and tail acute (asset-level, RP250)	78.8-82.2
Average acute (asset-level, EAI) vs. tail acute (asset-level, RP250)	96.7-97.7

- Average portfolio losses and portfolio Value at Risk (VaR) are computed from firm-level equity losses
- The estimation is strengthened using bootstrapping over 15,000 samples
- Assessment of the underestimation of climate-adjusted risk metrics from neglecting tail risk and asset-level data

Figure: Methodological framework for asset-level climate physical risk assessment (Bressan et al., 2022)

Asset-level probabilistic risk assessment - workflow



Impact

- Direct damages computed at different return periods and on average
- Info feeds into equity shocks and valuation adjustments

Hazards

- Tropical cyclones as computed in the CLIMADA model
- Other acute hazards shall be considered in further studies

Geolocalized assets

- Referenced by latitude/longitude
- Defined by asset type (e.g. power plant, mine, etc.)
- Non-financial variables (e.g. capacity, residual life)
- Financial variables (e.g. value)

Figure: Workflow for probabilistic disaster risk assessment for tropical cyclones in Mexico (Bressan et al., 2022).

Asset-level probabilistic risk assessment - hurricanes

- **Assets' geolocations** matched to wind-speed along tracks
- Assets are shocked with a damage function that translates wind speed in plant losses (monetary value):
  - $F_{index} = \frac{v^3}{(1+v^3)}$, $v = \frac{max((W_{spd} - W_{tresh}),0)}{(W_{half} - W_{tresh})}$
  - Where $W_{tresh} = 65 km/h$ and $W_{half} = 253 km/h$ (Dunz et al., 2021)
- Impact computed as **Expected Annual Impacts (EAI)**:

$$EAI_j = \sum_{i=1}^{N_{ev}} x_{ij} F(E_i), \tag{1}$$

- where X is the impact random variable, E_i an hurricane, F its annual frequency, N_{ev} are the independent events considered.
- Impact also computed for tail events (high **Return Periods (RP)**).

Climate-adjusted financial valuation

- We develop a three stages climate dividend discount model (CDDM)

$$V_0 = \sum_{t=1}^{t_1} \frac{D_t}{(1+r)^t} + \sum_{t=t_1+1}^{t_2} \frac{D_t}{(1+r)^t} + \frac{D_{t_2}(1+g_L)}{(1+r)^{t_2}(r-g_L)} \qquad (2)$$

- D_t dividends, r discount rate, g_L long-run growth rate of dividends.
- Calibration:
  - Between $t = 1$ and t_1 firms' dividends provided by S&P
  - Between t_1 and t_2 Earnings Per Share are multiplied by payout ratio to describe the reversion of dividends
  - From t_2 onward the terminal value is computed.
- CDDM distinguishes short and long run impacts of physical risk.

Chronic and acute physical risks lead to adjustments in g_L

$$\tilde{g}_{L,(I,j)} = g_L \sum_{i=1}^{K_j} \left(\frac{O_{I,j,i}}{O_{B,j,i}} \frac{1}{\delta_{I,j,i}} s_{j,i} \right) \tag{3}$$

Adjustments from g_L to the climate risk-adjusted $\tilde{g}_L$ depend on:

- **Chronic shocks** on sectors and business lines, described by $\frac{O_{I,j}}{O_{B,j}}$:
  - $O_{I,j,i}$ and $O_{B,j,i}$: output trajectories calculated for each business line i of owner j respectively under climate scenario I and baseline B
  - A ratio smaller than 1 implies a negative impact from chronic shock
- **Acute shocks** on assets described by $\frac{1}{\delta_{I,j,i}}$ for j:
  - δ: aggregation of acute shock on firms' assets by business lines
- The impact of both shocks is weighted by $s_{j,i}$, i.e. the **revenue share of the business line**, for all K_j firm's business lines.

Application to Mexico

- Mexico (MX) is relevant for cascading economic and financial losses: it is exposed to physical risks and has FDI and listed firms with global investors, it is also a main beneficiary of adaptation finance (UNEP, 2021).
- 177 firms (MX + internationally owned) with 1,820 geolocalized assets in MX
- Exposure of European investors (banks, pension funds, etc) to MX firms via 17,147 equity holdings, 290.11 bn USD (June 30, 2020)
- Climate adjusted financial evaluation carried out at the year 2020
- Climate financial risk metrics computed with bootstrap

Acute shocks at the asset level

- Assets are heterogeneously distributed in MX, and differ by sector and productive capacity
- The impact of tropical cyclones increases significantly for higher Representative Concentration Pathway (RCP) scenarios and RP

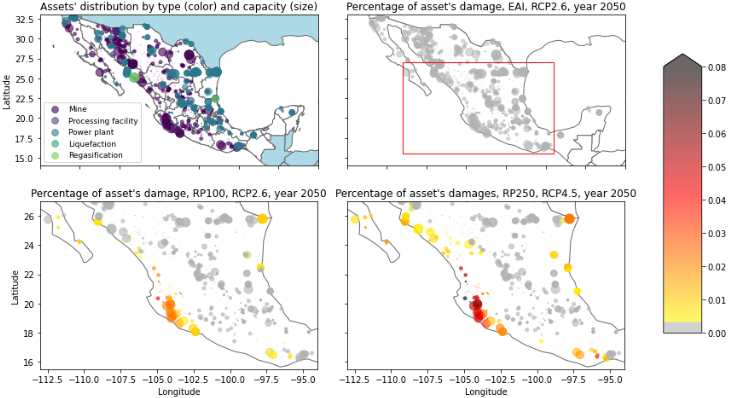
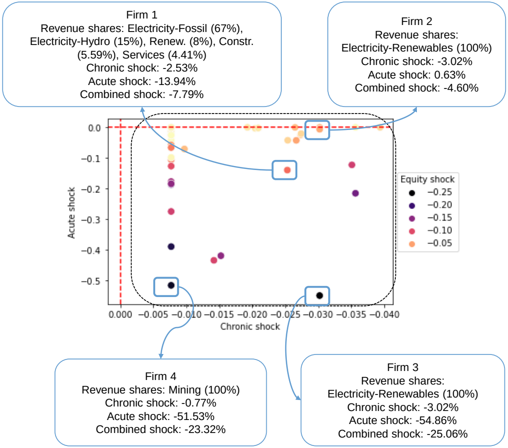


Figure: Assets' distribution and direct impact of hurricanes on assets (Bressan et al., 2022)

Acute vs chronic shocks on firms' stocks

1. Diversified firms (Firm 1) have both acute and chronic shocks depending on share of revenues from assets and geolocations
2. Firms can have similar chronic shock (because same sector) but very different acute shock (due to geolocalization, Firm 2 vs. Firm 3)
3. Firms can have large acute shocks even if operating in different sectors (Firm 3 vs. Firm 4)
4. Firms can be affected by similar large acute shocks but different chronic shock (same pair as above)



Firm 1
Revenue shares: Electricity-Fossil (67%), Electricity-Hydro (15%), Renew. (8%), Constr. (5.59%), Services (4.41%)
Chronic shock: -2.53%
Acute shock: -13.94%
Combined shock: -7.79%

Firm 2
Revenue shares: Electricity-Renewables (100%)
Chronic shock: -3.02%
Acute shock: 0.63%
Combined shock: -4.60%

Firm 4
Revenue shares: Mining (100%)
Chronic shock: -0.77%
Acute shock: -51.53%
Combined shock: -23.32%

Firm 3
Revenue shares: Electricity-Renewables (100%)
Chronic shock: -3.02%
Acute shock: -54.86%
Combined shock: -25.06%

Figure: Scatter plot: for each firm (dot) shows acute, chronic and combined shocks. Scenarios combination SSP3, RCP4.5, year 2040. X-axis: chronic shock (relative change in stock value to no-shock), Y-axis: % of asset damages (Bressan et al., 2022).

Acute impacts lead to large losses on firms' stock value

- Black line: equal RP250 and average acute shocks on firms
- Firms below the black line: RP250 shocks are larger than EAI
- RP250: longer tail and larger support of distribution than EAI
- For 35% of firms: acute tail risk (RP250 loss) 3x larger than average losses (measured as EAI). Ignoring acute shocks leads to underestimation of losses on stocks

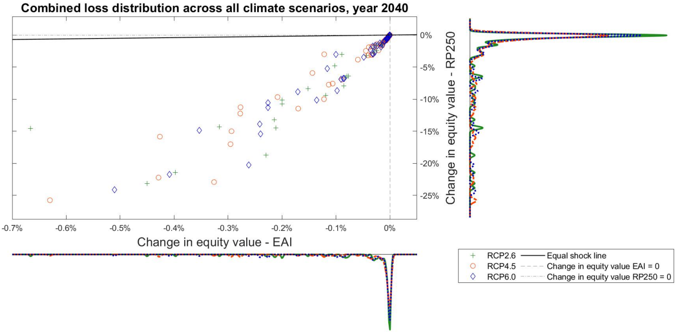


Figure: Scatter plot for the joint EAI and RP250 loss distributions for the year 2040, 86 companies with available asset-level data (Bressan et al., 2022).

Impact of discount rate and growth rate on equity value

- Higher (lower) **discount rate** r, lower (higher) equity losses
- Higher (lower) **growth rate** g_L, higher (lower) equity losses
- Higher (lower) **difference** $r - g_L$, lower (higher) equity losses

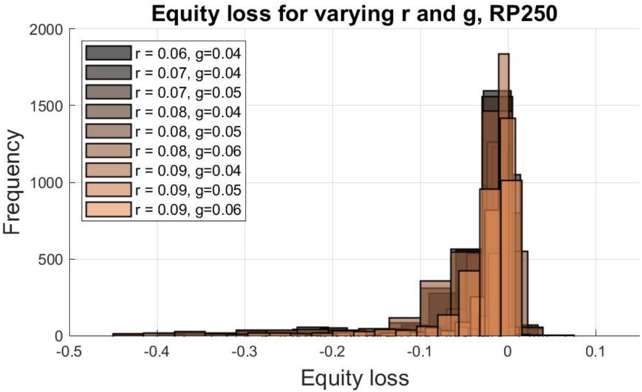


Figure: Sensitivity analysis of company-level losses from physical risk to different combinations of r and g_L (Bressan et al., 2022).

Tail acute risks and underestimation of losses

- How physical risks translate into portfolio losses for investors?
- We compare different futures of physical risks and quantify the underestimation of portfolio losses
- Neglecting acute risk leads to an underestimation of portfolio losses up to 82.2% Neglecting the tail component of acute risk (RP250) leads to an underestimation of portfolio losses up to 97.6%

Compared physical risk futures	**Underestimation range (%)**
Chronic vs. tail acute (asset-level, RP250)	73.2-79.3
Chronic vs. chronic and tail acute (asset-level, RP250)	78.8-82.2
Average acute (asset-level, EAI) vs. tail acute (asset-level, RP250)	96.7-97.4

Table: Underestimation of portfolio losses, scenario SSP3-RCP4.5, year 2040 (Bressan et al., 2022).

Asset-level data and underestimation of losses

- We compute results for the same firms as if asset information was not available, i.e. we measure physical risk at companies' MX HQ
- We quantify the underestimation of portfolio losses using firm-level instead of asset-level data
- Neglecting asset-level impacts leads to an underestimation of losses up to 70.8% for investors' portfolios

Case	**Underestimation range (%) firm-level vs. asset-level**
Acute RP250 (tail)	67.4-92.3
Chronic and acute RP250 (tail)	58.0-70.8

Table: Underestimation of portfolio losses (cont'd), scenario SSP3-RCP4.5, year 2040(Bressan et al., 2022).

Conclusions

- We introduce a **science-based methodology** to assess asset-level physical risks and loss cascades, with tail acute and chronic scenarios
- The methodology includes a CDDM model to integrate climate physical risk into **financial valuation adjustment** (stocks)
- Results:
    - neglecting the **tail component** of acute risk can lead to up to 97% underestimation of portfolio losses
    - neglecting **asset-level data** can lead to up to 70% underestimation of portfolio losses
- Thus, considering tail risk and asset-level info is crucial for **climate financial risk management** and to inform **adaptation finance**.

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Appendix

Asset-level probabilistic risk assessment - historical

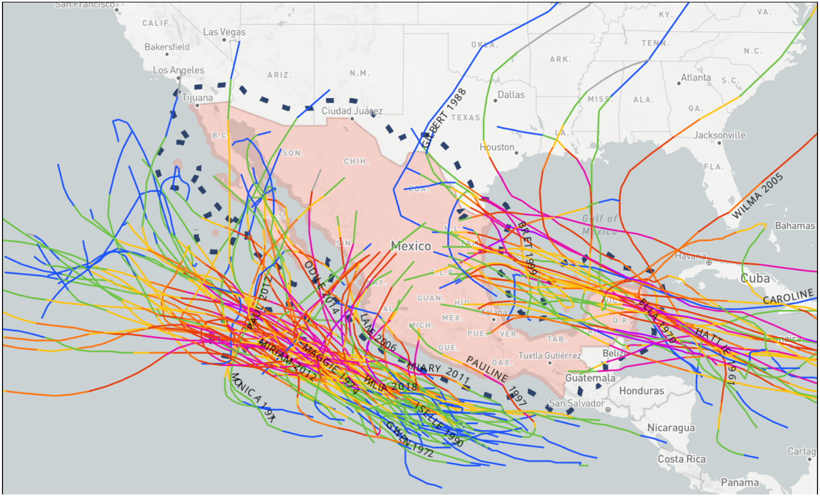
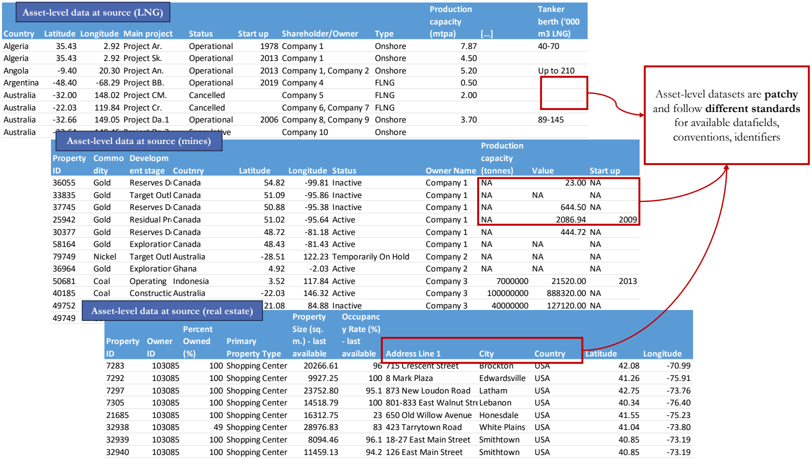


Figure: Historical data for tropical cyclones crossing Mexico. Source: NOAA.

Sample asset-level data: source structure



Asset-level data at source (LNG)

Country	Latitude	Longitude	Main project	Status	Start up	Shareholder/Owner	Type	Production capacity (mtpa)	[...]	Tanker berth ('000 m3 LNG)
Algeria	35.43	2.92	Project Ar.	Operational	1978	Company 1	Onshore	7.87		40-70
Algeria	35.43	2.92	Project Sk.	Operational	2013	Company 1	Onshore	4.50		
Angola	-9.40	20.30	Project An.	Operational	2013	Company 1, Company 2	Onshore	5.20		Up to 210
Argentina	-48.40	-68.29	Project BB.	Operational	2019	Company 4	FLNG	0.50		
Australia	-32.00	148.02	Project CM.	Cancelled		Company 5	FLNG	2.00		
Australia	-22.03	119.84	Project Cr.	Cancelled		Company 6, Company 7	FLNG			
Australia	-32.66	149.05	Project Da.1	Operational	2006	Company 8, Company 9	Onshore	3.70		89-145
Australia	[illegible]	[illegible]	[illegible]	[illegible]		Company 10	Onshore			

Asset-level data at source (mines)

Property ID	Commodity	Development stage	Coutnry	Latitude	Longitude	Status	Owner Name	Production capacity (tonnes)	Value	Start up
36055	Gold	Reserves D	Canada	54.82	-99.81	Inactive	Company 1	NA	23.00	NA
33835	Gold	Target Outl	Canada	51.09	-95.86	Inactive	Company 1	NA	NA	NA
37745	Gold	Reserves D	Canada	50.88	-95.38	Inactive	Company 1	NA	644.50	NA
25942	Gold	Residual Pr	Canada	51.02	-95.64	Active	Company 1	NA	2086.94	2009
30377	Gold	Reserves D	Canada	48.72	-81.18	Active	Company 1	NA	444.72	NA
58164	Gold	Exploration	Canada	48.43	-81.43	Active	Company 1	NA	NA	NA
79749	Nickel	Target Outl	Australia	-28.51	122.23	Temporarily On Hold	Company 2	NA	NA	NA
36964	Gold	Exploration	Ghana	4.92	-2.03	Active	Company 2	NA	NA	NA
50681	Coal	Operating	Indonesia	3.52	117.84	Active	Company 3	7000000	21520.00	2013
40185	Coal	Constructic	Australia	-22.03	146.32	Active	Company 3	100000000	888320.00	NA
49752	[illegible]	[illegible]	[illegible]	21.08	84.88	Inactive	Company 3	40000000	127120.00	NA
49749	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

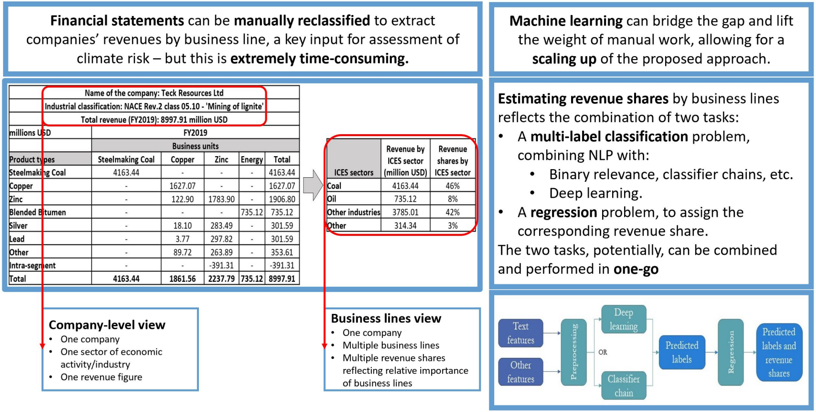
Asset-level data at source (real estate)

Property ID	Owner ID	Percent Owned (%)	Primary Property Type	Property Size (sq. m.) - last available	Occupancy Rate (%) - last available	Address Line 1	City	Country	Latitude	Longitude
7283	103085	100	Shopping Center	20266.61	96	715 Crescent Street	Brockton	USA	42.08	-70.99
7292	103085	100	Shopping Center	9927.25	100	8 Mark Plaza	Edwardsville	USA	41.26	-75.91
7297	103085	100	Shopping Center	23752.80	95.1	873 New Loudon Road	Latham	USA	42.75	-73.76
7305	103085	100	Shopping Center	14518.79	100	801-833 East Walnut Stre	Lebanon	USA	40.34	-76.40
21685	103085	100	Shopping Center	16312.75	23	650 Old Willow Avenue	Honesdale	USA	41.55	-75.23
32938	103085	49	Shopping Center	28976.83	83	423 Tarrytown Road	White Plains	USA	41.04	-73.80
32939	103085	100	Shopping Center	8094.46	96.1	18-27 East Main Street	Smithtown	USA	40.85	-73.19
32940	103085	100	Shopping Center	11459.13	94.2	126 East Main Street	Smithtown	USA	40.85	-73.19

Asset-level datasets are **patchy** and follow **different standards** for available datafields, conventions, identifiers

Figure: Sample of asset-level data (LNG, mines, real estate; source data). Sources: Refinitiv, S&P.

Business-line data deep dive



Financial statements can be **manually reclassified** to extract companies' revenues by business line, a key input for assessment of climate risk – but this is **extremely time-consuming.**

Name of the company: Teck Resources Ltd					
Industrial classification: NACE Rev.2 class 05.10 - 'Mining of lignite'					
Total revenue (FY2019): 8997.91 million USD					
millions USD	FY2019				
	Business units				
Product types	Steelmaking Coal	Copper	Zinc	Energy	Total
Steelmaking Coal	4163.44	-	-	-	4163.44
Copper	-	1627.07	-	-	1627.07
Zinc	-	122.90	1783.90	-	1906.80
Blended Bitumen	-	-	-	735.12	735.12
Silver	-	18.10	283.49	-	301.59
Lead	-	3.77	297.82	-	301.59
Other	-	89.72	263.89	-	353.61
Intra-segment	-	-	-391.31	-	-391.31
Total	**4163.44**	**1861.56**	**2237.79**	**735.12**	**8997.91**

ICES sectors	Revenue by ICES sector (million USD)	Revenue shares by ICES sector
Coal	4163.44	46%
Oil	735.12	8%
Other industries	3785.01	42%
Other	314.34	3%

Company-level view
- One company
- One sector of economic activity/industry
- One revenue figure

Business lines view
- One company
- Multiple business lines
- Multiple revenue shares reflecting relative importance of business lines

Machine learning can bridge the gap and lift the weight of manual work, allowing for a **scaling up** of the proposed approach.

Estimating revenue shares by business lines reflects the combination of two tasks:

- A **multi-label classification** problem, combining NLP with:
  - Binary relevance, classifier chains, etc.
  - Deep learning.
- A **regression** problem, to assign the corresponding revenue share.

The two tasks, potentially, can be combined and performed in **one-go**

Figure: Business-lines view of a company and possible ML-based extension to automate the task (Bressan et al., 2022)

Cascading climate financial risks

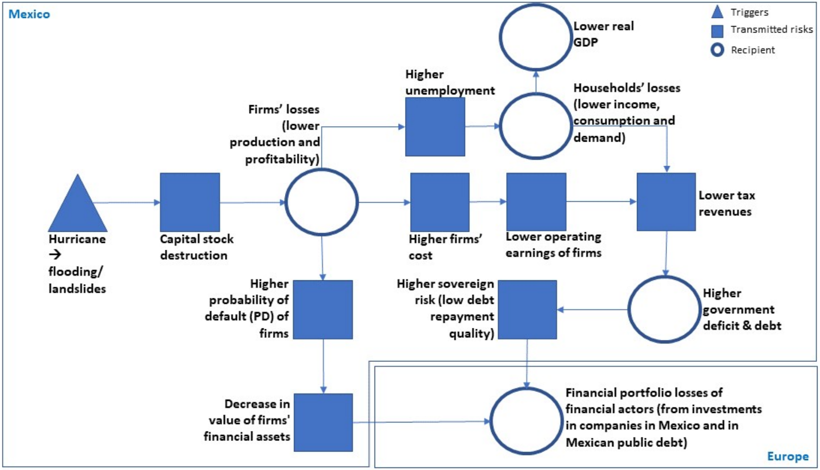
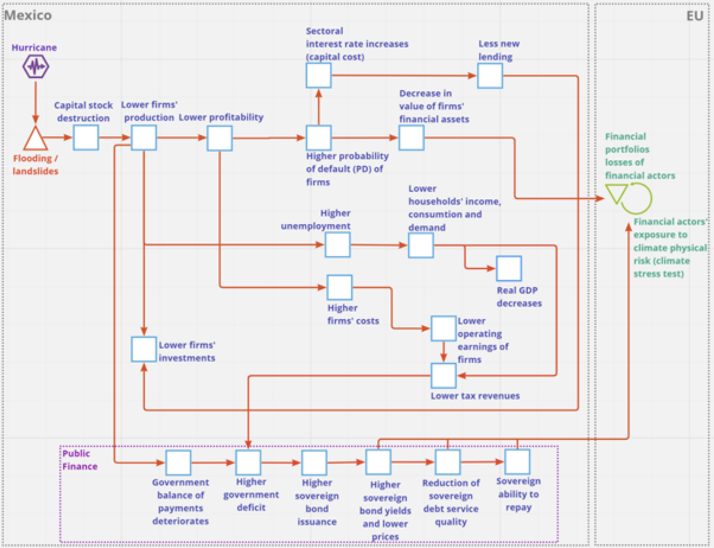


Figure: Cascading climate physical risk to the European financial system.

Cascading climate financial risks



Mexico

EU

Hurricane

Flooding / landslides

Capital stock destruction

Lower firms' production

Lower profitability

Sectoral interest rate increases (capital cost)

Less new lending

Decrease in value of firms' financial assets

Higher probability of default (PD) of firms

Financial portfolios losses of financial actors

Financial actors' exposure to climate physical risk (climate stress test)

Higher unemployment

Lower households' income, consumtion and demand

Real GDP decreases

Higher firms' costs

Lower operating earnings of firms

Lower firms' investments

Lower tax revenues

Public Finance

Government balance of payments deteriorates

Higher government deficit

Higher sovereign bond issuance

Higher sovereign bond yields and lower prices

Reduction of sovereign debt service quality

Sovereign ability to repay

Figure: Cascading climate physical risk to the European financial system.

IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

Digital twins for bridging climate data gaps: from flood hazards to firms' physical assets to banking risks[1]

E de L'Estoile, L Kerdelhué and T Verdier,
Bank of France

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

Digital twins for bridging climate data gaps: from flood hazards to firms' physical assets to banking risks

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[*] This paper reflects the opinions of the authors and do not necessarily express the views of the Banque de France.

December 12, 2024

Abstract

The frequency and severity of floods have increased in recent decades, and this trend is expected to continue due to the long-term rise in temperature, the more extreme weather patterns associated with climate change and the constant degradation of soil quality. Some studies show that floods have a significant and persistent negative effect on company performance (for instance, Fatica et al. (2022)). We complement them by assessing more precisely the location of the floods, distinguishing channels affecting owners and occupiers and connecting the risks faced by firms to the banks that are exposed to them. Combining a series of very granular datasets on flood risks, buildings, establishments, firms and loans, this paper assesses the exposure of banks to physical climate risks through the channel of firms' physical assets. Successive matches are used to obtain for each activity building the associated risk as well as the owner and occupier companies. This helps to disentangle the channels of potential damages that result from flooding. Property damages reduce the owner's equity and increase the Loss Given Default (LGD) associated to the premise while transferable damages (on stocks or productive capital) can affect the income of the user and thus its repayment capacity and Probability of Default (PD). Our application to flood risks in Paris show that losses associated with transferable assets are much bigger than those affecting properties.

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1 Introduction

Physical assets are increasingly exposed to acute climate-related risks like floods and wildfires. This is due to both rising hazards (IPCC, 2021) and the expansion of human activities in vulnerable ar-eas. In the near future, these physical hazards could have significant economic consequences for Non-Financial Corporations (NFCs) and the banks that finance them. Therefore, it is crucial to quantify and analyze the risks posed by climate events to physical assets, necessitating the development of analytical tools to assess both direct and indirect impacts.

Consequently, literature on natural disasters and asset losses is expanding, particularly focusing on flood-related events. This review is not exhaustive but emphasizes business-owned and used assets.

A primary thread of studies highlights the negative impact of hazards on asset prices, especially in residential and, to a lesser extent, commercial real estate (CRE).[1]. Fisher and Rutledge (2021) underline the short-term impacts of major hurricanes on commercial property valuations. They find heterogeneity by building type, as apartment and retail buildings recover faster than other types (office and industrial). In addition to the impact of *realized* disasters on prices, *potential* disasters should also affect prices: some papers show that updating risk perceptions, after observing a storm or learning about newly disclosed flood risk-related information, may induce price discounts. Probably due to data gaps, few studies attempt to quantify the value of the destruction, due to a natural catastrophe, of other types of assets such as machines.

Another strand of the literature derives the link from asset losses to company performances: the literature diverges on this topic. Investigating the impact of a major flood that hit Germany in 2013, Noth and Rehbein (2019) find that firms located in the disaster regions have significantly better economic and financial performance after the flooding, arguing some kind "creative destruction" effect. According to Fatica et al. (2022), this result is driven by the reallocation of capital to non-affected firms in the affected regions. Hence, when using the appropriate granularity, the negative effects of flooding on firm performance may appear more significant and persistent than generally thought. Their study, due to European comparability issues, relies on flood data at the NUTS 3 level and firms geolocation are represented only by their headquarters. Focusing on data at a national level, we complement their analysis by localising the floods risk exposure at the producing premise level.

We further analyze the mechanisms through which firms are impacted by flooding. Did it result in a loss of productive assets, leading to decreased revenues? Did property value decline, affecting the equity available as collateral for credit? Were there indirect effects from infrastructure flooding or disruptions in value chains? These channels are not separately identified, though they likely have distinct consequences, particularly in transmitting economic impacts to the financial system. This issue makes the connection with a last strand of the literature, that studies the impact of hazards on the relationship of affected entities to credit. On the one hand, natural disasters affect the performance of loans. Hurricane Harvey increased housing loans delinquency rates, while flood insurance mitigated some effects (Sweeney et al., 2022). Holtermans et al. (2022) displays convincing evidence that hurricanes Harvey and Sandy had a significant impact on commercial mortgage delinquency rates. On the other hand, the impact of supply of loans remains ambiguous: while earthquake risk reduced the supply of CRE bank loans in California by 2% in the 1990s (Garmaise and Moskowitz, 2009), small banks respond to climate shocks by increasing lending to affected areas and by withdrawing credit from other markets (Cortés and Strahan, 2017). Finally, studies on the impact of hazards on the health of financial institutions are scarce. In Canada, Johnston et al. (2023) find that the direct damages of current and potential floods have small impacts on the financial institutions' Loss Given Default (LGD) on their residential portfolios. They however admit that the lack of granular flood data may have led to an underestimation and smoothing of the risks. In effect, Caloia et al. (2023) consider floods tail risk events in the Netherlands at a more precise granularity and find slightly higher impacts on LGDs and PDs. Part of this higher estimated impact may be due to the fact that the country is partly below sea level, and thus has a relatively high exposure to flood risk.

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[1] A whole section of Contat et al. (2024) reviews empirical studies assessing the impact of flood on prices

This brief literature review highlights some limitations in existing works, which may affect their ability to fully and accurately assess the direct impact of climate-related hazards on firms' physical assets and their repercussions for the financial system. Three main elements could help making major improvements in that regard:

- the reliance on very granular datasets both for geographical data (climate hazards, physical assets should be geolocated at a very fine level) and economic/financial data (firms' balance sheets and loans).
- the definition of physical assets: distinguishing between *transferable* and *real estate* assets enables to identify the channels through which firms are impacted when a building is affected. Damages to transferable assets represent a loss for the firm that *uses* the building, while real estate damages negatively impact the firm that *owns* the building. As far as we know, this is the first time that this distinction is made to analyse and assess physical risks to firms.
- the identification of clear transmission mechanisms of climate hazards to the banks that are connected with impacted firms. Property damages reduce the owner's equity and the LGD associated to the premise while transferable damages can affect the income of the user and thus its repayment capacity and PD.

This paper integrates these three key characteristics as part of an international project led by De Nederlandsche Bank (DNB), Hong Kong Monetary Authority (HKMA), and Banque de France (BDF). The goal is to develop a common tool for supervisory authorities using the concept of Digital Twins. Digital Twins are virtual models of physical objects, like buildings, that can simulate shocks such as climate-related hazards. While the paper covers the project's foundation, it primarily focuses on a use case in France, assessing the exposure of buildings to flooding and identifying the users and owners of affected properties.

This paper contributes to several areas of literature. It enhances existing research on assessing physical risks to the economy by integrating highly granular data. It also introduces a new analytical framework linking flood hazards to firms' credit risks, distinguishing between real estate and transferable assets. Most importantly, it provides academics and institutions with an innovative, modular tool that can be easily adapted for assessing climate and nature-related hazards to the economy.

While Section 2 outlines the Digital Twin project and its motivation, Section 3 details the conceptual framework underpinning the French use case. Section 4 provides empirical evidence that supports our hypotheses. Section 5 details the methodology and data we rely on to derive our results displayed in Section 6. Finally, Section 7 provides an overview of the work-in-progress done to connect the Digital Twin to real time risk assessment with the use of satellite data, while Section 8 concludes.

2 The Digital Twins project: Global climate change, localized effects

The motivation underpinning the Digital Twins (DT) project lies in an apparent paradoxical feature of climate change: it is a *global* phenomenon affecting every region of the world but with very *localized* and differentiated consequences depending on many biophysical, social and economic parameters. This peculiarity calls for the development of both generic and very modular tools, in a context where central banks and supervisors still lack the information necessary to account for physical risks in decision-making. Bridging climate-related data gaps through international collaboration, the DT project aims to become a common good open to improvement and to be used widely, especially in countries that do not have the capacity to develop such a tool.

2.1 Project timeline

Phase 1 of the DT project occurred during year 2022 under the impulsion of the Bank of International Settlement Innovation Hub and had two objectives: i) the exploration of potential data sources suited for each institution and ii) the development of the generic architecture of the code. Each of the institutions participating in the project experimented a specific use case adapted to its needs and data resources: for instance, BDF and DNB applied the tool to estimate the impact of floods on real estate, while HKMA performed a similar assessment for typhoons. The structure of the tool is drawn from the hazard-vulnerability-exposure-finance framework commonly used to model catastrophes in the insurance industry. Three modules have thus been developed during Phase 1.

- The **hazard module** models the frequency and intensity of hazards.
- The **exposure module** collects the geographical and physical characteristics of the properties at risk.
- The **vulnerability module** calculates the amount of expected damage to the properties at risk.

The main goal of still ongoing phase 2 was to develop a **financial module** that translates the damage from the vulnerability module into metrics for financial institutions. In that perspective and to maximize the use of AnaCredit the very rich dataset of bank loans to NFCs, the French team decided to focus on the latter.

2.2 Trade-off between global and local data approaches: Evidence from floods

Regarding all the components of risk analysis, the data available at a global level is, most of the time, some sort of lowest common denominator. On the contrary, national data enables:

- Greater accuracy and detail for *hazards* (flood maps)
- Better coverage of *exposures* (location of firms' establishments)
- Tailored methodologies for *vulnerability* (damage functions)

On the other hand, global approach has also some advantages:

- Standardization: consistent definitions, classifications and methodologies, enabling more direct international comparisons.
- Broader perspective: identifying large-scale trends and patterns across regions.
- Efficiency: economies of scale

The Digital Twin bottom-up approach enables to take the best from each country while keeping a general framework, combining global and national approaches:

- Genericity: A common framework to ensure comparability
- Two-steps approach: we can use global datasets as a foundation, but supplement them with national data where available for greater accuracy and detail.
- Transparency: Clear documentation on data sources, methodologies, and limitations.

For instance, as we focus our analysis on France, for the hazards module we can use the national official floods maps. These maps provide higher accuracy than modelled maps often used in cross-country analysis (**?**). The recent modeled maps of **?** are available at 100 m resolution and do not account for the influence of local flood defences, in particular dyke system. In our official national map for France, the accuracy of the mapped information is approximately 1:25,000 and the protection from systems such as dykes is integrated.[2] As **?** has shown that protective measures reduce significantly negative flood impact for firms, our official flood data should lead to more realistic results than modeled flood data. The advantages of having modular inputs for exposure and vulnerability are detailed later.

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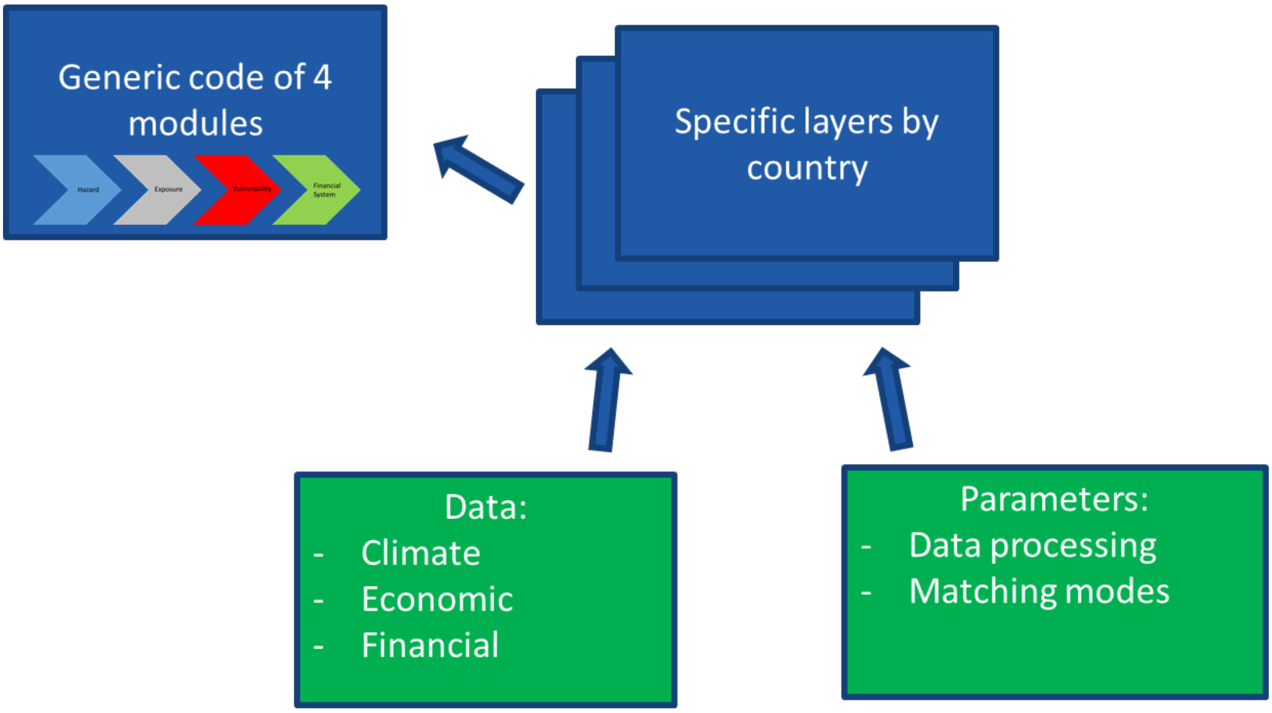
[2] Official maps for England, Spain and Po Bassin are 5 m resolution.

2.3 Structure of the tool: generic and flexible

The tool architecture is structured in order to maximize this bottom-up approach enabling to tailor use-cases to the needs and possibilities of each user, while fitting into the common tool.

Figure 1: Owners and occupiers



3 Conceptual Framework: from physical exposure to financial risk

The main objective of this section is to build a systematic framework of analysis to clearly identify the channels through which flood hazards translate into potential damages to firms and then transmit into risks for banks. To do so, we start with a very clear dichotomy: we distinguish buildings from transferable assets that lie inside them. This distinction matters for several reasons. First, it is in line with the analytical framework used by the national experts on flood damages: the National Research Institute for Agriculture, Food and the Environment in France, INRAE, explicitly developed property and transferable damage functions associated with flooding (see more below). Moreover, this distinction is also used by insurances and thus the insurance coverage of these two risks can differ across sectors. Last and certainly not least, the entities affected by these two types of damage differ most of the time: while CRE increasingly became a financial asset, the user of a a premise in a building is not necessarily the owner of this premise. In these cases, and they are many, transferable and real estate assets do not belong to the same entity.

3.1 Two types of direct flood-induced damages

Two direct damage channels are identified:

- *Property* damage: a drop in the value of the affected building or the necessity to pay repair costs;

- *Transferable* damage: the destruction of physical assets inside the building (machines, physical capital).

While indirect damages, such as the flooding of infrastructure or the breakdown of value chains (with customers or suppliers affected by floods), may be even higher than these direct damages, they are very difficult to grasp. Computing a granular exposure to such a risk and its potential impact seems complicated. Thus, we decided not to not take them into account.

3.2 Who is affected by what type of damages?

Table 1 recapitulates how losses are distributed between the firms that are connected to a building when it is flooded.

Table 1: Damage and firm types

Firm Type	Owner	Occupier	Owner/Occupier
Property damage	Yes	No	Yes
Transferable damage	No	Yes	Yes

When a building is flooded, its owner will face property damages reducing his asset, while transferable damages apply to the user's assets. Firms using the building they own (or when the user and owner firms belong to the same entity) face both property and transferable damages.

We develop a four-step strategy to account for these damages and link them to credit risk:

- Geographical matching of buildings and hazards
- Matching of buildings and establishments
- Computation of damages (asset losses)
- Connecting to the banking system

Sketch 2 is built as a decision tree that tries to sum up this whole framework up, namely both the conceptual framework deriving the transmission from climate hazards to credit risk metrics and at the bottom the successive methodological steps. We first match flood hazards data with buildings at a very high resolution (5 meters). For each building that has been spotted as exposed to floods, we identify its owner(s) and user(s). This step corresponds to the buildings with firms matchings (one matching for owners and for users). We then compute for each hazard/building/firm the associated damages. Finally, we connect the losses to banks and specific credit risk metrics. Transferable damages impair the productive capacity and the income of firms and can thus reduce their repayment capacity and probability of defaults (PD). Property damages decrease the value of the premise. While a significant share of NFC loans are collateralized by a real estate property, a drop in the value of this property increases the loan LGD, i.e. the value that the lender will not receive in case of default of the creditor.

3.3 Motivation: Effect of past floods on owner and occupier firms

Using historical data on floods, we show that owners and occupiers are affected differently through their real estate and technical installation. Based on this observation, the core of our paper builds a framework distinguishing channels for owners and occupiers to evaluate the effect of different floods scenarios on NFCs' assets and the exposure of banks to these NFCs.

We use French NFCs balance sheet data (Fiben) to determine which are owners and which are occupiers. NFCs having a positive amount of real estate assets are considered owners, while the others are considered users.[3]

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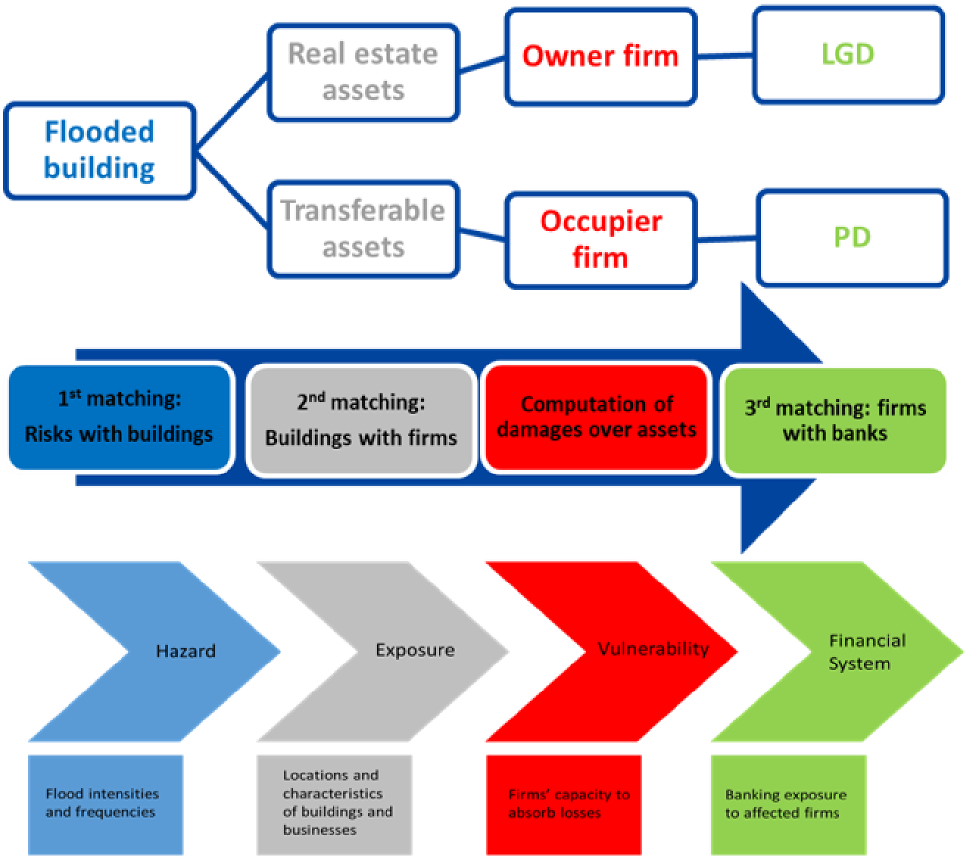
[3] This selection method identifies only renters as users, and does not enable to select owner-occupiers.

Figure 2: Sketching summary



We first present the main linear regressions, where we regress respectively real estate capital and transferable capital on city affected on flood shocks at the city level. We use French NFCs balance sheet data (Fiben) and location of historical floods according to the CatNat data. We consider a NFCs is affected by a flood at time t is the postal code in which it is localised is affected. We use local projection methods (Jorda, 2005), which involves running separate regressions for each horizon h = 0,...,6 years :

$$log(y_{i,t+h}) - log(y_{i,t+h-1}) = \beta_h F_{i,t} + \gamma_h X_{i,k<t-1} + \mu_i^h + \zeta_i^h + \epsilon_{i,t+h} \tag{1}$$

where the dependent variable is the cumulative percentage change in the logarithm of the real estate and transferable capital from period t to $t+h$ for firm i. $F_{i,t}$ is a binary variable indicating whether the city where the firm is located has been affected by a flood at time t. The vector of firm specific variables $X_{i,k<t-1}$ includes the number of employees, the sector and localisation at the NUTS 3 level of the firm. Thus, we control for economic shock occurring at NUTS-3 level and on a specific sector. Fixed effects μ_i^h control for the time invariant idiosyncratic firm characteristics and time fixed effects ζ_i^h account for unobserved aggregate shocks[4].

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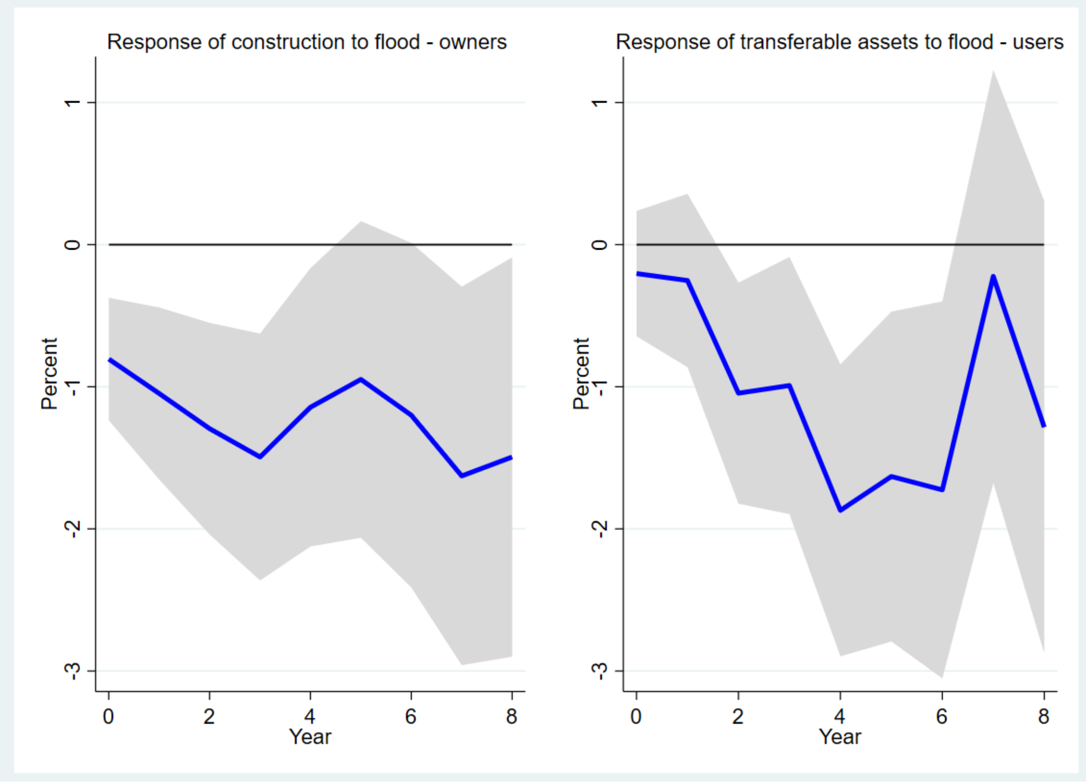
[4] We only select single establishment in the sample

Figure 3: Effect on real estate and transferable assets



Note : impulse response to a flood shock. The sample is 1989 - 2023. 90 % significance bands displayed.

Figure 3 confirms our hypothesis about differentiated impact of floods on owners and users. The left-hand side chart shows the effect on the value of real estate assets for owners. For these NFCs, being located in a city affected by a flood has a negative impact on the value of their real estate assets. Regarding transferable assets, while we do not find any negative impact of floods if we use the full sample of NFCs, we find one when restricting the scope to occupiers only (right hand side chart). Interestingly, even if firms should benefit from some insurance framework, we observe a significant impact on assets.

4 Data and Methodology

4.1 Comprehensive and granular datasets

The use-case has been tailored to maximize the use of the very comprehensive and granular datasets that are available in France. In order to favour the adoption of our tool and encourage its distribution to as much as possible, we used some open data sources for the measurement of exposure of physical assets to floods. The subsequent analyses rely on unique datasets on firms balance sheets and credits, provided by Banque de France and the Eurosystem.

4.1.1 Data on buildings

The BNDB (Base de Données Nationale des Bâtiments, National Buildings Database) is a mapping of the existing building stock. Structured at the "building" level, it provides detailed information for each of the 20 million residential or tertiary buildings in France. It is built by the CSTB using geospatial intersection of around twenty databases from public organizations. CSTB develops different products, we use the open dataset. Among many, the variables we use are the location of the building, the group of buildings to which it belongs and the owner.

4.1.2 Data on flood hazards

The data on flood hazards we use are static data that consists of the zoning of flood-prone areas with high human, social, and economic stakes, the *Territoires à Risque d'Inondation (TRI).* It is constituted of polygons each of which is characterized by a certain level of risk (high, medium and low probability of occurrence corresponding to *circa* 10, 100 and 1000 years period returns). The fact that TRI focus not on all hazards but only on those with significant exposure should not be of concern to us, as we do not try to explain the location of firms. Floods' scenarios are respectively :

- High frequency: An event causing the first significant damages, with a return period between 10 and 30 years.
- Medium frequency: An event with a return period between 100 and 300 years. If a historical reference event is not used, a centennial-type event is sought.
- Low frequency: An exceptional flooding event inundating the entire area of the functional alluvial plain (major bed) or the functional coastal plain, and for which any protection systems in place are no longer effective. As an indication, a return period of at least 1000 years is sought.

4.1.3 Data on firms and establishments

All French firms are characterized by a SIREN, a number. Establishments are firms' producing premises which are located in buildings. Produced by Insee, the Sirene database (Répertoire National d'identification des entreprises et des établissements) provides information on each business establishment located in France. It includes all the companies in activity when the database was created in 1973 and those created since then.[5] We use the dataset called StockEtablissementHistorique, including historical data on the establishments (each with an identifier called SIRET) of each company (each with an identifier called SIREN) in France. The variables of interest for us are the opening and closing dates of the establishment, its economic sector (NAF code or NAP code before 1993) and whether the establishment is hiring workers. We obtain the geolocation of each establishment thanks to a merge of this dataset with the "Géolocalisation des établissements du répertoire Sirene" dataset,[6] based on the SIRET identifier.

4.1.4 Data on loans

AnaCredit is a dataset of the European Central Bank, containing detailed information on individual bank loans in the euro area, harmonized across all member states, with data collection starting in 2018.

4.1.5 Data on historical floods

We use CatNat data on postal codes affected by floods, as defined by the French CatNat insurance system for natural disasters. Under this system, private insurers include natural disaster coverage in standard automotive and property policies. When a disaster occurs, a committee determines if it qualifies as a natural disaster. If so, the affected municipality receives the CatNat designation, and insurers compensate the victims. Additionally, firms may receive subsidies to cover disaster costs.

4.2 From hazards to exposure: a succession of matchings

4.2.1 First matching: hazards and buildings

This matching aims at getting information on the exposure of buildings to flood risks. For that, we compute the spatial intersection between the BNDB and the TRI at the building level: for each

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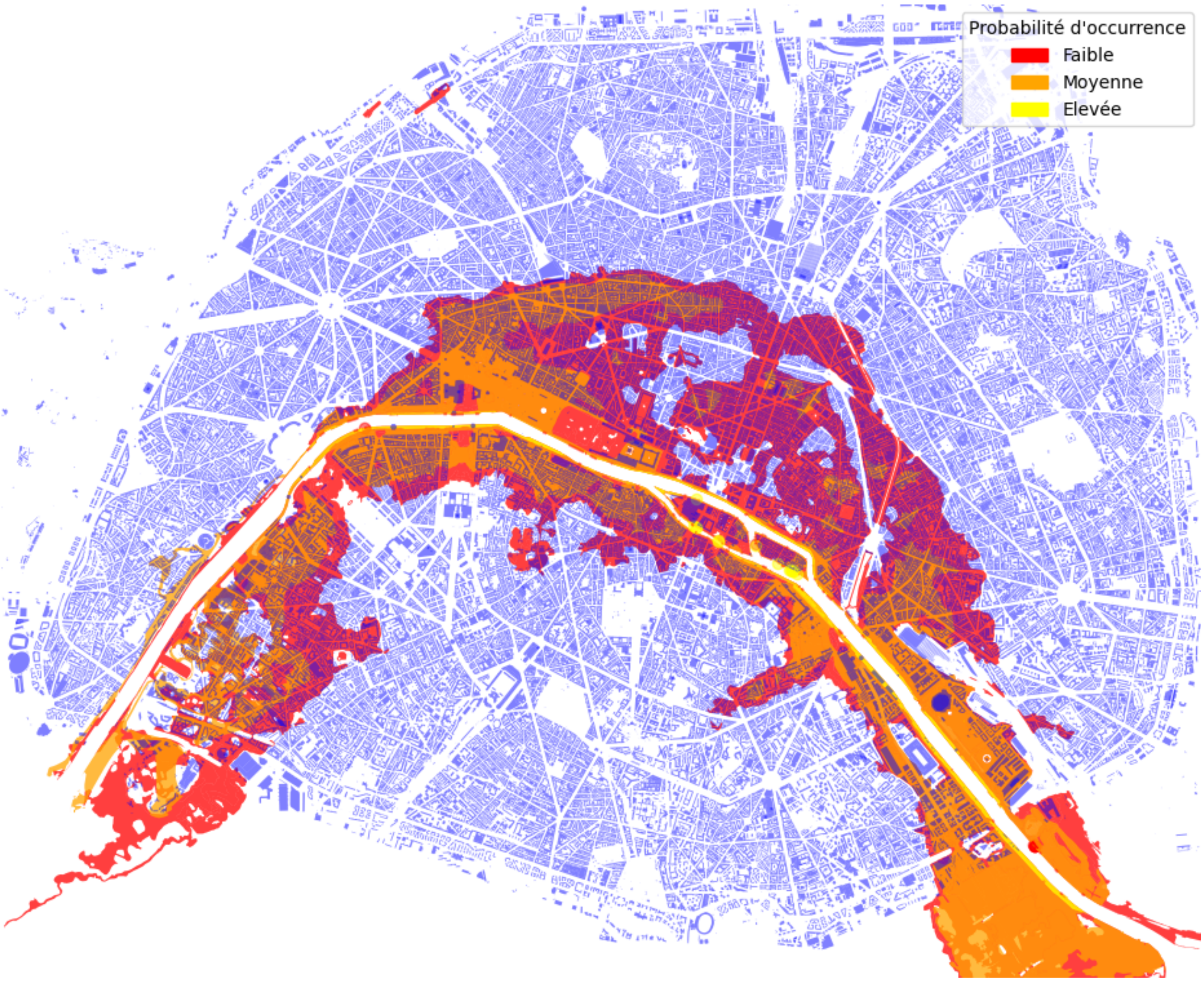
[5] Public administrations were included in 1983, and farms in 1993.

[6] https://www.data.gouv.fr/fr/datasets/geolocalisation-des-etablissements-du-repertoire-sirene-pour-les-etudes-statistiques/

French activity building, we obtain the flood hazards it is exposed to, according to three scenarios (high, medium and low occurrence probability). Figure 4 displays the buildings and the probability of flood occurrence. As a building can lie on several polygons of hazard, we keep only the polygon whose overlap area with the building is the largest.

Figure 4: Hazards and buildings



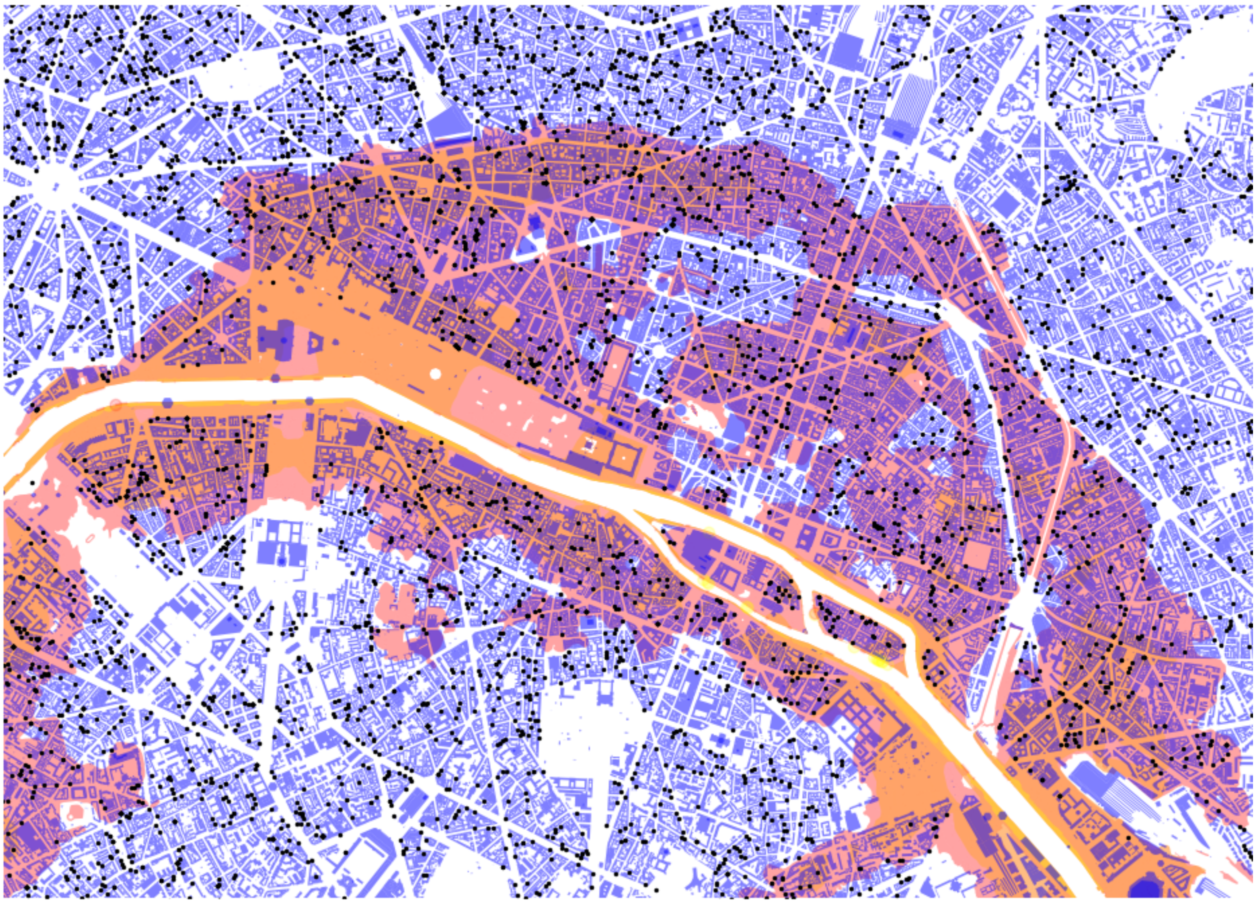
4.2.2 Second matching: buildings and firms

The idea of this second matching is to connect the threatened buildings to the entities that might suffer from the materialization of the risks. As explained above in the Framework section, this materialization can occur through distinct channels: damages to the building itself affect its owner, while damages to the physical capital *inside the building* will impact the firm that uses the building to produce, store its inventories or operate its business. We thus implement two different matchings, connecting buildings with their owner on one side and their user on the other.

Owners: Most of activity buildings do not belong to the firm that uses them. French data on CRE transactions show that about half of the volume is bought by investors. The BNDB displays for each building information on its owner: when it is owned by a legal entity (firms, most of the time), it is associated to a SIREN identifier. This very precious information thus enables us to identify the owners of exposed buildings, but also to compute some statistics on them.

Occupiers: We follow a method developed and detailed in de L'Estoile and Salin (2024), with a slight difference. While they match establishments with parcels from the Fichiers Fonciers database, we match them with buildings from BNDB. We match each point representing an establishment (SIRENE database) to the nearest polygon representing an exposed building through a nearest-neighbour spatial joint. Figure 5 helps vizualising this spatial matching. Hence, while one establishment can only be matched with one building, multiple establishments can happen to be in the same building. To increase the relevance of the matching, some filters are applied to the establishments database: only perfectly geolocated establishments are kept, while establishments that self-declare as non-employing are removed from the sample, to get rid of individual entrepreneurs, SCI and whose physical footprint, hence their exposure, is limited.

Figure 5: Buildings and Production sites



4.3 Computation of sector-varying transferable and real estate damages

When developing flood damage functions for firms, INRAE explicitly distinguished between real estate and transferable damages. As a very salient and interesting feature, they vary with the sector of the firm that is affected: for instance, the damage on transferable assets in the building occupied by an insurance company are much lower than those in a battery factory. For other parameters, these functions take the severity of the flood (height) and two specific variable accounting for the size of the asset loss: the size of the building in m^2 for property damages and the size of the firm in terms of employees for transferable damages. We then apply these functions to the pool of firms according to the dichotomy explained earlier: transferable function for users and property function for owners. These are the asset losses that will be hereafter used.

4.4 Discussion of the methodology: Some specific issues and limitations

4.4.1 What about insurances?

Insurances play a mitigating role in transferring losses out of the direct transmission from firms to banks. While we do not have the adequate data to account for them, our conceptual framework and estimates remain relevant to understand what would happen without insurances, in a context of growing concerns around insurance coverage gaps and inassurability in some sectors or areas.

4.4.2 What about floors?

Since the BNDB is at the building level and since the geolocation of the establishments is in two dimensions, our information remain at the building level. Thus we are not able to directly tell whether the owner or the user of a premise is really affected. This is a serious caveat and should of course not be neglected. However, the structure of the damage matrix should mitigate this issue. In effect, it gives more weight to industrial or commercial activities as compared to office activities (example?). While the latter are hosted in buildings with multiple floors, industrial or commercial activities tend to locate in 1 floor buildings (see [de L'Estoile and Salin (2024)]). Thus, the sectors that will face important damages should be the ones for which the issue of floor is less relevant.

4.4.3 Matching with Users: Why using buildings?

One major point of the methodology is the reliance on an intermediary object between hazards and firms: the building. Whereas a direct matching could seem more straightforward at first sight, this method is likely to imply important errors. In effect, the geolocation of establishments is represented as a point and thus do not account for its real physical exposure. The building step enables to give establishments back their real land footprint.

5 Stylized facts in Paris: From physical exposure to financial risks

This section sums up the results obtained by applying this methodology to the territory of Paris. This choice was made according to several reasons related both to high vulnerability and hazards:

1. it represents high economic and social stakes both in terms of physical assets and outstandings for banks
2. Paris' riverside location within a natural floodplain, its connection to major tributaries, tidal influences, and the narrow river channel all contribute to making the city highly susceptible to devastating floods originating from the Seine River
3. ageing infrastructure: Much of Paris' drainage and sewage infrastructure was built in the 19th century and is vulnerable to being overwhelmed during major flood events
4. the last 100 years return period flood dates back from 115 years, the catastrophic 1910 "Great Flood" where the Seine rose over 8 meters above normal levels.

Our results are split along the distinction we draw between users and owners. We start by displaying some metrics on the exposure of firms, especially by comparing the potential losses they face as compared to the assets they own. We then show that the banking system is rather exposed to threatened firms, and that these risks can be concentrated. Finally, we look at relevant credit risk metrics: PDs for users and LGDs for owners.

5.1 Metrics on the exposure of firms

A first salient feature is that many buildings and thus many firms are exposed to middle to low flood hazards in Paris. Specifically, we find that around 18406 buildings, 34000 user firms and 27000 owning firms could be hit by a flood with a low probability of occurrence.This unpredictable risk with extreme consequences is exactly the kind of "green swan" for which central banks and financial regulators need tools to understand, prepare for, and mitigate the impacts. Therefore, we will focus on this scenario for the remainder of the paper.

5.1.1 Metrics on the exposure of firms: users

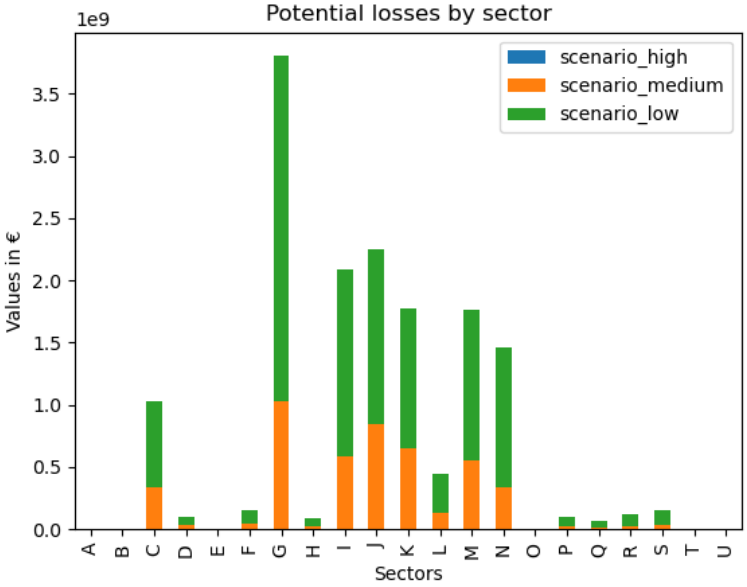
Table 2 displays some descriptive statistics regarding the exposure of user firms to flood hazards. As expected, the gravity of flooding grows when its probability of occurrence decreases. The worst case scenario estimates a 10 bns € losses in productive assets.

Table 2: Descriptive Statistics for User Firms by Scenario

Scenario	High	Medium	Low
Number of exposed firms	8	15656	33852
Damages in bns €	0.07	4.6	10

These losses are unequally distributed among sectors, as shows Figure 6. Retail and Gross Trade firms are the most affected (Sector G) with 3.6 bns € in the worst case scenario, mainly because a large share of affected firms are from this sector (30%). Interestingly, Manufacturing (Sector C), which represents only 5% of impacted firms, exhibits large losses because of the weight given by the damage function to manufacturing productive capital.

Figure 6: Potential losses by sector - User firms



In order to assess the vulnerability of user firms, we weight their losses by their total assets, computing their Losses on Assets ratio (LoA). In the following results, we define a firm as highly damaged when its LoA exceeds 10% (a threshold represented by the vertical red line in the following graphs). It it interesting to look at the characteristics of the most affected firms. Figure 7 shows that small firms (Petites et Moyennes Entreprises, PMEs) are likely to suffer the most as their assets are low. However, a number of intermediary firms (Etablissements de Taille Intermédiaire, ETI) could lose more than 20% of their assets. Figure 8 indicates that in two sectors, half of the firms could be highly damaged (Manufacturing (C) and Accommodation and Food Services (I)).

Figure 7: Potential losses on assets by size - User firms

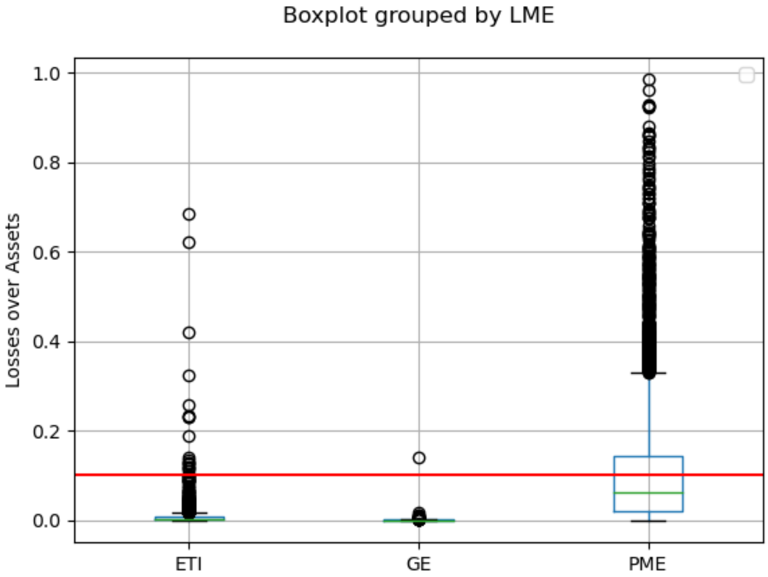
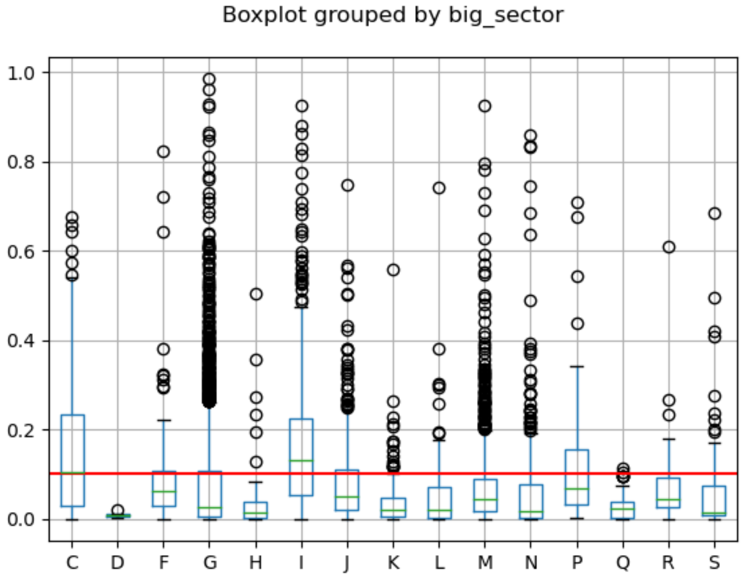


Figure 8: Potential losses on assets by sector - User firms



Finally, it is valuable to cross-reference these findings with additional information on firms' indebtedness-coming from the Fiben database[7]. Firms whose Debt/EBITDA ratio exceeds 6, a commonly used threshold to assess indebtedness (represented by the vertical red line in the following graph) are considered highly indebted. According to Figure 9, a significant amount of firms, at the upper-right of

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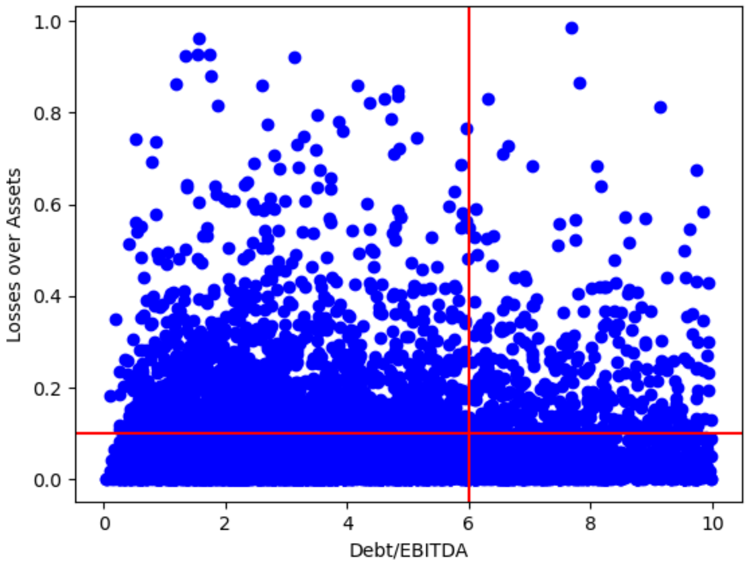
[7] By merging our dataset with Fiben, we lose 30% of our sample of firms whose annual turnover is lower than 750000€

the crossing lines, are both highly affected and very indebted, and thus represent a risk for the banks that are exposed to them. The exposure of banks to these risks are studied later.

Figure 9: Potential losses on assets vs Debt/EBITDA - User firms



5.1.2 Metrics on the exposure of firms: owners

Table 3 shows that, whereas the number of exposed owning firms is rather comparable to the number of user firms, their losses are much lower. This comes from the parameters of the damage functions where damages are much higher for transferable assets than for properties.

Table 3: Descriptive Statistics for Owner Firms by Scenario

Scenario	High	Medium	Low
Number of exposed firms	8	12400	26852
Damages in bns €	0.0003	0.05	0.2
Exposed surface in mns of m^2	0.001	1.1	2.2

These losses are mostly supported by real estate firms, but a significant share of them could be Sociétés Civiles Immobilières (SCI), a common type of firm in France that are often be used by non real estate firms to manage their real estate assets. Since it is not possible to attribute these firms to their parent, we should underestimate the exposure of other sectors than real estate.

5.2 Metrics on the exposure of banks

To assess the exposure of French banks to the highly threatened NFCs detailed above, we use the AnaCredit dataset.[8]

5.2.1 Metrics on the exposure of banks: users

The outstanding associated to highly vulnerable firms are relatively high as shown in Table 4. As

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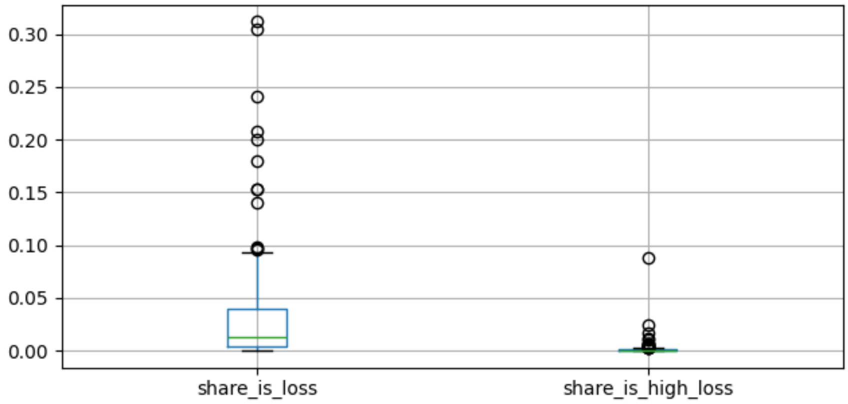
[8] The matching generates some losses in our firms samples (30% for users and 20% for owners)

Table 4: Descriptive Statistics for Exposure of Banks to User Firms (Low Scenario)

Statistic	Number	Outstanding in bns €
User	20644	4
User with heavy losses	6021	1.7
User with heavy losses and debt	2540	1

compared to the amount of lending of French banks to NFCs (around 1200 bns €), these figures remain quite low. But some medium banks have a significant share of their lending portfolios that are exposed to vulnerable firms : more than a quarter of French banks have more than 0.5% of their total lending to NFCs that is exposed to damaged NFCs (Figure 10).

Figure 10: Potential losses on assets by banks - User firms



5.2.2 Metrics on the exposure of firms: owners

While the majority of owner firms do not face a high LoA because of the high value of property assets, half of those that could be highly affected are also highly indebted (Table 5). This is due to the structural high leverage of real estate firms ().

5.2.3 Metrics on the exposure of banks: owners

Table 5: Descriptive Statistics for Exposure of Banks to Owner Firms (Low Scenario)

Statistic	Number	Outstanding in bns €
Owners	20216	0.2
Owners with heavy losses	2021	0.02
Owners with heavy losses and debt	1050	0.01

5.3 Credit risk metrics

5.3.1 Credit risk metrics for owners: LGDs

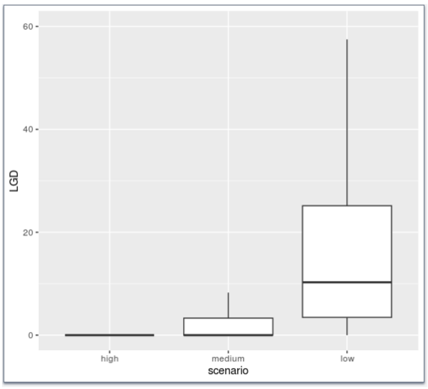
Loss given defaults (LGDs) are not reported in AnaCredit. Hence, we approximate loan-level LGDs by looking at the collateral value relative to the notional value of the loan. This is predicated on the assumption that, in the event of a default, a bank can only recover the collateral assigned to the loan and that it will be paid the full collateral value.

$$\text{LGD}_S^i = \max\left(0, \frac{L^i - C_S^i}{L^i}\right) \tag{2}$$

with L_i the outstanding amount of the loan and C_S^i the collateral value of CRE considering the damage specific to scenario S. The collateral value is depreciated by the damage impact estimated by the damage function. We only consider positive values, corresponding to cases in which the lender will not be able to recover the exposure in full.

Figure 11 shows that the median increase in LGD after the flood impact would reach around 10 basis points in the low probability of occurrence scenario. This result gives the same order of magnitude as Caloia et al. (2023).

Figure 11: Effects on LGD (basis points), by scenario



5.3.2 Credit risk metrics for owners: PDs

We also follow a stress test approach to assess the potential effect of floods on users' PD. To that end, micro-founded models are used using AnaCredit data. We estimate and project the PD for each sector separately. Even if the firm is only a user of the building, we project that the reduction of collateral increases the leverage as the debt is higher relative to assets the firm can use if the equipment inside is affected by the flood.

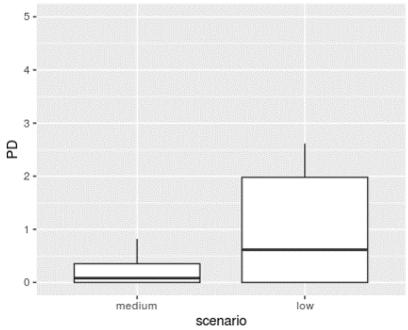
$$PD_t^i = \alpha + \beta_1 \text{leverage}_t^i + \beta_2 \text{asset turnover}_t^i + \epsilon_t^i$$

Where:

- leverage_t^i is total bank debt/total assets for scenario s and firm i
- $\text{asset turnover}_t^i$ is total sales/total assets for scenario s and firm i
- the dependent variable $\text{PD}_t^{i,s}$ is the average probability of default declared by banks for the counterparty i at time t. We estimate the model at half-yearly frequency as firms' annual account can be updated half-yearly

We project the probability of default (PD) using projected total asset values, which are reduced based on estimated damages from different scenarios. As in Emambakhsh et al. (2023), we estimate and project PD separately for each sector using the model. Figure 11 shows the distribution of PD effects by scenario. The impact remains small, as we only consider the asset channel. The hypothesis is that equipment destruction lowers total assets and firms' production capabilities. However, other significant channels, such as productivity loss following an adverse event like a flood, could also play a role.

Figure 12: Effects on PD (basis points), by scenario



6 Completing the Digital Twin: Towards real time risk assessment through the use of satellite data

To fully comply to the concept of a Digital Twin, we - together with the DNB team - have put a strong emphasis on developing the possibility to follow flood catastrophes and their near real-time impacts on firms and banks. To that end, we thoroughly worked on the interoperability between the tool and satellite data. We relied on the Global Floods Project[9], which provides free access to data from the European Copernicus Sentinel 1 satellite. This satellite provides radar imagery, which is relevant for observations of flooded areas. The site offers the possibility of using a REST API, which can be used to obtain images via various end points. The processes described below are written in Python.

The concepts to be familiar with are those of *zones of interest* and *products*. A *zone of interest* is the geographical area that needs to be monitored. A *product* is a set of data relating to flooded areas, stored as a set of files in a compressed archive. Within a product, different layers are displayed to describe flooding based on various criteria, including the extent of flood.

This element has been used to study the important floods that occurred in the North of France Pas-de-Calais region in November 2023. The process is as follows: we start by querying the area of interest for the period in question and obtain different *products* for each day of the period. We then retrieve files in GeoJSON format containing the geographic data corresponding to the flooded data.

Depending on the satellite trajectory, each *product* file corresponds only to a part of the area of interest. We thus merge all the areas provided over the period into a single one. Across this process, we check that the zone thus defined completely covers the area of interest to make sure we get all the flooded areas during the period. While this methodology is based on two-dimension representation and does not enable to account for the depth of floods, strong improvements are being made in that way.

This alternative flooding data is currently being implemented in the tool, so that it can be used as the hazard layer in replacement of the TRI data set. While this add-on to the tool enables to compute potential damages at a near-real-time frequency, it also demonstrates the modularity of the tool. It is thus emblematic of the deflating entry cost to the project.

7 Conclusion and avenues for future developments

This work relies on three main innovations: integration of very granular datasets, distinction between property and transferable assets and the identification of clear transmission mechanisms of climate hazards to banks *via* firms. We find that a high share of Parisian buildings and firms (owners and users) are exposed to flood hazards. These could turn into significant losses for firms, that may seriously impair firms' assets, especially for those which are highly indebted. Finally, our findings show that losses associated with transferable assets are much bigger than those affecting properties.

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[9]

In that sense, contents matter more than containers. However, the risks associated to a decrease in the value of impacted collateral is not neglectable. It is important to bear in mind that the hazard data we use for the moment reflects flood probabilities of occurrence based on past data. The planned incorporation of projection data would certainly worsen the picture.

This methodological work opens the floodgates to numerous subsequent analyses. While there are already extremely rich information to derive from descriptive statistics, more analytical questions could be answered. For instance, our setup enables to study the evolution of credit distribution patterns in connection with flooding events. Finally, the Digital Twin project from which this work emanates is set to improve in the near future across two directions: *deepening*, with an improvement of existing use-cases; and *enlargement*, with the integration of other types of risks (wildfires, drought etc.) and other participants.

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IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

A multi-country study of forward-looking economic losses from floods and tropical cyclones[1]

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

A Multi-Country Study of Forward-Looking Economic Losses from Floods and Tropical Cyclones[1]

Prepared by Michele Fornino, Mahmut Kutlukaya, Caterina Lepore and Javier Uruñuela López[2]

ABSTRACT: The study provides forward-looking estimates for economic damages from floods and tropical cyclones (TC) for a wide range of countries using global datasets. Damages are estimated for three Intergovernmental Panel on Climate Change (IPCC) scenarios and aggregated at the country level, building them from geographically disaggregated estimates of hazard severity and economic exposures across 183 countries. The results show that, for most countries, floods and TC's damage rates increase (i) during the estimation span of 2020 to 2100, and (ii) with more severe global warming scenarios. In line with other global studies, expected floods and TCs damages are unevenly distributed across the world. The estimates can be used for a wide range of applications, as damage rates represent the key variable connecting climate scenarios to economics and financial sector risk analysis.

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[1] This paper relies heavily on the IMF Working Paper: A Multi-Country Study of Forward-Looking Economic Losses from Floods and Tropical Cyclones (Fornino and others 2024). All authors are from the IMF. The views expressed are those of the authors and do not necessarily represent the views of the IMF, its Executive Board, or IMF management. The boundaries, colors, denominations, and any other information shown on the maps do not imply, on the part of the International Monetary Fund, any judgement on the legal status of any territory or any endorsement or acceptance of such boundaries.

[2] The authors would like to thank Hiroko Oura, Artak Harutyunyan, Padma Hurree-Gobin, Ivo Krznar, Henk Jan Reinders, Mehdi Benatiya Andaloussi, Gregor Schwerhoff, Emanuele Massetti, Divya Kirti and Jens Mehrhoff for useful feedback and discussions.

1. Introduction

The frequency and intensity of natural hazards have increased across several regions in the world since 1950s (Arias and others, 2021). These hazards can cause large economic losses. On a global level, economic loss associated with natural hazards has averaged around $170 billion per year over the past decade, with peaks of $300 billion in some years (UNDRR, 2022). Further, economic losses from these events have risen significantly since the 2000s, in line with their amplified intensity and frequency (UNDRR, 2022). As many countries prepare measures to reduce risks from these natural hazards, it becomes of first order importance to assess future economic losses from the latter under various climate scenarios.[3]

This paper aims to bridge the gap between economic and climate literature by adopting a simple framework for analyzing losses from floods and tropical cyclones (TCs) on a forward-looking basis. We propose a methodology to estimate economic losses from natural hazards that can be applied to a wide range of countries globally.[4] We apply the methodology to estimate forward-looking losses from (riverine and coastal) floods and TCs for a large number of IMF member countries (183 for floods and 89 for TCs) under three Intergovernmental Panel on Climate Change (IPCC) scenarios.[5]

Damages arise as the interaction of three components: the projections of individual hazards (hazard severity), the exposure of economic assets to these hazards, and their resulting vulnerability in the event the hazard materializes. We rely on global datasets for each of these components, with the goal to maximize the coverage of IMF member countries. In terms of hazards, we focus on floods and TCs and used data procured from the private vendor Jupiter Intelligence.[6] For exposures, we use publicly available datasets on spatially disaggregated GDP with global coverage as a proxy for the distribution of physical assets, which is consistent with future socio-economic projections, available decennially up to 2100. To measure vulnerability, we adopt damage functions from existing academic studies and publicly available datasets which translate the magnitude of hazards into quantifiable damages.

Our results point to three key takeaways from the analysis. First, most countries we consider will experience an increase in floods and tropical cyclones damages by mid-century. These countries represent a significant share of the global economy. Second, for most countries considered, damages are higher for more severe climate scenarios, pointing to a positive correlation between global flood and tropical cyclones risks and global warming. Third, floods and tropical cyclones risks are unevenly distributed across the world.

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[3] For example, we refer to Duenwald and others (2022) for a discussion of the importance of climate adaptation strategies for the Middle East and Central Asia region.

[4] The terms *losses* and *damages* are used interchangeably in this paper.

[5] Floods considered in this study include river and coastal floods, but not rainfall-induced flooding, given data availability (see Section 3.1).

[6] The literature and data on vulnerability and damages from other hazards, such as droughts and wildfires, is still limited, especially at global scale. Therefore, this study focuses exclusively on floods and tropical cyclones.

2. Literature Review

The direct losses from floods and TCs are the focus of this study.[7] There is a growing literature on indirect losses from hazards which are not reviewed here. We instead focus on direct losses, which are likely to serve as a lower bound of total losses, in relation to individual hazards, as they ignore indirect losses. Further, we focus on two hazards only (floods and TCs). This choice is based on the availability of hazards and vulnerability data.

2.1 Floods

The direct damages from floods mainly depend on the depth of the water. Damage functions for floods link the depth of water to damages—either in percentage of total value or as the absolute damage amount—and can be applied to both types of floods. Even though many different inundation characteristics, like depth, duration, velocity may influence the amount and degree of damage, in the current state-of the-art of flood damage evaluation mainly inundation depth is incorporated in damage functions as it seems to have the most significant influence.

Several studies in the literature use a multi-model framework, integrating simulations of river flow and flooding processes with datasets on exposures and flood protections to determine damages from floods. Alfieri and others (2017) find: (i) a positive correlation between atmospheric warming and future flood risk at global scale, and (ii) risks are unevenly distributed across the world. Similarly, Dottori and others (2018) analyze socioeconomic costs of river floods, using a multi-model framework. The study finds particularly higher impacts under 3 degrees Celsius warming scenario, with uneven regional distribution. Smith and others (2019) use high-resolution (approx. 30 x 30 m) population density to map flood exposure to population data for 18 countries. The results of the study when compared to other studies suggest that exposure estimates are sensitive to the resolution of the underlying hazard data.

Huizinga and others (2017) estimate empirical damage curves for each continent and asset type, which are now widely used in the literature.[8] To estimate these damage curves, the authors collected a large and globally consistent dataset on flood damages and then produced damage curves providing fractional damage as a function of water depth based on the data. Damage curves are estimated by damage class (residential, commerce, industry, transport, roads, railroads, agriculture) and continent.

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[7] Direct damages are caused by the hazard event itself. Indirect damages do not occur through the event itself but subsequently via connections between system elements as defined by Bachner and others (2023).

[8] These damage functions are available on the JRC website. These functions have also been used by the NGFS. See, Bertram and others (2021).

Table 1: Global Studies on Economic Losses from Floods

	Year	Coverage	Publicly available damage function	Forward Looking
Huizinga and others	2017	Global – by continent Maximum damage available for 200+ countries	Yes	No
Smith and others	2019	18 developing countries	Yes	No
Alfieri and others	2017	Global	Based on Huizinga and others (2017)	Yes
Dottori and others	2018	Global	Based on Huizinga and others (2017)	Yes

Note: Studies focusing on a single country are excluded.

2.2 Tropical Cyclones

TCs typically inflict damage due to strong sustained surface winds, storm surge-driven inundation, and torrential rain. The maximum sustained windspeed is the most important factor to quantify the impact of TCs, also used as an input to damage functions for the assessment of direct economic damage (Emanuel (2011), Czajkowski and Done (2014)).

A large part of the literature on TCs damages focused on the United States. For the United States, damage functions are available for different building types (FEMA, 2011), as well as for aggregate economic losses for several regions of the U.S. Atlantic and Gulf Coasts (Hallegatte, 2007).

The literature on TCs with global coverage is expanding. Yamin and others (2014) conduct a risk assessment for around 200 countries on TCs. Damage functions are obtained from the HAZUS MH 2.1 Hurricane Model, however, calibrated only for the USA and consider building type and characteristics.[9] Mendelsohn and others (2012) studies global TC damages using an integrated assessment model based on USA's elasticity of damages with respect to storm intensity to calibrate the global damage function. Bakkensen and Mendelsohn (2019) address this modelling drawback, by broadening the damage estimates for a larger set of countries using both a cross-sectional model and an error components model with country and time fixed effects to calculate damage functions. This study shows that the United States is an outlier in TC vulnerability (i.e., much higher elasticities), conditional on its income levels and exposure, hence the risk of overestimating losses when using USA-based damage functions for other countries. Gettelman and others (2017) adopted the TC damage model from the open-source natural catastrophe modelling tool CLIMate ADAptation (CLIMADA)[10] using spatially disaggregated GDP to estimate the impact of future changes in TCs on damages. Authors find increasing global storm damage by around 50 percent in 2070 in comparison to 2015, despite decreasing storm numbers in the future and strong landfalling storms increase in East Asia.

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[9] HAZUS is a multi-hazard loss estimation methodology developed by the Federal Emergency Management Agency (FEMA, 2011).

[10] The CLIMADA cyclone damage model produces damage estimates by year and spatial location based on a set of probabilistic cyclone tracks.

Eberenz and others (2021) developed regionally calibrated damage functions by comparing simulated damages to historical reported damages. Reported damage estimates used in the study are available from the International Disasters Database (EM-DAT). For the regional calibration of the TCs impact model, distinct calibration regions were defined based on geography, data availability, and patterns in damage ratios.[11] The impact functions provided by the study feature considerable differences in the slope and level of uncertainty across model regions. Authors note the largest uncertainties for the North-West Pacific regions.

Table 2: Global Studies on Economic Losses from Tropical Cyclones

	Year	**Coverage**	**Publicly available damage function**	**Forward Looking**
Yamin and others	2014	Global	No – based on damage functions calibrated for the USA	No
Mendelsohn and others	2012	Elasticities based on the USA data.	Yes	Yes
Bakkensen and Mendelsohn	2019	Global – 87 countries that report damage from TCs	No	No
Eberenz and others	2021	Global	Yes – with regionally calibrated damage functions	No
Gettelman and others	2017	Global – 73 countries	No – Results calibrated to the USA data	Yes

Note: Studies focusing on a single country are excluded.

3. Data

Damages from physical risks arise as the interaction of three components: hazard, vulnerability, and exposure. In this section we discuss the data used to quantify each of these components.

3.1 Hazard data

In this study, we used hazard data for floods and TCs severity supplied by the private vendor Jupiter Intelligence.[12] For floods, data covers river and coastal flood depth projections under different scenarios, using data from GCMs as an input.[13] The Jupiter Intelligence's inland river flooding model uses projected regional changes in extreme streamflow to estimate how flood depth and extent may change in a future climate. For coastal floods, multiple climate projection datasets are used to estimate the effects of sea-level rise and storm surge and tides on coastal inundation, as well as storm surge and lake levels on lake shoreline inundation. Values of sea-level rise, long-term lake levels and surge and tides from the same climate scenario are combined to produce a unified estimate of the expected water levels for each scenario. Then river and coastal floods results are consolidated into a single estimate. For TCs, hazards data reflect wind speeds, defined as the maximum 1-minute sustained wind speed at 10 meters above ground level. This measure is produced using data from GCMs and a synthetic TCs model. The maximum 1-minute sustained windspeed

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[11] These functions are also used by the NGFS.

[12] Additional details, including selection of locations, are provided in Fornino and others (2024).

[13] Rainfall-induced flooding is currently not available.

variable from the vendor dataset is used in the damages' calculation only for areas where TCs have been observed historically (Figure 1). This approach guarantees consistency between the methodology on the hazards and vulnerability.

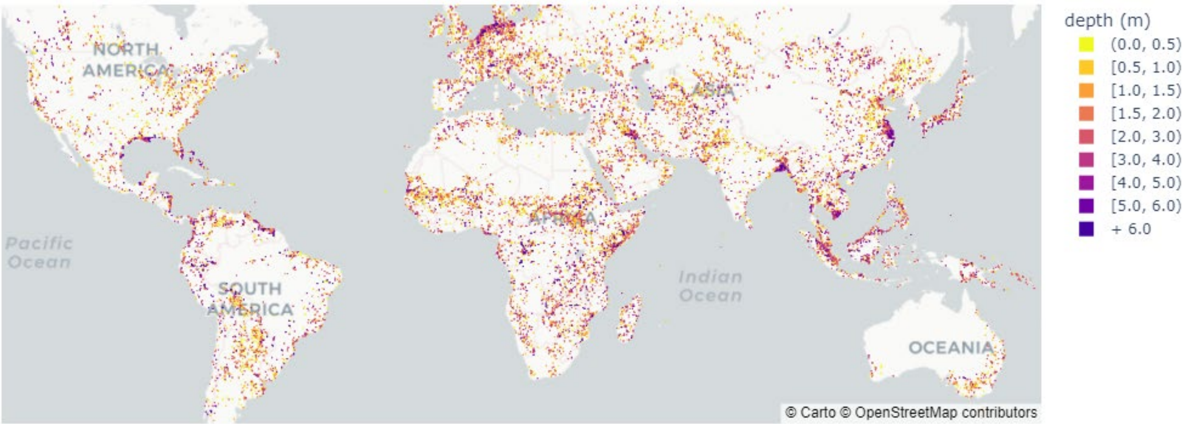
We use data for the mean levels for flood depth and wind speed, for 10, 20, 50,100, 200, and 500-year return periods. The data also covers fraction of land flooded in 3 arcseconds grids for 10, 20, 50,100, 200, and 500-year return periods. These measures are provided for a baseline (climate for 10-year period centered on 1995) and projections from 2020-2100 with 5-year increments under three scenarios: SSP1-2.6, SSP2-4.5, and SSP5-8.5, which represent a low, intermediate and very high GHG emission scenario respectively.[14] The three scenarios are drawn from the IPCC Sixth Assessment Report (IPCC, 2021). As an example, Figure 2 shows flood depth for 1-in-500-year return period in 2050 under the scenario SSP2 4.5.

Figure 1: Tropical Cyclones grids

Source: Jupiter Intelligence. Notes: Grids that consider TC simulations in wind parameter estimates from Jupiter Intelligence

Figure 2: Jupiter Intelligence flood depth

flood depth in meters



Source: Jupiter Intelligence. Notes: Values for mean depth meters for 1-in-500 year in 2050 under SSP2-4.5

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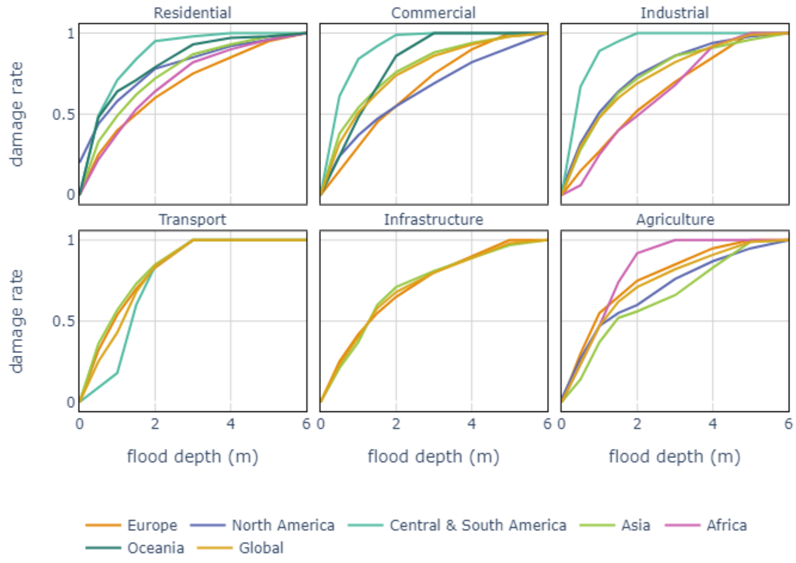
[14] We note that the SSP5 - 8.5 represents an extreme scenario, and its plausibility is currently debated in the literature. However, as noted in (IPCC, 2023), this scenario cannot be ruled out. Furthermore, for some of the potential applications of our results, such as financial sector stress testing analysis, it is important to adopt extreme scenarios to analyze the potential implications of tail risk events.

3.2 Vulnerability – Damage functions

Damage functions relate economic damages to climate inputs. Hazards can be linked to economic and financial exposures using damage functions that define the impacts of specific hazards on real assets and activities (BIS, 2021). These functions can be estimated using different methodologies, including by using empirical approaches looking at correlative relationship between past data on damages and hazards variables and using simulated data of physical hazards and models to explicitly describe the system behavior in response to climate change (Feyen and others 2020). Damage functions vary by hazard, type, and geographical location (e.g., regions, continents, or countries) of exposures. This granularity is intended to capture differences in the way in which a climate hazard of the same intensity differently impacts physical assets at different locations–for example because of different climate resilience of existing infrastructure. We selected the functions estimated by Huizinga and others (2017) and Eberenz and others (2021), as they are widely used, publicly available and provide globally consistent coverage.

The damage functions provided by Huizinga and others (2017) can be used to calculate damages from floods. These functions are piecewise linear, depicting fractional damage as a function of water depth for a variety of categories: buildings and contents (residential, commercial, and industrial), transport facilities, infrastructure (roads and railroads) and agriculture (Figure 3). The functions have been calibrated using quantitative data from multiple studies. Damage functions vary also by geography, they are calibrated for six continents: Europe, Africa, Asia, Oceania, North America, South and Central America.[15]

Figure 3: Floods damage functions by asset type



Source: Huizinga and others (2017)

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[15] As noted by the authors the amount of historical data in which acute events are properly recorded is larger for the countries and continents with a more established systematic damage assessment 'tradition', like the USA, Australia, Japan and South Africa. However, and specifically in the African continent (except South Africa), the information available is not equally distributed over the continent and mostly available for sub-Saharan Africa.

The damage functions provided by Eberenz and others (2017) are calibrated for the assessment of economic damages caused by TCs. These functions are regionally calibrated (Figure 4) by using simulated damages from CLIMADA and reported damages. The functional form is sigmoidal, expressing the percentage of damage as a function of wind speed:

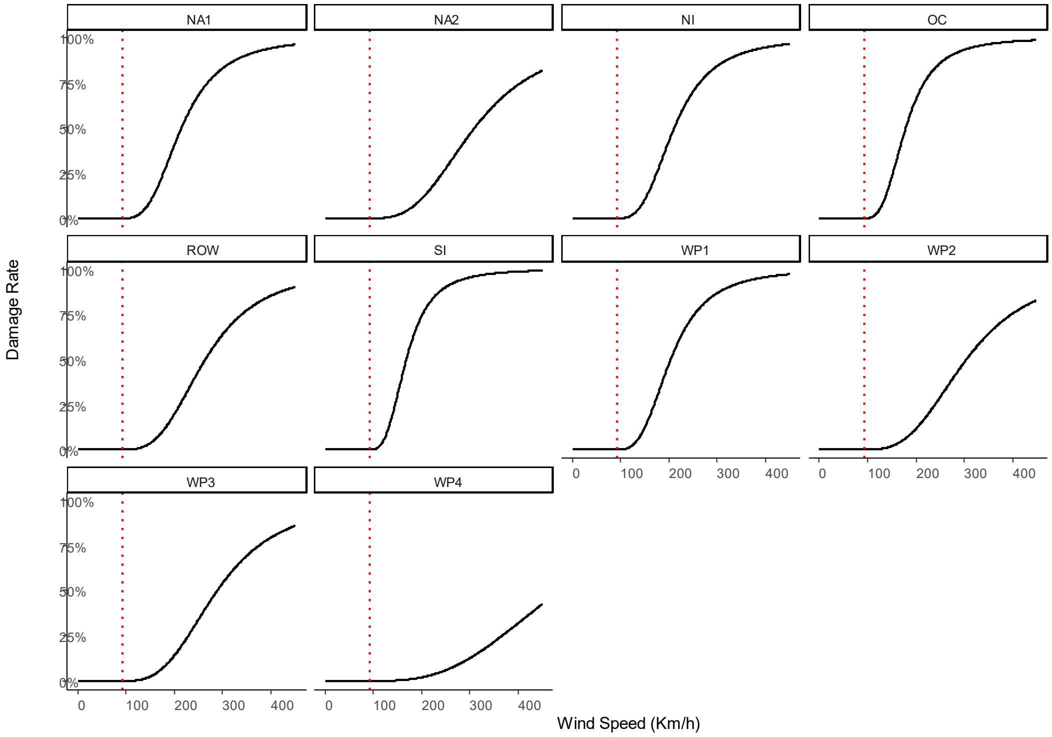
$$f = \frac{v_n^3}{1 + v_n^3},$$

where

$$v_n = \frac{MAX[(V - V_{thresh),} 0]}{V_{half} - V_{thresh}}.$$

In this formula, V is the 1 min sustained wind speed at 10 m above ground per storm event. V_{thresh} is a minimum threshold for the occurrence of impacts, as no directly wind-induced damage is expected for low wind speeds. V_{half} is the slope parameter, signifies the wind speed at which the function's slope is the steepest and the impact reaches 50 percent of the exposed asset value. This functional form, introduced by Emanuel (2011), builds on empirical studies relating wind to damage suggesting a high power-law dependence of damage on wind speed (Pielke 2007). Emanuel (2011) argues that on physical grounds damage should vary as the cube of the wind speed over a threshold value. Further, the fraction of the property damaged should approach unity at very high wind speeds.

Figure 4. Calibrated TC Damage Functions by Regions



Source: Eberenz and others (2021)

Notes: The red dotted line represents a windspeed of 25.7 m/s, or 92.5 km/h, which is the threshold below which the damage rate is assumed to be zero. Regional groupings are defined in detail in appendix Table A.1 of Eberenz at al (2021), p.409. For reference, NA=North Atlantic, NI=North Indian, OC=Oceania, ROW=Rest of the World, SI=South Indian, WP=North West Pacific. Numbers denote sub-regional groupings of countries that share similar characteristics. NA2=CAN, USA, WP2=PHL, WP3=CHN, WP4=HKG, KOR.

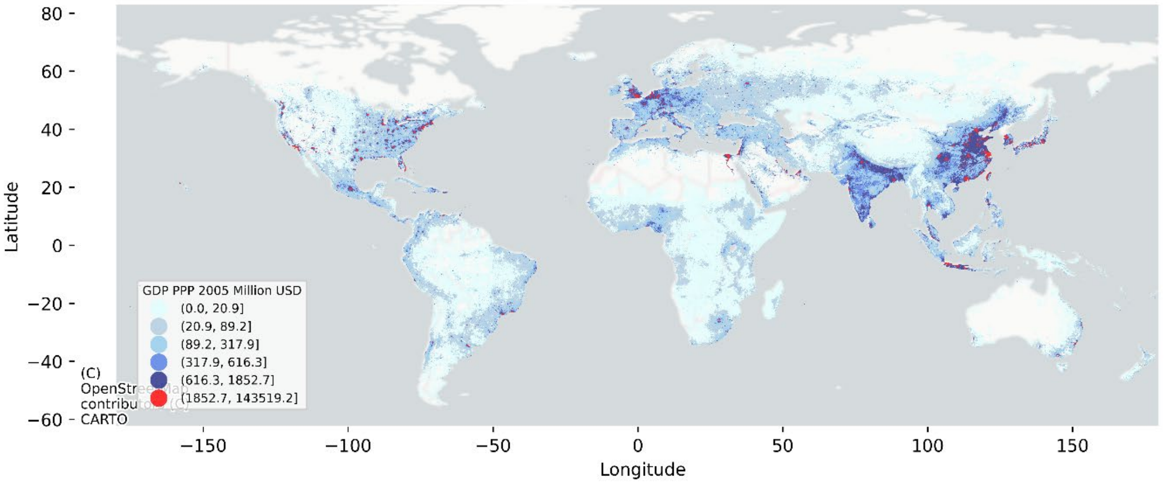
3.3 Exposures

We proxy economic exposures using downscaled GDP data. Several studies have developed methodologies to downscale national or subnational GDP data into finer spatial units, combining it with other auxiliary datasets (such as population data). In these datasets, each GDP value has an associated latitude and longitude, which corresponds to the centroid of the corresponding geographical grid cell. In particular, Murakami and others (2021) develop a downscaling methodology to estimate gridded GDP under different SSPs, which we use in our analysis. Details of the downscaling approach are provided in Fornino and other (2024).

The global dataset of downscaled GDP data at 30 arcminutes is publicly available. The dataset spans between 1980 and 2100 by 10-year intervals. The data between 1980–2010 are estimated by downscaling actual GDPs by country, while those between 2020–2100 are estimated by downscaling projected GDPs under three SSPs (SSP1-2.6; SSP2-4.5; and SSP5-8.5). Figure 5 illustrates Gridded GDP under SSP2-4.5 scenario for 2050.

Figure 5: Gridded GDP SSP2-4.5 for 2050

GDP PPP 2005, Million USD



Source: Murakami and others (2021)

Notes: GDP groupings have been defined using the following percentiles [0, 50, 75, 90, 95, 99, 100]

4. Methodology

This section provides the methodology adopted to estimate damages. We define damage rates as the loss of value of assets, expressed in percent of the value of those assets before being hit by the hazard. Damage rates from floods and TCs are calculated separately. Caution should be applied if interested in combining damages from both floods and TCs, as these events are likely to be correlated, for example, with TCs possibly leading to flooding. In this section, we describe how damage rates for a specific location (given by latitude and longitude) are computed and we detail how location-level damage rates are used to calculate aggregate damage rates at the country level. The methodology can be applied for different projection horizons and scenarios, as depicted in Section 5.

4.1 Location-level damage rate

The calculation of the damage rate at the individual location requires applying the damage function to the hazard data for that point. The variables $depth_{c,i,RP,t,s}$, $frac_{c,i,RP,t,s}$, and $wind_{c,i,RP,t,s}$ denote the flood depth, fraction of land flooded, maximum sustained windspeed respectively in country c, location i, return period RP, projection year t and scenario s. The RP denotes the return period at which specified hazard intensity is expected; for example, the 1-10 years flood depth denotes the severity of a hazard that is expected to occur no more than once in 10 years.[16] Next, we denote the damage function for floods as df_{floods} and the damage function for TCs as df_{storms}. These functions take as inputs either the flood depth or the maximum sustained windspeed and return the fraction of assets that are lost as a result.

For floods, the specific damage function depends on the percentage of built-up area in the location. For each covered cell in the gridded dataset, we divide the exposure measure into built-up and non-built-up areas using the land cover data Copernicus Global Land Operations “Vegetation and Energy” (CGLOPS-1) for 2019 from Buchhorn and others (2020). At the time of the analysis, this was among the few publicly available datasets that cover built-up areas, but this data is rapidly evolving and further granularity can be integrated in the future. For built-up areas, we combine the residential, commercial, and industrial damage functions (Figure 3), by equally weighting each function, while for non-built-up areas we consider agriculture and infrastructure damage functions. For TCs the damage function differs by country groups (Figure 4).

The damage rate for floods is defined as:

$$d_{c,i,RP_j,t,s} = frac_{c,i,RP_j,t,s} * df_{floods}(depth_{c,i,RP_j,t,s}).$$

The damage rate for TCs is defined as:

$$d_{c,i,RP_j,t,s} = df_{storms}(wind_{c,i,RP_j,t,s}).$$

Expected annual damage rate can be calculated using the damage rates for different return periods for a given location. Hazard data are available for 10, 20, 50,100, 200 and 500-year return periods, which are denoted as $RP_{10}, RP_{20}, RP_{50}, RP_{100}, RP_{200}, RP_{500}$. The trapezoidal rule is used to approximate the area under the damage-return curve (Figure 6).

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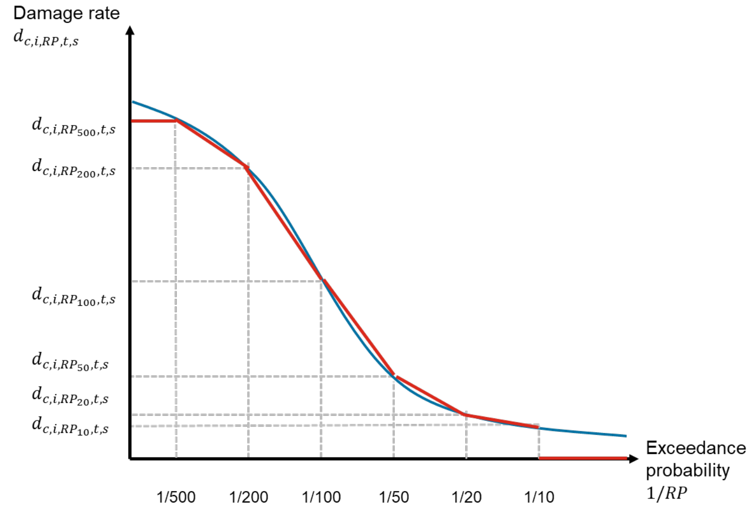
[16] The return period is the inverse of the probability of that flood depth or wind level being exceeded in a year. It is common practice to provide hazard severity data for specific return periods and to use the data to estimate the average expected damage per year.

Figure 6: Damage-probability curve



Source: IMF staff calculations

For floods and TCs, the discretized random variable $d_{c,i,t,s}$, with severity measure $sev_{c,i,t,s} \geq 0$, is defined as follows:

$$d_{c,i,t,s} = \begin{cases} 0, if\ sev_{c,i,t,s} < \ sev_{c,i,RP_{10},t,s} \\ \dfrac{d_{c,i,RP_j,t,s} + d_{c,i,RP_{j+1},t,s}}{2}, \quad if\ sev_{c,i,RP_j,t,s} \leq sev_{c,i,t,s} < \ sev_{c,i,RP_{j+1},t,s} \\ d_{c,i,RP_{500},t,s}, \ if\ sev_{c,i,t,s} \ \geq sev_{c,i,RP_{500},t,s} \end{cases}$$

where $j \ \in \ \overline{RP} = \{10,20,50,100,200,500\}$. In turn, the location-level expected annual damage rate can be calculated as:

$$E\left[d_{c,i,t,s}\right] = \sum_{j \in \overline{RP}} \left(\frac{1}{RP_j} - \frac{1}{RP_{j+1}}\right)\left(\frac{d_{c,i,RP_j,t,s} + d_{c,i,RP_{j+1},t,s}}{2}\right) + \frac{d_{c,i,RP_{500},t,s}}{RP_{500}}.$$

4.2 Country-level expected damage rate

Damage rates for specific locations in a country are aggregated to obtain country-level damage rates, which incorporate both hazard and exposure factors. We consider all locations $i = \{1, \ldots, n\}$ in a country c for which we have hazard data, so that n represents the number of cells considered in country c. We denote the gridded GDP at a location as $GDP_{c,i,t,s}$, and the total GDP of the country as $GDP_{c,t,s}$. We define the country-level expected damage rate for a specific year and scenario, denoted with $E[D_{c,t,s}]$, as the weighted average of the location-level expected damage rates, where the weight of a location is given by its GDP:

$$E[D_{c,t,s}] \ = \sum_{i=1}^{n} E[d_{c,i,t,s}] \ \frac{GDP_{c,i,t,s}}{GDP_{c,t,s}}$$

Key results of the paper in the next section focus on the country-level expected damage rate by time and scenarios, hereafter referred to as damage rate for simplicity. Results are also presented in terms of the change in levels and relative change of the damage rate in a given year and scenario relative to the historical baseline, which represents the hazard for the 10-year period centered around 1995 and GDP in 2000. These are defined, respectively, as

$$E[D_{c,t,s}] - E[D_c](\text{baseline})$$

and

$$(E[D_{c,t,s}]/E[D_c](\text{baseline})) - 1.$$

These variables provide information on whether and how flood and TCs risks are expected to change in the future, as well as how these changes vary depending on the scenario considered.

5. Results

This section discusses floods and TCs damages, respectively, and compares results with other studies. We selected 2050 and 2100 as projection horizons to showcase our results. The year 2050 is important for convergence to net zero in time to successfully mitigate global warming, while 2100 is the furthest year available in the sample at our disposal.

5.1 Floods damages

Flood risks are projected to increase for most countries by mid-century. Depending on the scenario considered, 58-67 percent of the countries (representing 74-80 percent of global GDP in 2020) display an increase in the country-level expected damage rate in 2050 relative to the baseline (Table 3). The median damage rate for these countries is 0.28-0.35 percent in 2050 and 0.36-0.41 percent in 2100 depending on the scenario. For the remaining countries, 25-33 percent (representing 18-25 percent of global GDP in 2020) display a decrease in flood risks, and the rest display no change. The median damage rate for these countries is 0.22-0.32 percent in 2050 and 0.25-0.27 percent in 2100 depending on the scenario. The number of countries with rising flood risks increases over time and with global warming, being highest under the SSP5-8.5 scenario.

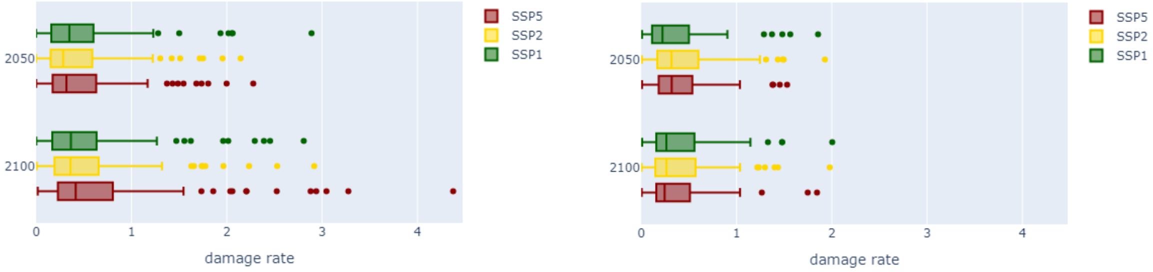
Table 3: Key statistics for flood damages

Time	Scenarios	# of countries (median country-level damage rate in percent) with increasing flood risks	# of countries (median country-level damage rate in percent) with decreasing flood risks
2050	SSP1-2.6	107 (0.35)	60 (0.22)
	SSP2-4.5	115 (0.28)	52 (0.32)
	SSP5-8.5	123 (0.32)	45 (0.32)
2100	SSP1-2.6	121 (0.36)	47 (0.26)
	SSP2-4.5	117 (0.36)	51 (0.27)
	SSP5-8.5	124 (0.41)	44 (0.25)

The variability of damage rates increases for more severe scenarios at the end of the century for countries with increasing risks. Figure 7 shows the distribution of damage rates, conditional on the damage rate increasing (LHS) or decreasing (RHS) relative to the baseline year**.** The number of extreme observations increases as well. Most of these are countries characterized by having a small land area, and hence more concentrated flood risks and economic activity, such as small island countries. The distribution of damage rates for countries with decreasing damage rates is more stable across time and scenarios, with the extreme observations scattered in various regions.

Figure 7: Floods' damage rates for countries with increasing (left-hand panel) and decreasing (right-hand panel) damages relative to the baseline.

In percent

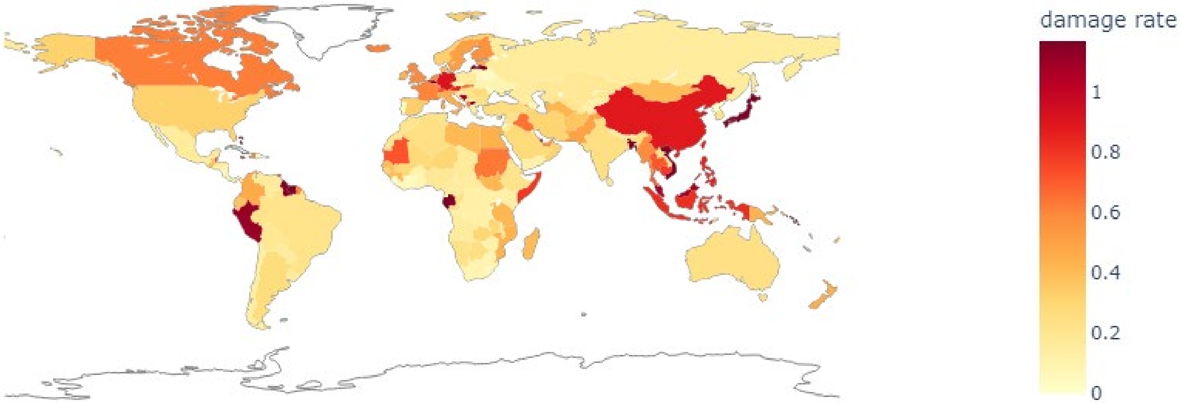


Source: IMF staff calculations

In line with other global studies (Alfieri and others 2017; Dottori and others 2018) we find that floods risks are unevenly distributed across the world. We focus our attention to the SSP2-4.5 scenario, which represents an intermediate emissions scenario. Similar general findings hold for the other scenarios SSP1-2.6 and SSP5-8.5, representing a low and very high greenhouse gas emission scenarios.[17] We find that the countries among the top 10 with the largest damage rates in the three scenarios are in different geographical regions, mostly in tropical and sub-tropical regions, and most have a small land area.

Figure 8: Floods' damage rate for 2050 under SSP2-4.5

In percent



Source: IMF staff calculations

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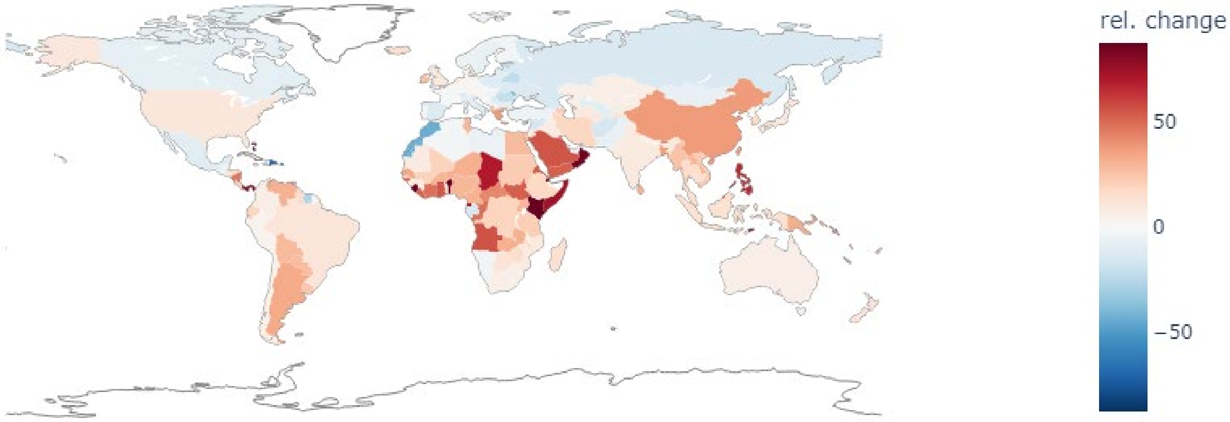
[17] The results are available in Fornino and others (2024).

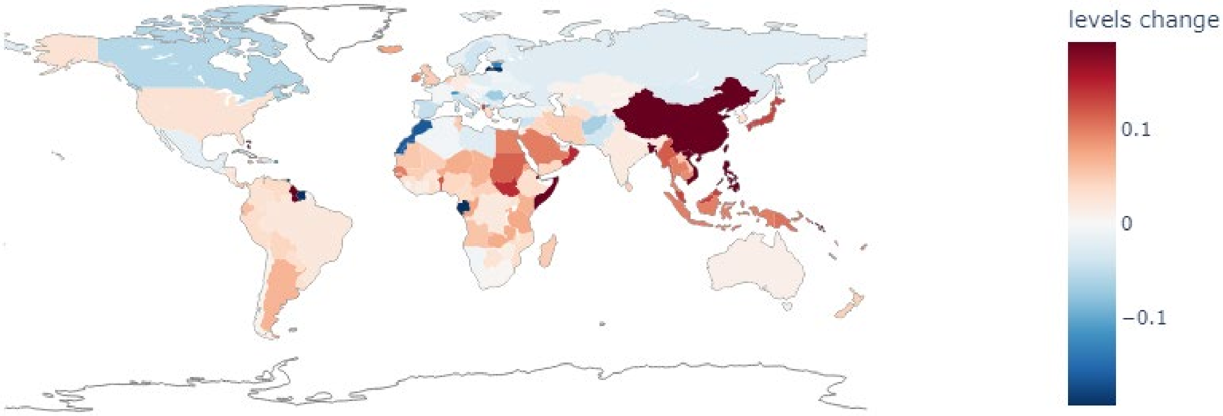
Several countries experience significant relative increases in floods' damages already by 2050, relative to the baseline, as well as by the end of the century. The relative changes have a median of 8.46 and 17.37 percent by 2050 and 2100, respectively. The largest relative changes in damage rates are in South America, Africa, and Southeast Asia. The changes in levels reflect a similar geographical distribution but are generally small, with a median of 0.02 percentage points in 2050 and 0.03 in 2100. It is important to consider all these three metrics together when assessing flood risks for a specific country to have a complete picture.

Figure 9: Floods' damage rate relative and levels change between the baseline and 2050 under SSP2-4.5

Relative change
In percent



Levels change
Percentage points



Source: IMF staff calculations

Country-level damage rate changes over time and scenarios are mainly driven by corresponding changes of the hazard severity (flood depth). For most countries damage rates increase over time and as we consider more severe scenarios. An important driver of this findings is the change in (average) flood depth over time, which displays generally increasing trends across time and scenarios. However, certain regions of the world including in high-latitude regions such as Canada and some parts of Europe, are expected to experience drier climates which can lead to a decrease in riverine floods risks.[18] More details on the drivers of floods hazard damages are provided in Fornino and others (2024).

5.2 Tropical cyclones damages

Most countries historically exposed to TCs will see an increase in damages associated to TCs in future decades (Table 4). We calculate projected damages from TCs for 89 countries that are in regions where such events are in the historical record. Depending on the scenario, 66-67 percent of the exposed countries (with the exposed areas representing 40-42 percent of global GDP in 2020) display an increase in country-level expected damage rate in 2050 relative to the baseline, with a median damage rate for these countries of 0.11-0.12 percent in 2050 and 0.12-0.16 percent in 2100 depending on the scenario (Table 4).[19] In the sample, 16-17 percent (with exposed areas representing 4-5 percent of global GDP in 2020) display a decrease in TC risks. The number of countries with increasing damage rates is highest for SSP5-8.5.

Table 4: Key statistics for TCs damages

Time	Scenarios	# of countries (median country-level damage rate in percent) with increasing TC risks	# of countries (median country-level damage rate in percent) with decreasing TC risks
2050	SSP1-2.6	59 (0.11)	15 (0.0019)
	SSP2-4.5	60 (0.11)	14 (0.0006)
	SSP5-8.5	59 (0.12)	15 (0.0025)
2100	SSP1-2.6	57 (0.12)	17 (0.0015)
	SSP2-4.5	60 (0.13)	14 (0.0012)
	SSP5-8.5	63 (0.16)	11 (0.0007)

The distributions show that the variability of damage rates increases for more severe scenarios at the end of the century for countries that will see an intensification of risk. In Figure 10, we plot the distribution of damage rates conditional on the damage rate increasing (left-hand panel) or decreasing (right-hand panel) relative to the baseline year. The number of extreme observations is overall stable for countries with increasing and decreasing damage rates. All the extreme values in the Figure 10 (left-hand panel) are island countries; small island countries are among the top five countries by damage rate for 2050 and 2100 in the different scenarios.

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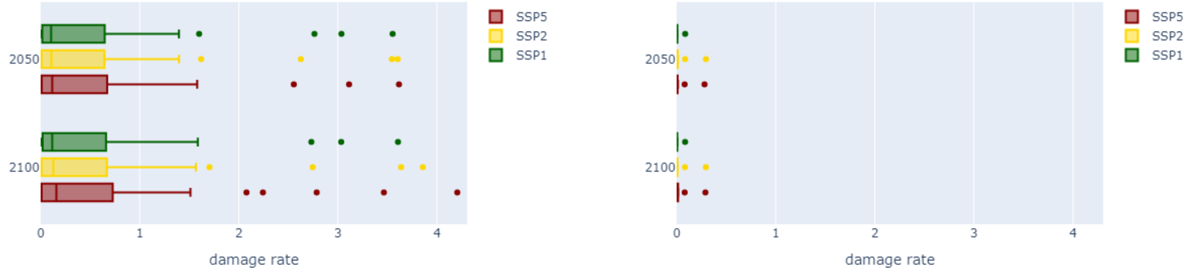
[18] While flood risks are expected to decrease for these countries, other hazards such as droughts and wildfires might be increasing. Hence, our results should not be interpreted as physical risks being decreasing overall for these countries.

[19] When only certain parts of a country are exposed to TCs, we account only for the GDP within these grids.

Figure 10: Tropical cyclones' damage rates for countries with increasing (left-hand panel) and decreasing (right-hand panel) damages relative to the baseline

In percent

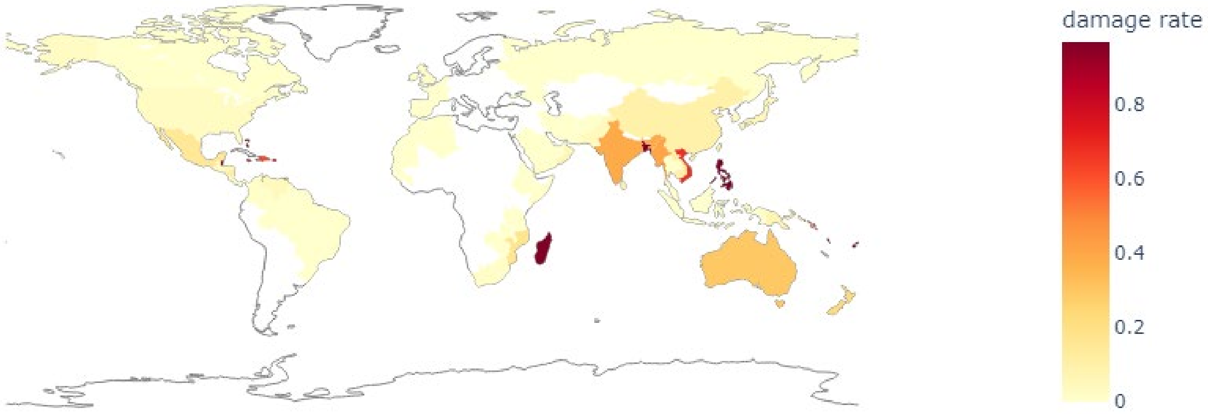


Source: IMF staff calculations

Geographical distribution of TC's damages indicate concentration in certain regions under SSP2-4.5 scenario. Similar general findings hold for the other scenarios SSP1-2.6 and SSP5-8.5.[20] Countries with the highest damage rates are in the Caribbean, South and Southeast Asia, Eastern Africa, and Oceania.

Figure 11: Tropical cyclones' damage rate for 2050 under SSP2-4.5

In percent



Source: IMF staff calculations

Most countries historically exposed to TCs experience increases in TCs related damage rates. Countries show a relative change median of 6.95 percent by 2050, which reaches 14.20 by the end of the century. North and Central and South America, and countries along the coast from Eastern Africa to Oceania, show the largest changes. High changes in the levels of damage rates are observed in countries in the Caribbean, Southeast Africa, and Southeast Asia. Drivers of TCs hazard damages are provided in Fornino and others (2024).

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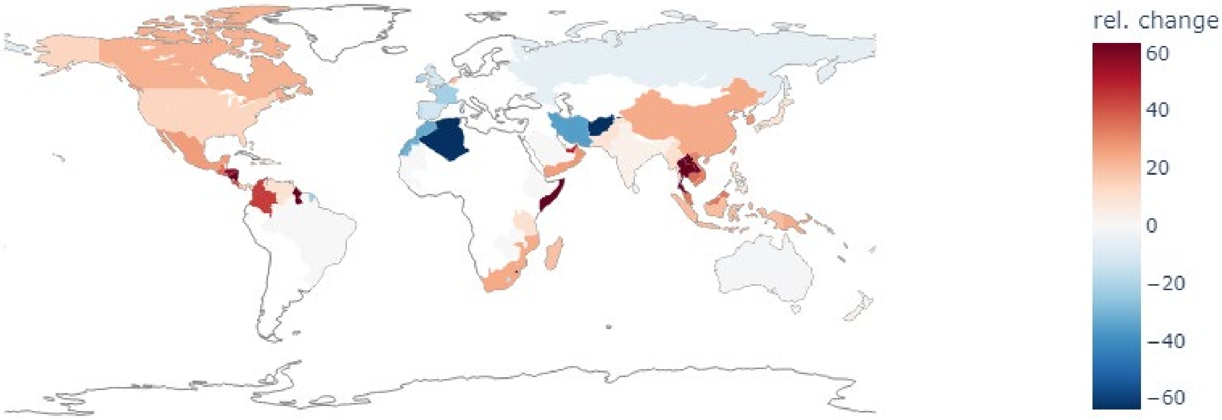
[20] The results are available in Fornino and others (2024).

Figure 12: Tropical cyclones' damage rate relative and levels change between the baseline and 2050 under SSP2-4.5

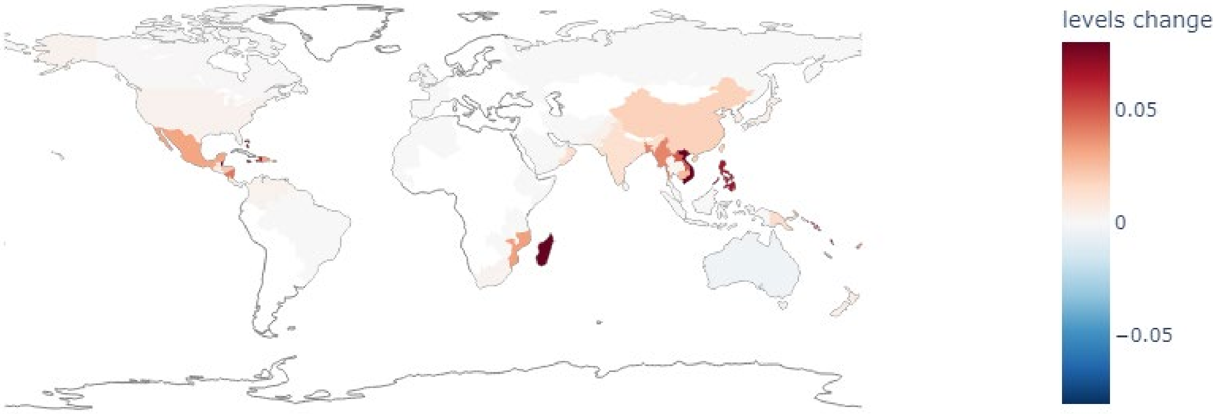
Relative change

In percent



Levels change

Percentage points



Source: IMF staff calculations

5.3 Limitations

While our results provide a useful starting point for the analysis of physical risk, there are several important limitations and challenges. For example, hazards projections are subject to uncertainty from the climate modelling and statistical techniques used to produce them. Adaptation measures, which are an important factor, are challenging to measure and as such not explicitly accounted for in this study.[21] Furthermore, this study analyzed floods and TCs damages in isolation. As explained above, combining damage rates from floods and TCs may prove challenging given the likely correlation between these events. Finally, given the wide range of countries covered, we relied on global datasets. When focusing on a single country calibrated data for the specific country might be more useful. A detailed description of limitations and comparison of results with other studies are available in Fornino and others (2024).

6. Conclusions

The IMF recently integrated climate change considerations in its work program, as climate change is found to be macro-critical.[22] For example, IMF's surveillance work now routinely includes the impact of climate change on fiscal and monetary policy, while a new climate-related financial instrument, the Resilience and Sustainability Facility, has been recently introduced.[23] The focus on climate change also spotlighted some important data gaps. The IMF's Data Gaps Initiative 3 (DGI-3) aims to bridge policy-related data gaps by developing suitable methodologies to develop adequate data.[24] In particular, recommendation #5 of the DGI-3 focuses on forward looking physical and transition risk indicators to assist policymakers in determining the timing and scope of climate policies.

The damage estimates provided by this study are a step towards closing forward-looking, physical risk-related data gaps. The estimates can be used for cross-country assessments of the importance of certain physical risks (floods and TCs) and connect future climate projections to economic and financial sector risk analysis**.** Nowadays, most of the available estimates are backward looking and often subject to limitations such as missing data. Our results provide forward-looking estimates for floods and TCs risks at country-level based on granular data, expanding the available literature. Finally, as discussed above, these results can be used as inputs to the calibration step of quantitative macroeconomic models that may be used for policy assessments.

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[21] Only for floods in the USA, England, the Netherlands, and Germany Jupiter assumes that locations protected by levees will be protected up to and including a 100-year flood.

[22] See Kristalina Georgieva's speech available here.

[23] The Resilience and Sustainability Facility (RSF) provides affordable long-term financing to countries undertaking reforms to reduce risks to prospective balance of payments stability, including those related to climate change and pandemic preparedness.

[24] Further details on DGI-3 can be found here.

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CBRT-IFC WORKSHOP ON ADDRESSING CLIMATE CHANGE DATA NEEDS: THE GLOBAL DEBATE AND CENTRAL BANKS' CONTRIBUTION

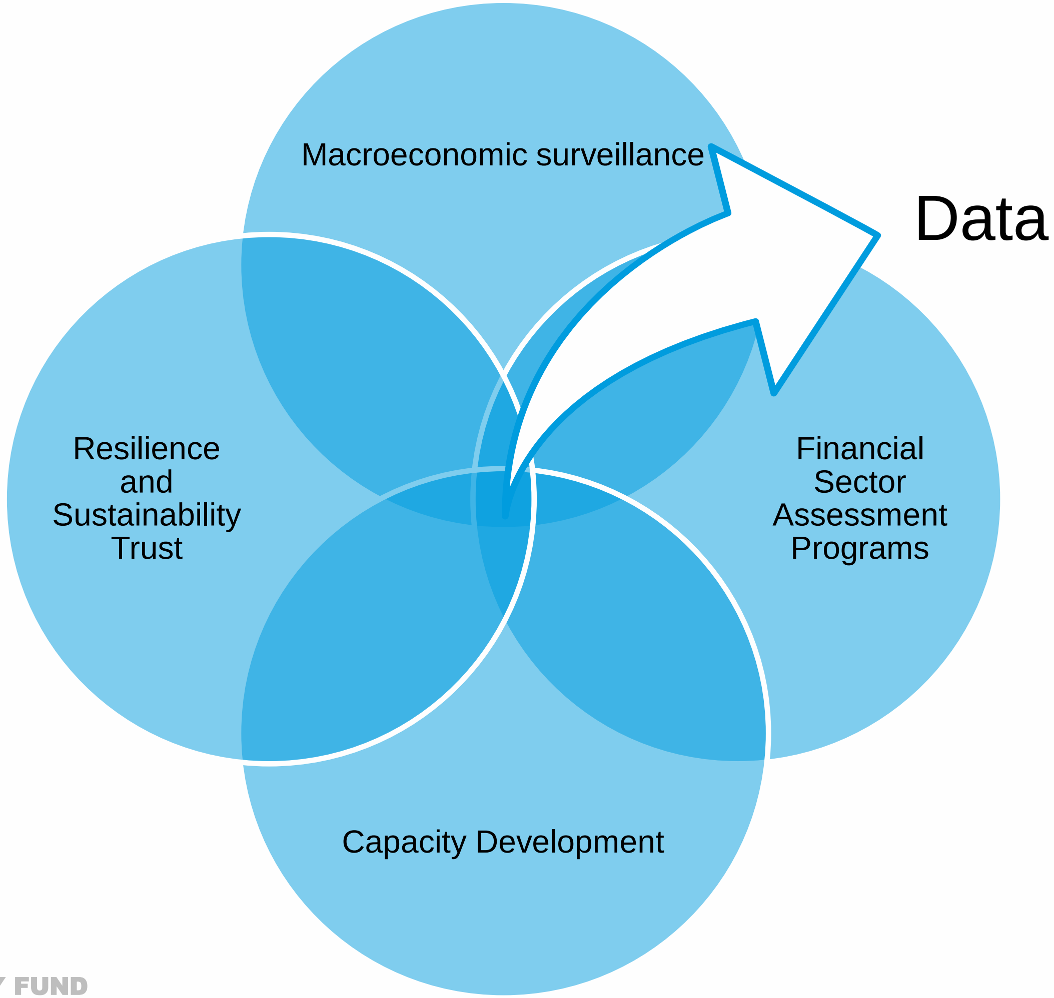
A MULTI-COUNTRY STUDY OF ECONOMIC LOSSES FROM FLOODS AND TROPICAL CYCLONES

MICHELE FORNINO, MAHMUT KUTLUKAYA,
CATERINA LEPORE AND JAVIER URUÑUELA LÓPEZ

MAY 6, 2024

IMF's work require high quality, consistent and comparable data

- The IMF is systematically covering climate-related issues through lending, analytical, surveillance, and capacity development work.



Macroeconomic surveillance

Resilience and Sustainability Trust

Financial Sector Assessment Programs

Capacity Development

Data

Climate related data are critical for the Fund

Informed decisions at local, national, and global levels.

Design **effective policies**.

Economic damages from physical risks: Key variable linking climate scenarios and the risk assessments

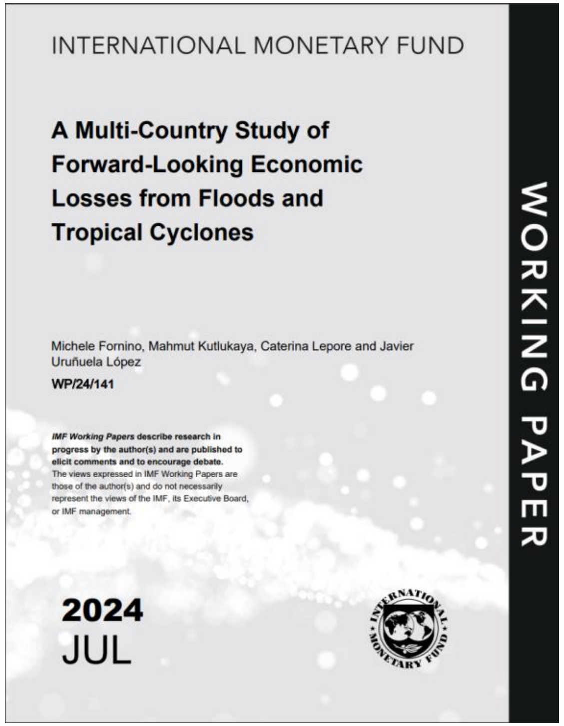
The Resilience and Sustainability Trust

G20
DATA GAPS INITIATIVE 3
DELIVERING INSIGHTS FOR ACTION

- Diagnostic tool e.g., for FSAP - Stage 1 climate risk framework
- Calibrate macro scenarios for stress testing analysis in FSAPs
- Relevant for RST countries to assess forward looking physical risks
  - Financial risks
  - Fiscal risks
- Input to macro-models:
  - Shock to capital
  - Assess mitigation and adaptation strategies (e.g., DIGNAD)
- Recommendation 5: Forward looking physical and transition risk indicators.
  - to monitor the impact of climate change on the economy and the financial system.

What do we do?

- We estimate forward-looking economic losses from floods and tropical cyclones under three IPCC scenarios.
  - ➢ Floods impacts in 183 countries
  - ➢ TCs impact in 89 countries
    - Why specifically floods and TCs?
      - Data availability – Vulnerability and hazards
- Losses are aggregated at country level building from highly-geographically-disaggregated estimates.
- A simple methodology that is applied to a wide range of countries and customizable for further analysis (e.g., granular exposures data).
- Working paper available online: [A Multi-Country Study of Forward-Looking Economic Losses from Floods and Tropical Cyclones]()



INTERNATIONAL MONETARY FUND

A Multi-Country Study of Forward-Looking Economic Losses from Floods and Tropical Cyclones

Michele Fornino, Mahmut Kutlukaya, Caterina Lepore and Javier Uruñuela López

WP/24/141

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The views expressed in IMF Working Papers are those of the author(s) and do not necessarily represent the views of the IMF, its Executive Board, or IMF management.

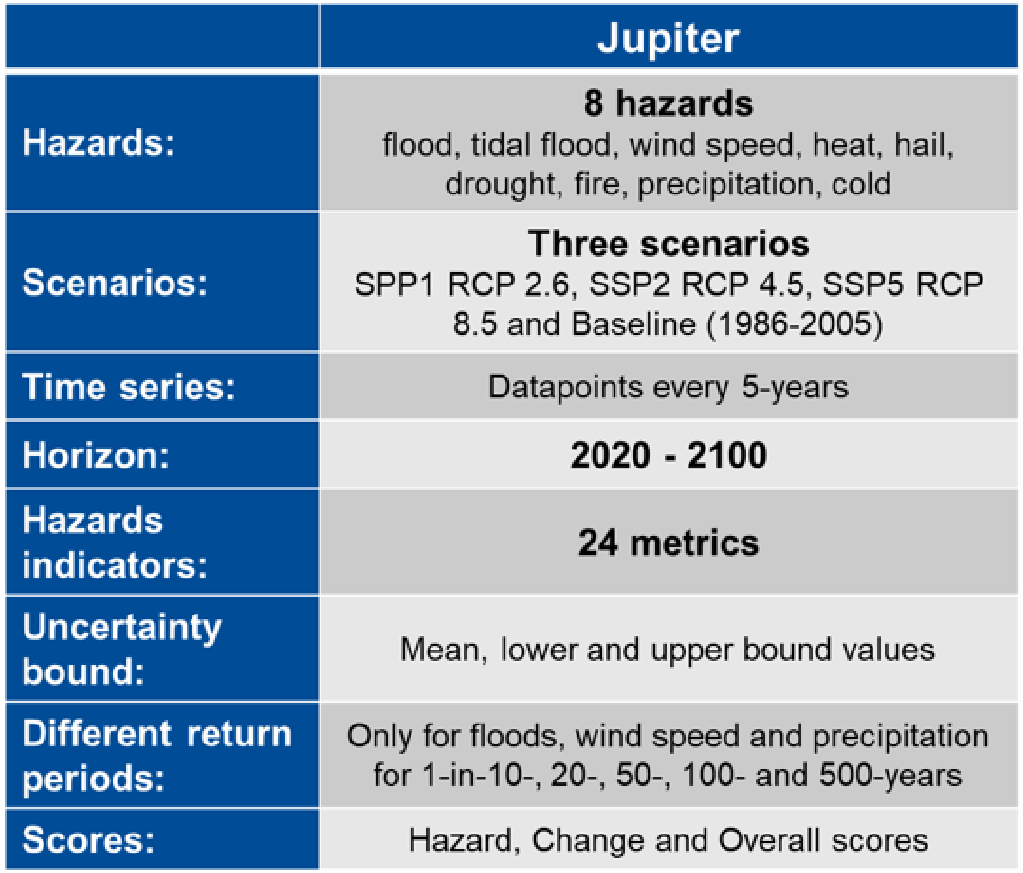
2024
JUL

WORKING PAPER

Hazards Data

JUPITER™

Jupiter provides forward-looking, scenario-based physical climate risk projections at a high geographical resolution for risk management, risk disclosure, and resiliency planning.



	Jupiter
Hazards:	**8 hazards** flood, tidal flood, wind speed, heat, hail, drought, fire, precipitation, cold
Scenarios:	**Three scenarios** SPP1 RCP 2.6, SSP2 RCP 4.5, SSP5 RCP 8.5 and Baseline (1986-2005)
Time series:	Datapoints every 5-years
Horizon:	**2020 - 2100**
Hazards indicators:	**24 metrics**
Uncertainty bound:	Mean, lower and upper bound values
Different return periods:	Only for floods, wind speed and precipitation for 1-in-10-, 20-, 50-, 100- and 500-years
Scores:	Hazard, Change and Overall scores

- The data is provided for specific locations, identified by latitude and longitude.
- 100k locations spread over all IMF member countries.
- Locations were selected to maximize GDP coverage.
    - 97% of global GDP coverage
- The data does not correspond to single events but summarizes the probability distribution or statistics of a parameter related to the hazard in each location.
- Data for different return periods is estimated using the distribution of the maximum values in a year for a specific location.

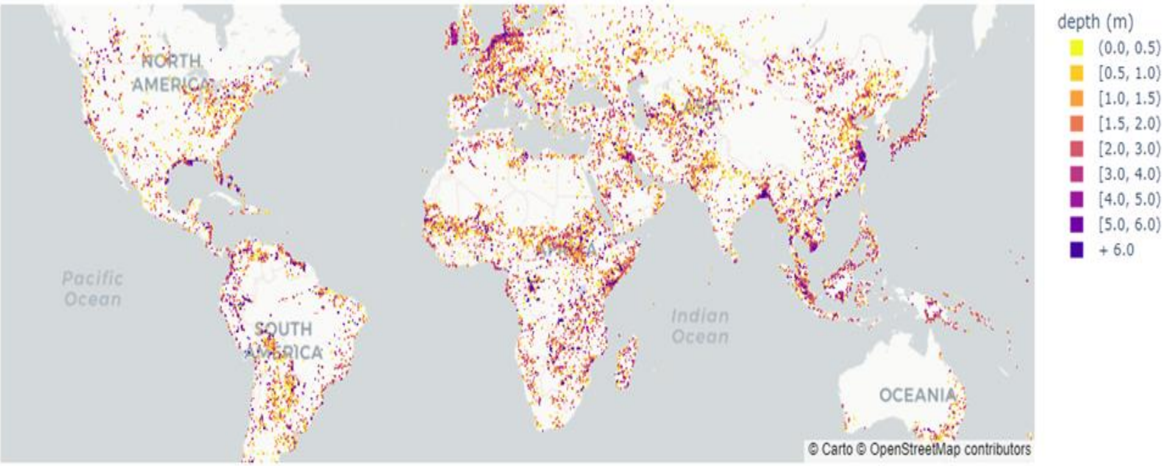
The annex includes the process followed to estimate the climate parameter for the Floods and TCs by Return Period and the process of the 100k locations selection.

Hazards Data: Floods and TCs

JUPITER™

- **Floods (river and coastal) depth and fraction flooded by return periods**.

- **Maximum 1-minute sustained wind speed at 10 meters above ground level by return period**.



© Carto © OpenStreetMap contributors

Note: Jupiter flood depth: mean depth meters for 1-in-500 year in 2040 under SSP2 RCP 4.5 (only positive values are reported).

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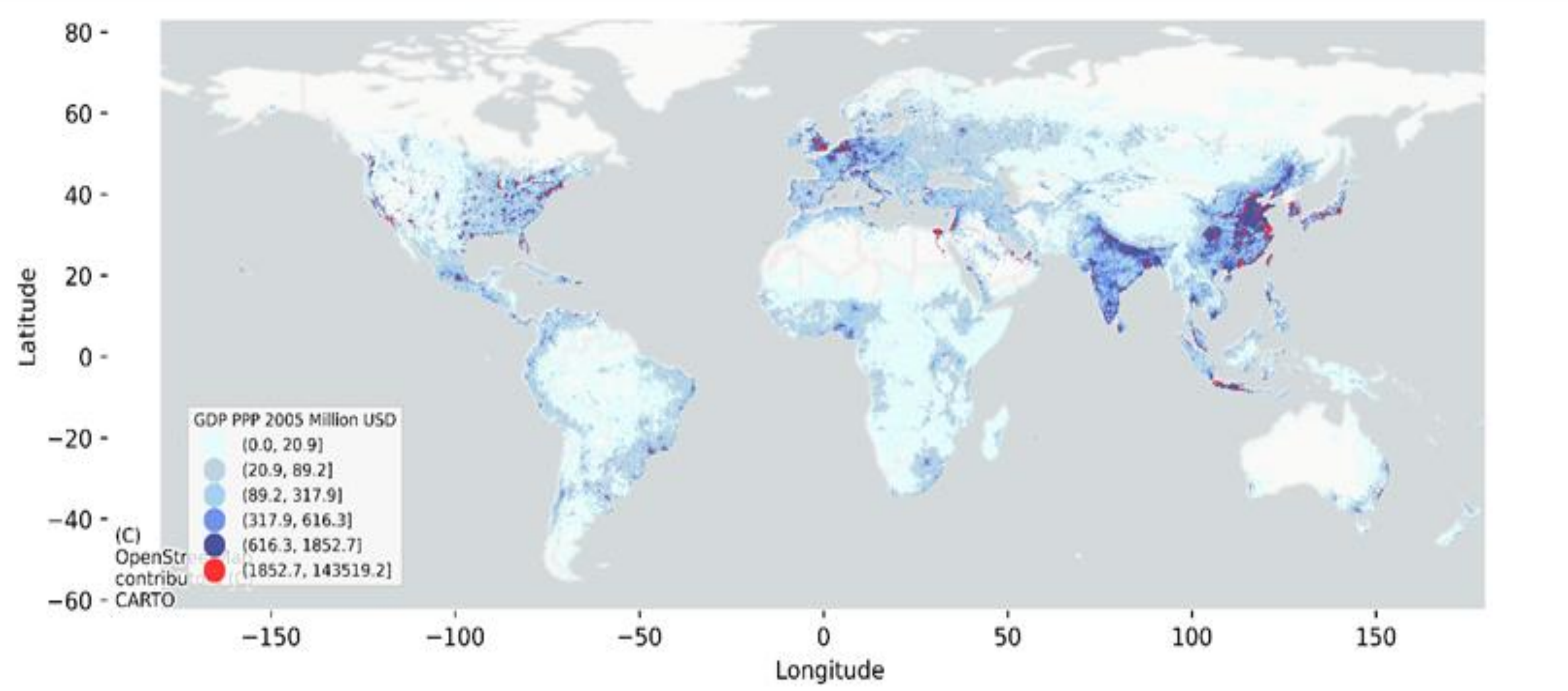
Note: Grids that consider tropical cyclones simulations in wind parameter estimates from Jupiter.

Exposures

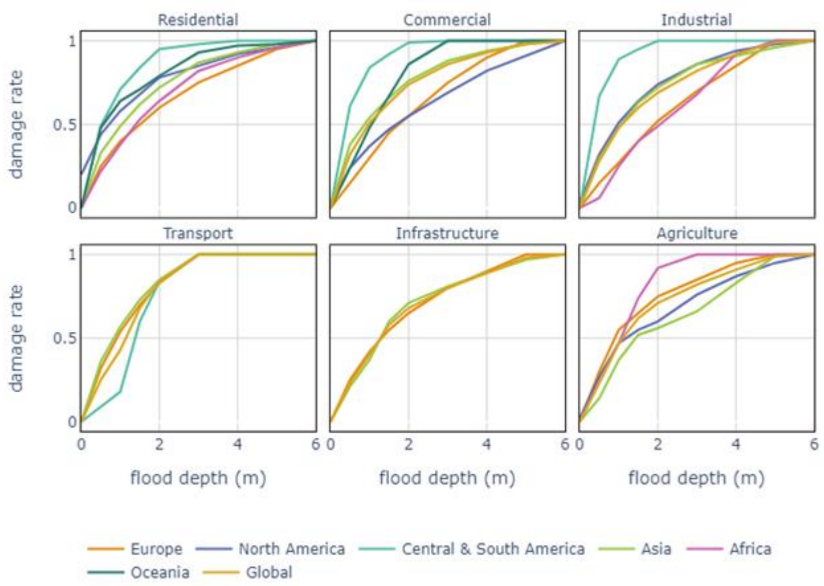
- Murakami et al., (2021) - downscaled GDP projections under all five SSPs at 5 arcminutes for 2010-2100 (10-years intervals).



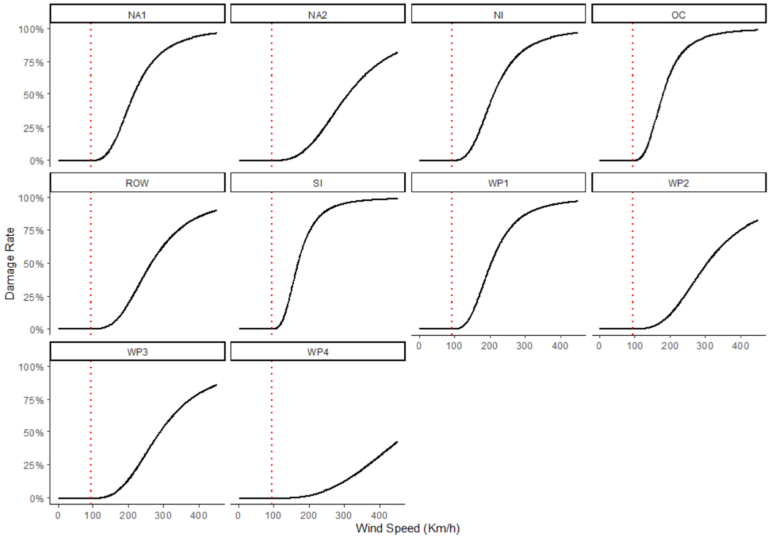
Source: Murakami D, Yoshida T and Yamagata Y (2021) “Gridded GDP Projections Compatible With the Five SSPs (Shared Socioeconomic Pathways)”.
Notes: Gridded GDP under SSP2 in 2040. GDP has been grouped by the following percentiles [0, 50, 75, 90, 95, 99, 100].

Vulnerability: Floods and TCs damage functions

- Huizinga, de Moel, and Szewczyk (2017)
- For each GDP cell: Divide the exposure into built-up and non-built-up based on Copernicus Global Land Operations "Vegetation and Energy" (CGLOPS-1).
  - For built-up areas: Combine the residential, commercial, and industrial damage functions, by equally weighting.
  - For non-built-up areas: Consider agriculture and infrastructure damage functions.

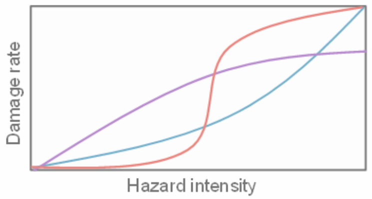


- Eberenz et al. (2021)
- Regionally calibrated damage functions (sigmoidal).
- No directly wind-induced damage is expected for low wind speeds.



Source: Eberenz et al (2021) and IMF Staff Calculations.
Note: The red dotted line represents the lower threshold of windspeed (25.7 m/s or 92.52 Km/h) below which the damage rate is assumed to be zero.

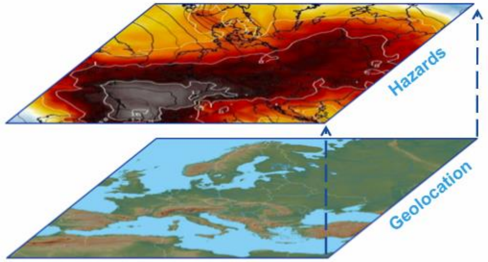
Methodology



- Damage functions by regions
- Geolocational hazards data (by location and return period)

Damage rate

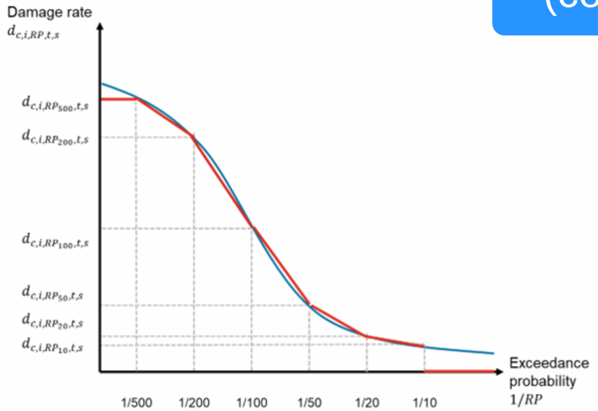
(location level)



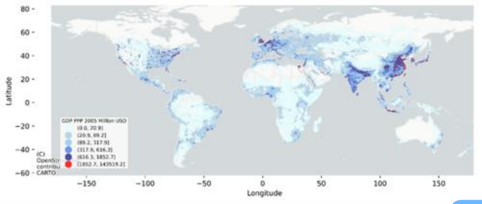
Expected damage rate

(location level)

- Calculate expected annual damage rate based on the damage rates by return period



Gridded GDP



- Aggregate locations damage rates at the country level by linking to GDP exposure

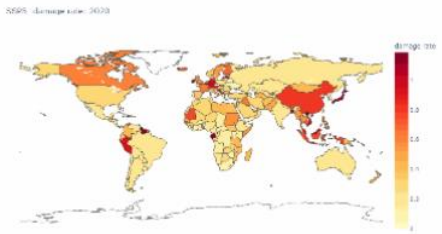
Aggregation

(country level)

Analysis

- Country level damage rate
- Levels change
- Relative change

Country damage rates

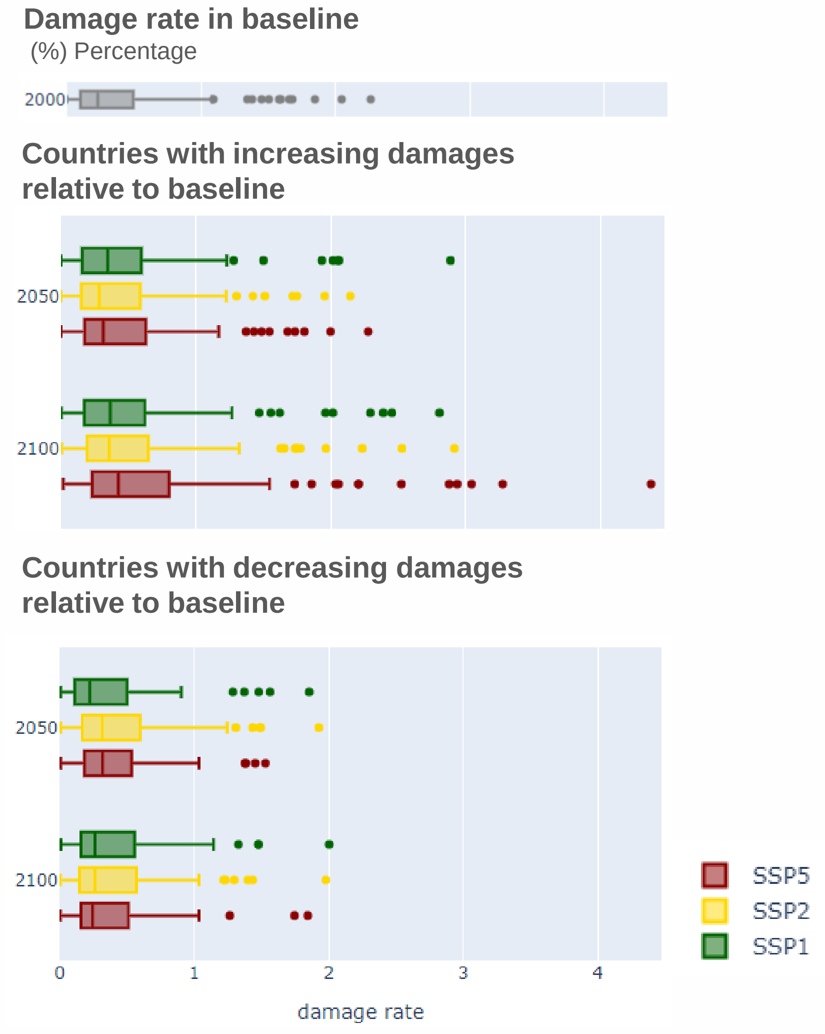


Damage rates: the loss of value of assets, expressed in percent of the value of those assets before being hit by the hazard.

Flood risks are projected to increase for most countries by mid-century

Key results

- **58-67 percent of the countries display an increase in the country-level expected damage rate** in 2050 relative to the baseline (74-80 percent of global GDP in 2020)
- **25-33 percent display a decrease in flood risks** (18-25 percent of global GDP in 2020), and the rest display no change.
- **The variability of damage rates increases for more severe scenarios.**
- **Extreme observations are countries characterized by having a small land area.**



Number of countries

183

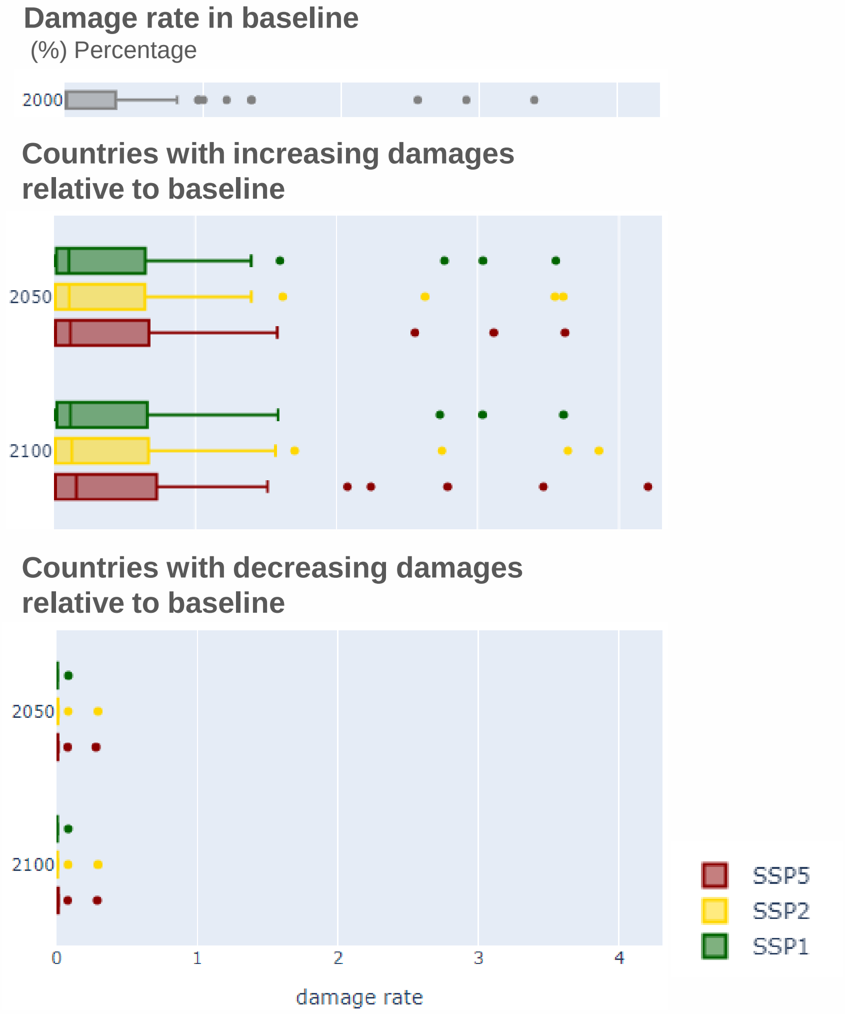
107
115
123
121
117
124

60
52
45
47
51
44

Source: IMF staff calculations

Most countries will see an increase in damages associated to TCs in future decades

- **66-67 percent of the exposed countries display an increase in country-level expected damage rate** in 2050 relative to the baseline (40-42 percent of global GDP in 2020).
- **16-17 percent display a decrease in TC risks** (4-5 percent of global GDP in 2020).
- The number of countries with **increasing damage rates is highest for SSP5-8.5**.
- **Extreme values are island countries**, with small island countries being among the top five countries through years and scenarios.



Number of countries

89
59
60
59
57
60
63
15
14
15
17
14
11

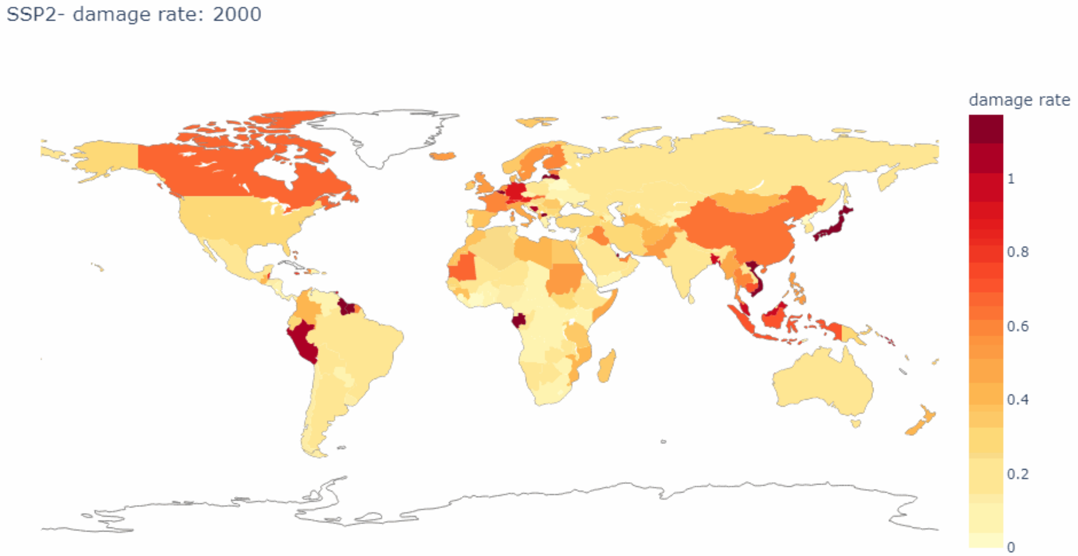
Source: IMF staff calculations

Damage rates

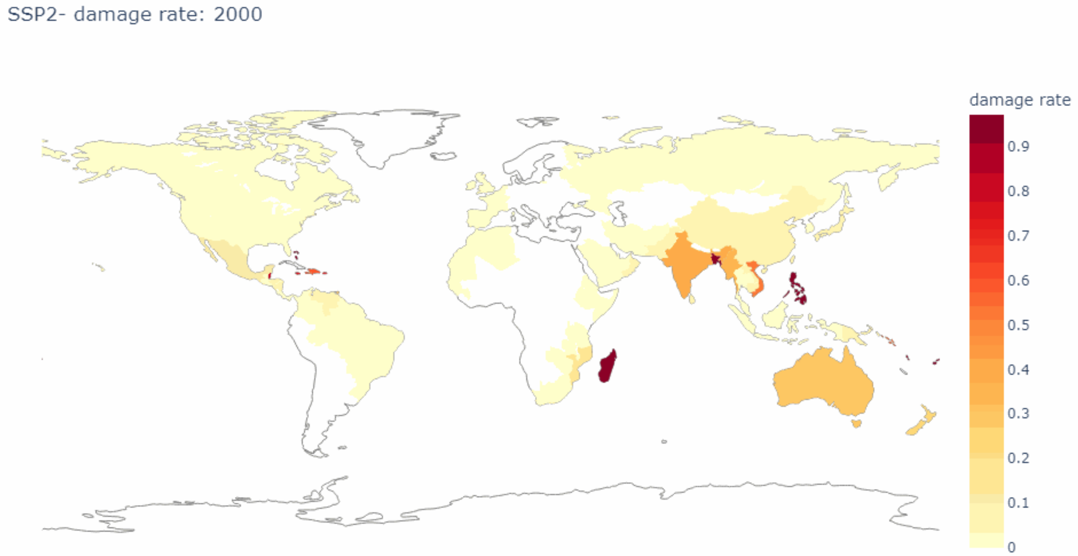
- **Flood risks are unevenly distributed across the world for the SSP2-4.5** scenario; similar general findings hold for the other scenarios, SSP1-2.6 and SSP5-8.5.
- Countries among the **top 10 with the largest damage rates** in the three scenarios are **not in specific geographical region, but most have a small land area**.

- Distribution of TC's damages indicates **concentration in certain regions under SSP2-4.5**; similar general findings hold for the other scenarios, SSP1-2.6 and SSP5-8.5.
- Countries with the **highest damage rates are in the Caribbean, South and Southeast Asia, Eastern Africa, and Oceania**.

Damage rate SSP2, 2000-2100
In percent



Damage rate SSP2, 2000-2100
In percent



Source: IMF staff calculations

A note of caution: caveats and limitations

- Hazards data.
  - Uncertainties in climate modelling.
  - Global dataset with only 100k locations, hence data might not always be representative (in particular for floods).

- Exposures data.
  - Gridded GDP is a proxy of assets/capital.
  - The output to capital ratio (Y/K) is assumed constant within a country, given a lack of granular data for every country.

- Adaptation and mitigation measures.
  - Challenging to measure
  - Not explicitly accounted for in this study (with the exceptions of some countries).

- Damage functions.
  - Calibration
  - Availability

- Hazards are considered in isolation.
  - Caution should be applied if interested in combining damages from different hazards.

- Focus on direct damages.
  - indirect damages not accounted for.

IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

The puzzle of forward-looking climate transition risk metrics[1]

I Félez de Torres and C González,
Bank of Spain,

and E Triebskorn,
Deutsche Bundesbank

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

The puzzle of forward-looking climate transition risk metrics (*)

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Banco de España – *DG Statistics*

*Clara I. González***
Banco de España – *DG Operations, Markets and Payment Systems*

Elena Triebskorn
Deutsche Bundesbank – DG Statistics

24 January 2025

(*) The views expressed in this paper are those of the authors and do not necessarily coincide with those of the Banco de España, Bundesbank and the Eurosystem.

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Abstract

With climate change effects becoming more evident every year, preventing and, ideally, reversing it is a pressing challenge. The Paris Agreement was a milestone in the fight against climate change, setting a series of specific targets for 2050. The agreement sets out a series of goals, including to hold the increase in the global temperature to below 2°C above pre-industrial levels and to pursue efforts to limit the increase to 1.5°C. Assessing the world's progress towards this goal requires forward-looking information on the transition to net-zero of companies, the financial sector, and countries alike.

In this paper, we begin by highlighting the importance of forward-looking indicators for assessing climate-related transition risks, both for corporations and countries. We then assess a range of currently available data sources. These data sources provide a variety of indicators, particularly for corporations. However, we find that results vary depending on the data sources used, and only a limited number of firms, primarily large ones, are currently disclosing forward-looking indicators. These discrepancies can partly be attributed to differences in methodology, they are not always easy to understand, nor are they always comparable or communicated transparently. Therefore, their appropriate use depends on specific use cases. We also analyse the goals and pathways stablished by countries to achieve the Paris Agreement's general target through different data sources and frameworks. We find that there are different approaches based on the original goals set by each country.

We close the paper by outlining potential ways forward for central banks, as well as how statisticians, standard setters, and other relevant stakeholders, including private entities, can help improve the quality, accessibility, and comparability of forward-looking transition risk data.

Key words*:* climate change, targets, forward-looking, indicators, transition plans

1. The importance of climate forward-looking metrics

The Paris Agreement was a milestone in the fight against climate change, setting a series of specific targets for 2050. The agreement sets out a series of goals, including to hold the increase in the global temperature to below 2°C above pre-industrial levels and to pursue efforts to limit the increase to 1.5°C. Assessing the world's progress towards this goal requires forward-looking information on the transition to net-zero of companies, the financial sector, and countries alike.

The Intergovernmental Panel on Climate Change (IPCC), established in 1988 to provide policymakers with regular scientific assessments on the current state of knowledge about climate change, shows in its Special Report on Global Warming of 1.5°C that pathways limiting global warming to 1.5°C with no or limited overshoot would require rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems (Finding C.2. in IPCC (2018)). In its assessment reports, the IPCC summarizes the state of knowledge on climate change, its widespread impacts and risks, and climate change mitigation and adaptation, serving as a reference for scenario building. The IPCC (2021) finds that unless there are immediate, rapid, and large-scale reductions in greenhouse gas emissions, limiting warming to close to 1.5°C or even 2°C will be beyond reach.

Achieving the long-term climate goals set in the Paris Agreement requires a transition process that impacts every sector of the economy, including finance, investment, and asset management. Collectively, individual goals will enable the ultimate global goal to be met. This necessitates detailed planning by both financial and non-financial corporations, outlining strategies that encompass climate and environmental risk management and sustainability factors. Such planning will make short, medium, and long-term business models more resilient in achieving global net-zero emissions[1]. The United Nations (2022) emphasizes that while governments must lead in reducing emissions, action by non-state actors is also crucial in this process.

To assess progress towards achieving these targets, it is necessary to combine the establishment of intermediate targets with final targets. This process forms an integral part of developing transition plans. The parameters of this process are based on the need for both backward-looking and forward-looking data and metrics. The former helps understand past trends and serves as the starting point for the latter, which focuses on the future.

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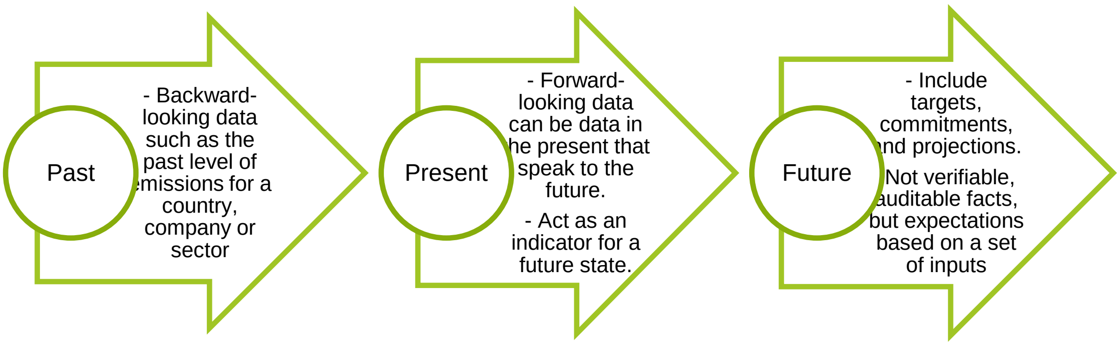
[1] Net zero is defined by United Nations (2022) as a state by which the greenhouse gases going into the atmosphere are reduced as close to zero as possible and any residual emissions are balanced by permanent removals from the atmosphere by 2050.

In 2021, a report by the Future of Sustainable Data Alliance (FoSDA) showed that data for sustainability can be broadly categorized into past, present, and future data. Past data refers to backward-looking data, such as the historical level of emissions for a company or sector. Forward-looking data can be present data that indicate future trends, acting as indicators for a future state. Future data include targets, commitments, and projections. They differ in that they are not verifiable, auditable facts, but rather expectations based on a set of inputs[2].

Infographic 1. Sustainability Data according to time-horizon



Source: own elaboration based on FoSDA (2021).

According to FoSDA (2021), forward-looking data fulfils three key uses:

- They enable investors to differentiate between companies with different potentials in terms of their sustainability outlook.
- They enable investors to assess the company's adaptive performance.
- They are crucial for benchmarking against scenarios.

As is often the case when working with climate related data, users of climate risk metrics should properly understand the key assumptions underlying a metric to appropriately interpret its result[3]. This is especially important when working with forward-looking data related to net zero, which is a newer field of analysis[4].

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[2] FOSDA _ Forward looking data – Fosda Review 2021
https://futureofsustainabledata.com/wp-content/uploads/2021/10/FoSDA-Forward-Looking-Data-report-1.pdf

[3] See: Understand what you measure: Where climate transition risk metrics converge and why they diverge.
https://www.sciencedirect.com/science/article/pii/S1544612322004561

[4] See United Nations (2022)

In this paper, we begin by highlighting the relevance of forward-looking indicators for assessing climate-related transition risks in Section 2, focusing on both countries and corporations. We gather several key elements or pieces that are relevant for designing targets and forward-looking methodologies. Specifically, we take a closer look at the case of countries in Section 3 and corporates in Section 4, assessing a series of currently available data. We close the paper by outlining potential ways forward for central banks, as well as how statisticians, standard setters, and other relevant stakeholders, including private entities, can help improve the quality, accessibility, and comparability of forward-looking transition risk data.

2. From backward-looking to forward-looking climate metrics.

Assessing global progress towards the Paris Agreement goals involves setting targets and designing a pathway to achieve net zero emissions. This process must be supported by the development of comprehensive and feasible transition plans that outline how to meet these targets. To establish medium and long-term objectives, it is essential to develop transition plans and forward-looking indicators.

According to the European Environmental Agency (2008): “well designed and sound forward-looking assessments and scenario-based approaches can effectively support different phases of the policy cycle. They can, for example, support policy making by providing a platform for reflecting on different options for the future, for identifying uncertainties, for framing policies by identifying priority and emerging issues, for checking whether and how targets can be met, for developing robust measures and precautionary actions, for analysing cause-effect relationships, for anticipating possible surprises, and for facilitating short and long-term thinking in a structured way.”

In this context, drawing up transition plans is one way of setting decarbonisation goals, and of designing the process to meet them. A 2022 OECD report highlights that the "adoption of credible transition plans by corporations can facilitate the financing of decarbonisation actions by providing financial market participants with confidence in the corporation's commitment to decarbonise."[5]

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[5] See OECD (2022).

The Task Force on Climate-related Financial Disclosures (TCFD)[6] included the preparation of transition plans among its voluntary recommendations for disclosing climate-related risks and opportunities. Similarly, both the European Financial Reporting Advisory Group (EFRAG) and the International Sustainability Standards Board (ISSB) have incorporated this element into their standards. Currently, transition plans are in the development stage within the corporate and financial sectors. According to a 2023 report from the Carbon Disclosure Project (CDP)[7], over 4,000 firms (out of 18,600 analysed) had a climate transition plan. However, when drawing up their plans, only 81 of these firms (0.4%) included all 21 of the CDP's indicators in their plans.

For assessing climate-related transition risks from both countries and corporations, forward-looking indicators are essential tools for setting targets. As more countries, firms, and financial institutions publicly commit to achieving climate goals, forward-looking metrics become increasingly important. These metrics are a useful to ensure that the goals and pathways set are credible and comparable. Various methodologies are currently being developed by data providers and institutions, both public and private. However, compared to backward-looking metrics, this is an area where greater expertise is still needed. Setting and meeting net-zero targets requires the use of different metrics that combine a forward-looking approach with long-term goals.

So far, most analyses have been carried out using historical records, such as examining how GHG emissions have evolved over time. The main indicator for analysing the past is Greenhouse Gas (GHG) emissions. When we look at historical data, we see that in the European Union (EU), for instance, GHG emissions in 2021 were down by 30% compared to 1990 levels, representing an absolute reduction of 1,401 million tonnes of CO2-equivalents (see graph 1).

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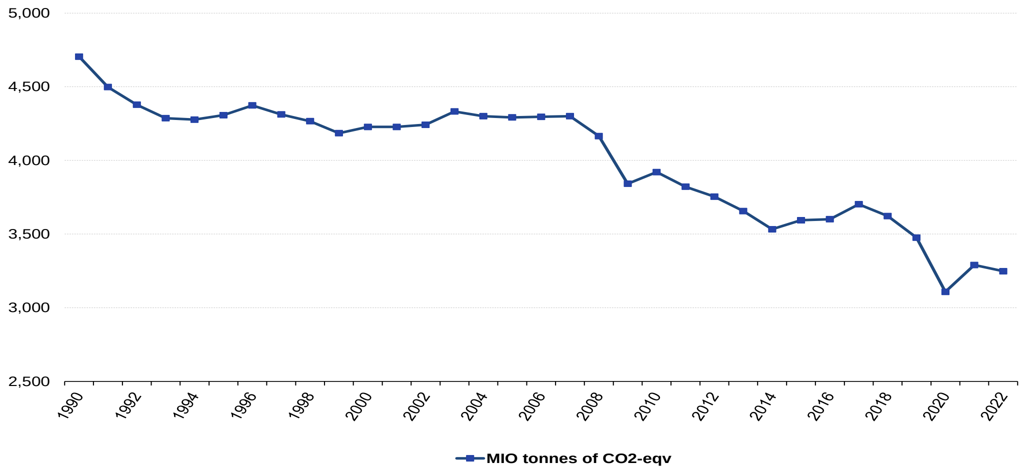
[6] The TCFD was set up in late 2015 by the Financial Stability Board (FSB), at the request of the G20, and is made up of representatives from the private sector. It was charged with drawing up a set of voluntary recommendations for the comparable disclosure of information on climate change-related financial risks and opportunities. Specifically, these recommendations refer to four areas: i) governance, ii) strategy, iii) risk management, and iv) metrics and targets.

[7] CDP (2023).

Graph 1: Historical greenhouse gas emissions in the European Union- 1990-2022[8]



Source: European Environment Agency (online data code: env_air_gge) (Net greenhouse gas emissions (including international aviation, including Land Use, Land-Use Change, and Forestry (LULUCF))

According to the GHG protocol, there are three types of emissions: Scope 1 (direct), Scope 2 (indirect from the generation of purchased electricity), and Scope 3 (all other indirect). These categories provide a foundation for businesses to measure, plan, and track progress toward science-based and net-zero targets in line with the global 1.5°C goal.

The EU has set targets for reducing its greenhouse gas emissions progressively. By 2050, Europe aims to become the world's first climate-neutral continent (see graph 2 and section 3). To achieve this, the EU has established two intermediate goals:

- In 2023, the EU adopted a set of Commission proposals to align its climate, energy, transport, and taxation policies with the goal of reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels[9].
- In February 2024, the European Commission presented its assessment for a 2040 climate target for the EU, recommending a reduction of the EU's net greenhouse gas emissions by 90% by 2040 relative to 1990.[10]

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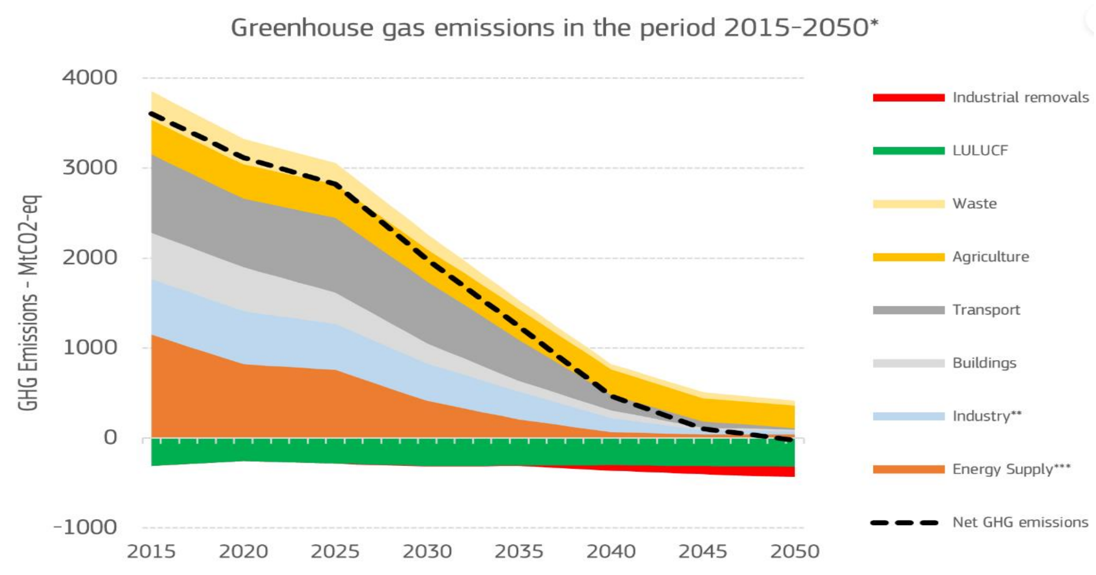
[8] Source: Greenhouse gas emission statistics - emission inventories - Statistics Explained (europa.eu); Greenhouse gas emission statistics - emission inventories - Statistics Explained (europa.eu)

[9] https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2030-climate-targets_en

[10] https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2040-climate-target_en

Graph 2: Climate targets in the European Union by sector

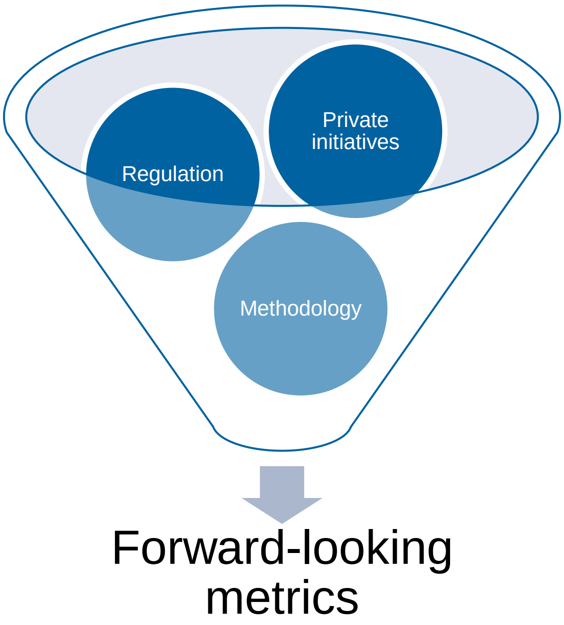


**Source: PRIMES, GAINS, GLOBIOM*
***Excluding non-BECCS industrial removals*
****Including Bioenergy with carbon capture and storage (BECCS)*

Source: 2040 climate target - European Commission (europa.eu)

To achieve these collective targets, several pieces of the puzzle are developing simultaneously. On one hand, the EU has approved various regulations related to the creation and disclosure of transition plans. Additionally, private initiatives are designing sector-specific plans and targets, while providers are developing methodologies for forward-looking metrics and indicators (see infographic 2).

Infographic 2: Ingredients for the development of forward-looking metrics



2.1 Regulation

In recent years, several **pieces of regulations** (see infographic 3) have been approved in Europe as part of the Sustainable Finance Plan, aiming to align financial flows with the goal of achieving the 1.5°C target set by the Paris Agreement.

Infographic *3: Pieces of Climate Regulation in the EU:*

Climate Law

Taxonomy

Benchmarks

Disclosures

Some of these regulations focus on this alignment, while others require the development of transition plans, including:

a. EU Climate Law.

The European Climate Law[11] writes into law the goal set out in the European Green Deal for Europe’s economy and society to become climate-neutral by 2050. It also sets an intermediate target of reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels. Achieving climate neutrality by 2050 means reaching net zero greenhouse gas emissions for EU countries as a whole. The law aims to ensure that all EU policies contribute to this goal and that all sectors of the economy and society play their part.

Progress is reviewed every five years, in line with the global stocktake exercise under the Paris Agreement. In 2023, for the first time, the Commission assessed progress towards the climate neutrality and adaptation objectives, as required under the European Climate Law. The findings were published as part of the Climate Action Progress Report[12] and in a separate document on national progress. Based on the assessment, the Commission issued recommendations to Member States under the European Climate Law in December 2023[13].

b. Taxonomy alignment

To advance reliable and comparable climate-related data, the action plan on financing sustainable growth called for the creation of a common classification system for sustainable economic activities, known as the "EU taxonomy." The EU taxonomy aims to improve market transparency and is designed to help direct investments to the economic activities most needed for the transition. It is a classification system that defines criteria for economic activities aligned with a net zero trajectory by 2050 and broader environmental goals beyond climate[14]. The EU taxonomy is currently being implemented. The Platform on Sustainable Finance[15], an advisory board of the European Commission, published a report on a compendium of market practices. This report demonstrates that the EU taxonomy is

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[11] European Climate Law - European Commission (europa.eu)
[12] Progress made in cutting emissions - European Commission (europa.eu)
[13] National energy and climate plans (europa.eu)
[14] https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en
[15] Platform on Sustainable Finance - European Commission (europa.eu)

being used for setting transition strategies, structuring financial transactions, and reporting on sustainability efforts, among other tools[16].

c. EU Climate Benchmarks – i) EU climate transition benchmark and ii) EU Paris-aligned benchmark.

In 2019, the European Commission announced the creation of two new benchmark categories or labels that consider the carbon footprint of the underlying assets (climate benchmarks) [17]. A climate benchmark is defined as an investment benchmark that incorporates specific objectives related to greenhouse gas (GHG) emission reductions and the transition to a low-carbon economy through the selection and weighting of underlying constituents[18]. The methodologies for the EU climate benchmarks, "EU Climate Transition" and "EU Paris-aligned," are based on the commitments outlined in the Paris Agreement. Both benchmarks pursue similar objectives but differ in their level of ambition[19].

d. Disclosure – Directive on corporate sustainability reporting (CSRD).

Last but not least, disclosure requirements are a crucial cornerstone in the establishment of transition plans. In the European Union, the Corporate Sustainability Reporting Directive (CSRD)[20] states that a large number of companies will need to disclose a transition plan aligned with the 1.5°C limit. The CSRD requires companies to disclose: (1) climate targets for all three scopes of carbon emissions, (2) whether these targets are compatible with the 1.5°C temperature increase limit, and (3) and how scenarios are used to construct these targets. Under the CSRD, companies must disclose near- and long-term targets every five years between 2030 and 2050, expressed in absolute values, to ensure the rapid decarbonization of economic activities. Additionally, it is considered that this information should be reported in a single electronic format to create a European Single Access Point (ESAP) for public corporate information.

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[16] See Platform on Sustainable Finance (2024).

[17] https://cnmv.es/portal/Benchmark/Indice-Climatico.aspx?lang=en

[18] https://www.unepfi.org/wordpress/wp-content/uploads/2022/02/Climate-Benchmarks_all-members-presentation.pdf

[19] https://finance.ec.europa.eu/regulation-and-supervision/financial-services-legislation/implementing-and-delegated-acts/eu-climate-transition-benchmarks-regulation_en

[20] Directive (EU) 2022/2464 of the European Parliament and of the Council of 14 December 2022 amending Regulation (EU) No 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive 2013/34/EU, as regards corporate sustainability reporting (Text with EEA relevance) . https://finance.ec.europa.eu/capital-markets-union-and-financial-markets/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en

2.2. Private initiatives

At the same time, the private sector has been working on various **initiatives that set sector-specific targets**. For example:

- Race to Zero – A coalition of non-state actors with the goal of halving global emissions by 2030[21]. All members must meet robust, science-aligned criteria. Since June 2020, over 13,000 members have joined the campaign, committing to the same goal: reducing emissions across all scopes in line with the Paris Agreement, with transparent action plans and robust near-term targets.
- UN-convened Net-Zero Asset Owner Alliance: Established in 2019, this alliance consists of asset owners committed to achieving net-zero emissions neutrality in their investment portfolios by 2050, consistent with a maximum temperature rise of 1.5°C[22]. The pathway includes interim reduction targets ranging from 22% to 32% by 2025 and from 40% to 60% by 2030.
- Net Zero Asset Managers Initiative: Launched in 2020, this initiative has over 300 signatories committed to supporting investments aligned with net zero emissions by 2050. They set decarbonisation targets for 2030 for Scope 1 and 2 emissions and, to the extent possible, Scope 3 emissions. This initiative is a formal partner of the UNFCCC's Race to Zero Campaign.
- Paris Aligned Asset Owners Initiative: Established in 2019 by the Institutional Investors Group on Climate Change[23]. In 2021, it became a global initiative in collaboration with similar investor networks in Asia, North America, and Australasia. Its objective is to provide a basis for investors to commit to achieving global net zero emissions by 2050, in line with the Paris Agreement.
- Net Zero Banking Alliance: A sector-specific alliance for banks under the Glasgow Financial Alliance for Net Zero[24]. This industry-led and UN-convened initiative is formed by global banks committed to financing ambitious climate action to transition the real economy to net-zero greenhouse gas emissions by 2050.
- Glasgow Financial Alliance for Net Zero (GFANZ): Launched in April 2021, GFANZ is a global coalition of leading financial institutions committed to accelerating the decarbonization of the economy[25]. GFANZ has developed tools and methodologies to support financial institutions' net-zero commitments and includes eight sector-

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[21] https://racetozero.unfccc.int/system/race-to-zero/

[22] https://www.unepfi.org/net-zero-alliance/

[23] https://www.parisalignedassetowners.org/

[24] https://www.unepfi.org/net-zero-banking/

[25] Glasgow Financial Alliance for Net Zero (gfanzero.com)

specific alliances: Net-Zero Asset Owner Alliance, Net-Zero Asset Managers Initiative, Paris Aligned Asset Owners, Net-Zero Banking Alliance, Net-Zero Insurance Alliance, Net Zero Financial Service Providers Alliance, Net Zero Investment Consultants Initiative, and The Venture Climate Alliance.

2.3. Forward looking indicators

Regarding **forward-looking indicators**, several methodologies have been developed. It is important to note that different methodologies apply to physical climate change risks and transition risks.

For **physical risk**, Fehr, Triebskorn, and Mehrhoff (2022) compared data from third-party providers to extract relevant aggregates at the sector and country levels [26]. The forward-looking metrics refer to physical risk in 2050, depending on various Representative Concentration Pathways (RCPs) that represent different levels of global warming, as defined by the Intergovernmental Panel on Climate Change (IPCC). They encountered the following issues:

- Limited coverage of company-level data.
- The variation between the different data providers is high, similar to other areas of sustainability data.
- The hazards covered, as well as their definitions, are not consistent across data providers and therefore need to be considered when analysing results.
- Physical risk metrics should be comparable across years and scenarios and reflect financial damages.

In the case of **transition risks**, which is the focus of this article, there are several frameworks and metrics. Various initiatives are underway, detailed in the next two sections—one dedicated to countries and the other to corporations. We will see that, depending on the use case and data needs, the appropriate sources and methodologies will differ.

As outlined in a 2024 OECD Review on aligning finance with climate goals (OECD, 2024), climate-alignment assessments require methodological transparency and different methodological assumptions, such as the choice of reference scenario, can lead to diverging results. In this respect, relying on a robust set of complementary metrics

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[26] Constructing forward-looking climate-related physical risk indicators (bis.org)

provides a more complete and accurate view of progress towards transition plans and alignment.

Therefore, an important **additional piece of the puzzle** is that the development of methodologies and goals must be based on **scenarios**, primarily the IPCC scenarios. Additionally, the Network for Greening the Financial System (NGFS) has developed several scenarios based on the IPCC. Scenario analysis is a key part of the toolbox for central banks and other international financial institutions[27]. By nature, scenarios are forward-looking, making forward-looking data a critical ingredient for their use. The NGFS published its climate scenarios portal[28], highlighting six scenarios to assess transition and physical risks, ranging from the 'delayed transition' and 'current policies' bad outcomes to 'below 2 degrees' or even more ambitious 'net zero 2050' scenarios.

As we have seen, targets can be set at different levels of aggregation: countries, economic sectors, companies, or portfolios, to name a few. Ideally, targets at the disaggregated level should collectively contribute to the implementation of emission reduction targets for a country as a whole. In the next section, we will examine various sources of data at distinct levels of aggregation and compare these results.

3. Puzzle pieces in the case of countries.

Under the Paris Agreement, countries commit to achieving their ultimate goals through the establishment of their NDCs, which involves setting long-term goals and measures to reach them. The main metric to evaluate the alignment with the Paris Agreement is the evolution of total GHG emissions and the compliance with the interim goals set in order to achieve the long-term objectives in 2050. In the case of sovereigns there is no standard method to perform this analysis and the forward-looking methodologies and metrics are under development. Currently we can find several initiatives that are under development such as Net Zero Tracker, ASCOR Project or Climate Action Tracker that collects information on the type of commitment of countries and assess the state of play of their achievement.

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[27] https://futureofsustainabledata.com/wp-content/uploads/2021/10/FoSDA-Forward-Looking-Data-report-1.pdf

[28] NGFS Scenarios Portal

3.1. Paris Agreement, NDCs targets and national plans

The main goal of the Paris Agreement is to prevent global temperatures from rising by more than 2 degrees Celsius (2ºC) above pre-industrial levels, while striving to limit this increase to 1.5ºC. Additionally, it sets two further objectives: enhancing the economy's capacity to adapt to the adverse effects of climate change and reducing greenhouse gas emissions; and promoting the financing of investments needed to support sustainable growth.

The Paris Agreement was adopted in 2015 at the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change, held in Paris. This agreement was signed by 195 out of 198 Parties to the United Nations Framework Convention on Climate Change. Each Party to the Paris Agreement is required to establish a Nationally Determined Contribution (NDC). The NDCs contain information on targets, policies, and measures for reducing national emissions and adapting to climate change impacts. They also include details on the needs for, or provision of, finance, technologies, and capacity building for these actions. Countries communicate new or updated NDCs every five years, starting in 2020.

Countries establish their NDCs by setting targets for mitigating the greenhouse gas emissions that cause climate change and for adapting to climate impacts. The plans define how to reach the targets and how to monitor and verify progress. Some countries also link their NDCs to national development plans, including those aimed at achieving the Sustainable Development Goals[29]. Currently, some Parties have issued at least a first NDC, and some have communicated an update; however, ambitions vary. Some countries, due to their economic, technological, or developmental circumstances, may not be in a position to commit to the strictest target and, therefore, are allowed to follow a less ambitious goal.[30]

In the case of mitigation targets, they range from economy-wide absolute emission reduction targets to strategies, policies, plans, and actions for low-emission development. According to

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[29] See more in https://www.un.org/en/climatechange/all-about-ndcs

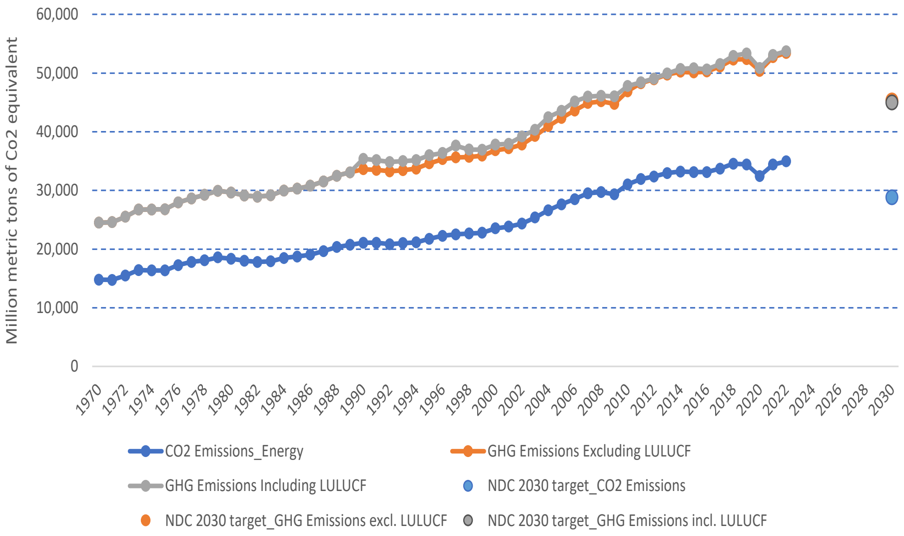
[30] Countries under the Paris Agreement are classified into different groups based on their commitments, as outlined in Annex I and Annex II of the United Nations Framework Convention on Climate Change (UNFCCC). Annex I Parties include industrialized countries that were members of the Organisation for Economic Co-operation and Development (OECD) in 1992, along with countries with economies in transition (EIT), such as the Russian Federation, the Baltic States, and several Central and Eastern European States. Annex II Parties are a subset of Annex I Parties, specifically the OECD members, excluding the EIT Parties. Non-Annex I Parties are mostly developing countries. The obligations are not the same in each group: i) Annex I Parties are required to adopt national policies and take measures to limit their greenhouse gas emissions. They are also expected to report regularly on their progress in reducing emissions, ii) Annex II Parties have additional responsibilities to provide financial resources to developing countries to help them undertake emissions reduction activities and adapt to the adverse effects of climate change. They are also required to promote the development and transfer of environmentally friendly technologies to both EIT Parties and developing countries, iii) Non-Annex I Parties are encouraged to implement national measures to mitigate climate change and adapt to its impacts. They receive support from Annex II Parties in the form of finance, technology, and capacity-building. See https://unfccc.int/parties-observers .

the “2023 NDC Synthesis Report” prepared by the United Nations and based on the NDC registry as of 25 September 2023:

- 94% of Parties provided quantified mitigation targets, expressed as clear numerical targets, while 6% included strategies, policies, plans, and actions for which there is no quantifiable information as components of their NDCs.
- 80% of Parties communicated economy-wide targets, covering all or almost all sectors defined in the 2006 IPCC Guidelines, with an increasing number of Parties moving to absolute emission reduction targets in their new or updated NDCs.
- A total of 93% of Parties communicated an NDC implementation period until 2030, while 7% specified an implementation period until 2025, 2035, 2040, or 2050.

The main metric that serves as the starting point for the analysis is the total Greenhouse Gas (GHG) emissions. It is a backward-looking metric because it reflects past data. As shown in Graph 3, the evolution of reported GHG emissions for the World should exhibit a decreasing trend to comply with the NDC targets for 2030 globally. There has been an increasing trend since 1990, particularly in recent years, despite the temporary decrease in total emissions in 2020 due to COVID-19. This is observed in both GHG emissions, including and excluding Land-Use and Land-Use Change and Forestry (LULUCF) emissions (in gray and orange, respectively), as well as in CO2 emissions from the energy sector (in blue). The NDC targets for the three series in 2030 are well below the values recorded in 2022.

Graph 3. Reported Emissions vs NDCs targets. World



Source: IMF - Climate Change Dashboard.

In Europe, the European Climate Law, part of the European Green Deal announced in 2019, aims to make the economy and society climate-neutral by 2050. This means achieving net zero GHG emissions for EU countries as a whole, primarily by cutting emissions, investing in green technologies, and protecting the natural environment. The law also sets an intermediate target of reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels. Additionally, since February 2024, the European Commission recommends a 90% net greenhouse gas emissions reduction by 2040 compared to 1990 levels. This target is aligned with the ambition to achieve climate neutrality by 2050.

Each EU Member State must develop national long-term strategies on how they plan to achieve the greenhouse gas emissions reductions needed to meet their NDC commitments under the Paris Agreement and the EU's climate neutrality objective. According to the Regulation on the governance of the energy union and climate action (EU) 2018/1999, Member States had to design their draft National Energy and Climate Plans[31] for the period 2021-2030 and submit an updated plan in 2023. The EU-wide assessment of 21 plans by the European Commission[32] concludes that Member States are on the right track, but ambition gaps remain to achieve the recently agreed increased targets and objectives for 2030 in climate and energy policies.

Graph 4 illustrates the historical and projected GHG emissions (including LULUCF) for the European Union 27 up to 2050. There are two projection scenarios: (a) with existing measures (WEM), which reflect current policies and measures, and (b) with additional measures (WAM), which include further policies and measures that Member States plan to implement in the coming years. Under the WAM scenario, emissions would be lower than in the WEM scenario and compared to 1990 levels, emissions would be 51% lower in 2030 and 68% lower in 2050. The LULUCF sector plays a key role in achieving the European Union’s goal of zero net emissions by 2050, for example these activities removed net 236 million tonnes of CO2 equivalent (MtCO2e) from the atmosphere in 2022, equal to 7% of the EU’s annual greenhouse gas emissions. The goal of neutrality in 2050 depends on reducing greenhouse gas emissions but also on increasing CO2 removals from the atmosphere. Among the EU Member States, Romania, Sweden, Spain, Italy, Poland, and France were responsible for the largest cumulative net removals from the LULUCF sector in the past 10 years.

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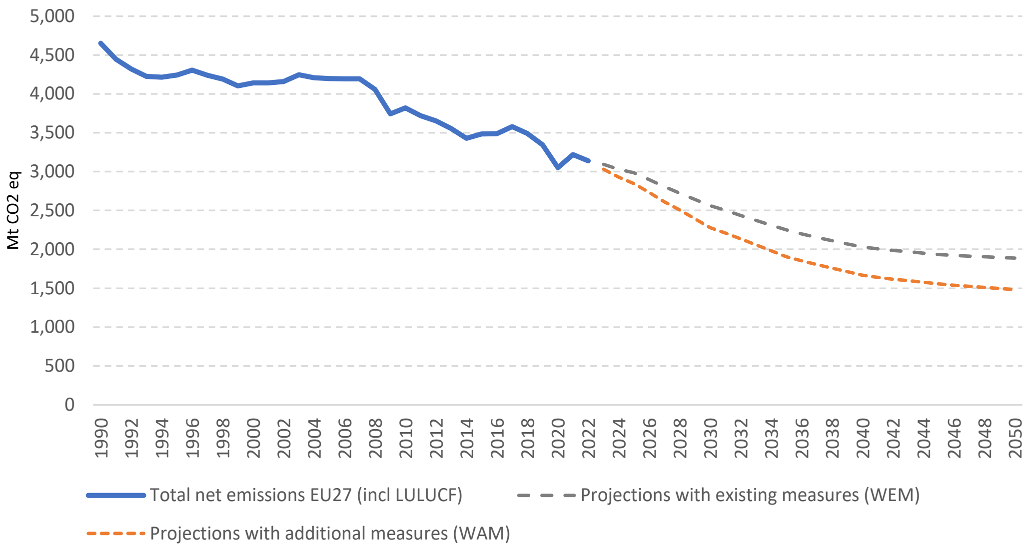
[31] draft National energy and climate plans

[32] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS EU wide assessment of the draft updated National Energy and Climate Plans An important step towards the more ambitious 2030 energy and climate objectives under the European Green Deal and RePowerEU. COM/2023/796 final

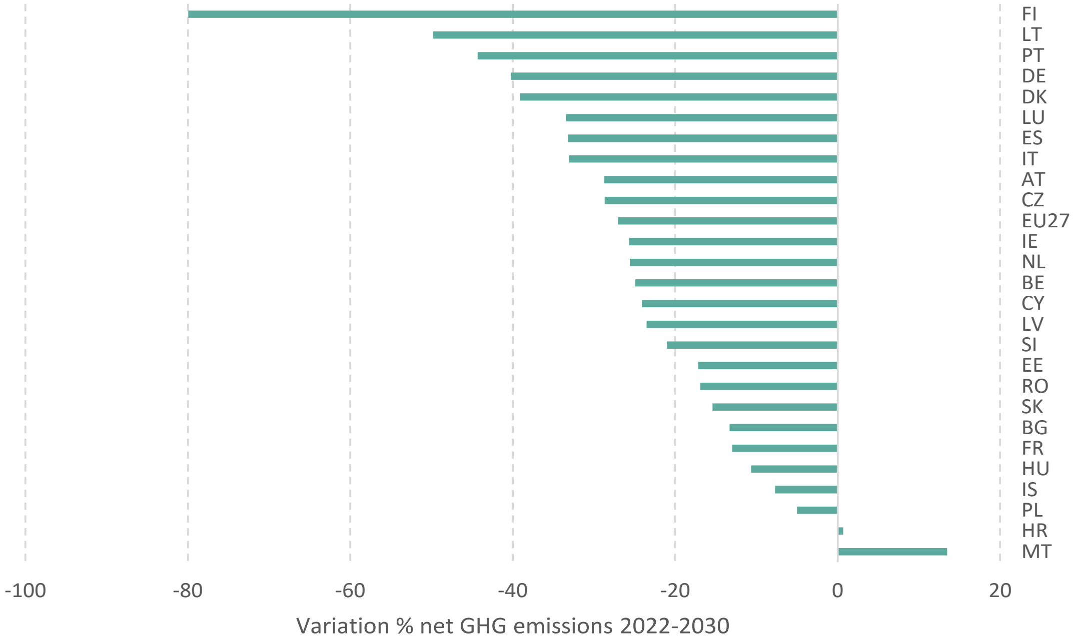
Graph 4. Historical and projected GHG net emissions (including LULUCF) - EU 27



Source: Own elaboration based on European Environment Agency data

EU Member States are required to report their GHG projections every 2 years (and optionally every year) under Article 18(1)(b) of the Governance of the Energy Union and Climate Action and under both WEM and WAM scenarios. Graph 5 shows the variation in GHG emissions (including LULUCF) between 2022 and 2030 that would be necessary in each country to achieve the targets set for 2030. As can be seen, most countries would need to achieve a reduction of over 20%, and in some cases, the reduction would need to exceed 40%.

Graph 5. Variation (%) in GHG Emissions (including LULUCF) 2022-2030 – With additional measures (WAM) by country



Source: Own elaboration based on European Environment Agency data

3.2. Net zero tracker

The Net Zero Tracker gathers information on sovereigns and corporations, focusing on the types of commitments and interim targets. It analyzes all nations that are parties to the UNFCCC, every region within the 25 largest emitting nations, all cities with over 500,000 inhabitants, and the world's 2,000 largest publicly listed companies by revenue. See Net Zero Tracker (2024a)[33].

Table 1 shows the types of commitments and the number of countries by geographical area. The majority of countries have set a "net zero" goal, followed by "carbon neutrality". In Europe, there are almost the same number of countries under "net zero" and "emissions reduction target", although some fall under "carbon neutrality" and "carbon neutral". These types of commitments are established by law or policy documents in most European countries; however, in other regions, they are still under consideration, as shown in Graph 5. Regarding interim targets, according to data from the Net Zero Tracker, around 75% of countries have set an interim target, with 40% of those being an

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[33] Details on the framework and data are available on the website https://zerotracker.net/

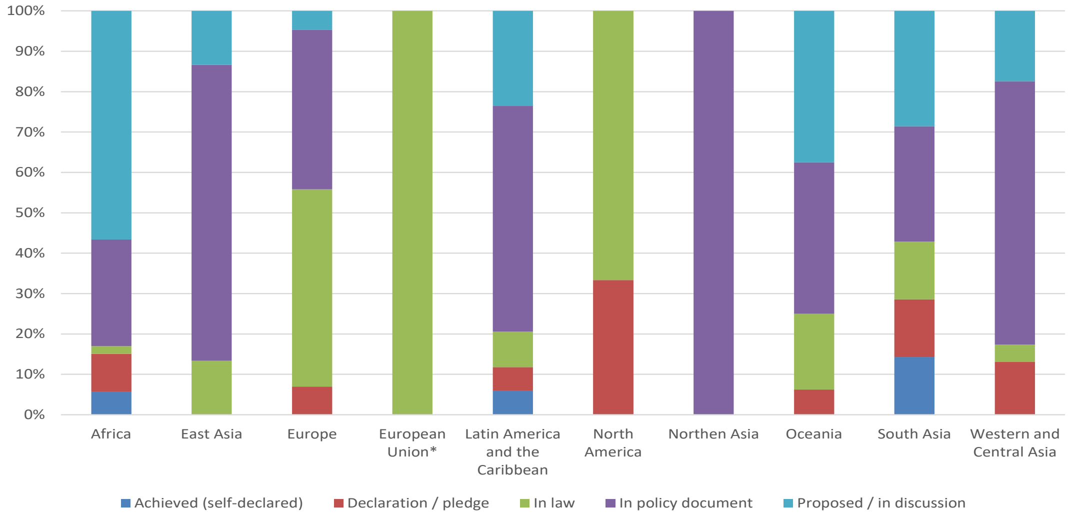
“emissions reduction” target." According to Net Nero Tracker (2024a), many of the countries without net zero targets are low- or lower-middle income countries, which can justify longer timelines to achieve net zero emissions compared with other countries.

Table 1. Number of countries by type of compromise and geographical area

Area	Absolute emissions target	Carbon negative	Carbon neutral(ity)	Climate neutral	Emissions intensity target	Emissions reduction target	Net zero	No target	Other	Reduction v. BAU	Zero carbon	Zero emissions	Total
Africa			3			3	39	1	1	7			**54**
East Asia			3			2	8			2			**15**
Europe			8	9		13	12					1	**44**
European Union*				1									**1**
Latin America and the Caribbean	1		5			3	18	1	3	2	1		**34**
North America							2			1			**3**
Northern Asia			1										
Oceania							16						**16**
South Asia		1	1				5						**7**
Western and Central Asia			3	2	1	4	9	1	3	1			**24**
Total	**1**	**1**	**24**	**12**	**1**	**25**	**109**	**3**	**7**	**13**	**1**	**1**	**198**

Source: own elaboration based on Net Zero Tracker data. *European Union as a whole

Graph 6. Countries by end target status and geographical area



Source: own elaboration based on Net Zero Tracker data. *European Union as a whole

3.3. ASCOR Project

The project “Assessing Sovereign Climate-related Opportunities and Risks” (ASCOR) was created by a coalition of international investors and is led by asset owners, asset managers, and investor networks with the academic collaboration with the Transition Pathway Initiative Centre[34] to assess the climate action and alignment of sovereigns.

The framework is structured around several key pillars: the greenhouse gas emission pathways of a country and their alignment with global climate goals, the policies and measures implemented to mitigate climate change, the financial and economic policies that support or hinder climate action, and the social and governance aspects that influence a country's ability to manage climate risks and opportunities (see ASCOR, 2023).

The assessment relies on various indicators and metrics grouped into three pillars, as illustrated in Table 1. The goal is to evaluate the progress made by countries in managing the low-carbon transition and addressing the impacts of climate change.

Table 2. ASCOR Framework

Pillar 1. Emissions Pathways (EP)	Pillar 2. Climate Policies (CP)	Pillar 3. Climate Finance (CF)
EP 1. Emissions trends EP 2. 2030 targets EP 3. Net zero targets	CP 1. Climate legislation CP 2. Carbon pricing CP 3. Fossil fuels CP 4. Sectoral transitions CP 5. Adaptation CP 6. Just transition	CF 1. International climate finance CF 2. Transparency of climate costing CF 3. Transparency of climate spending CF 4. Renewable energy opportunities

Source: ASCOR (2023)

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[34] The TPI Centre is part of the Grantham Research Institute on Climate Change and the Environment based at the London School of Economics and Political Science (LSE).

In 2024, ASCOR reviewed the climate change performance of 70 high-, middle-, and low-income countries[35] through its framework[36]. Out of these, 40 countries have established a legal framework for national climate policy via a climate framework law[37]. Focusing the analysis on Pillar 1, Emissions Pathways, it is divided into three blocks: (i) emissions trends, (ii) 2030 targets, and (iii) net zero targets, each containing various indicators and metrics.

Key findings regarding targets[38] are:

- 40 of the 70 countries have reduced their emissions over the past five years,
- 96% of the countries have set a 2030 emissions reduction target (indicator EP 2a). However, no country has a historical emissions trend or 2030 target aligned with its national 1.5ºC benchmark (indicator EP 2c). ASCOR calculates the targeted reduction relative to 2019 emissions (metric EP 2ai), and almost 75% of the countries are below their corresponding benchmark, with values less than a -0.5%.
- 80% of the countries (56) have set a net zero CO2 target (indicator EP 3a). These countries are primarily from Europe, Central Asia, Latin America, and the Caribbean. Most of them have set 2050 as the target year (metric EP 3ai), with thirty-eight of the 45 high-income countries committing to net zero by 2050 at the latest. However, there are some countries that have set earlier target years: 2030 (Barbados, Norway), 2035 (Finland), 2040 (Austria), and 2045 (Denmark, Germany, Sweden). And others have set later target years: 2053 (Turkey), 2060 (Bahrain, China, Kazakhstan, Russian Federation, Saudi Arabia), and 2070 (India, Nigeria). Regarding the alignment of these net zero targets with a global 1.5°C scenario (indicator EP 3b), ASCOR identifies 38 countries as aligned, 7 as not aligned, and 25 as exempt.[39]

3.4.Climate Action Tracker (CAT)

The Climate Action Tracker (CAT) is an independent scientific project resulting from the collaboration between two organizations, Climate Analytics and the NewClimate Institute[40]. CAT tracks government climate actions and measures them against the globally agreed Paris Agreement. It quantifies and evaluates climate change mitigation targets and policies implemented by governments, assessing how these are likely to

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[35] Accounting for more than 85% of global greenhouse gas (GHG) emissions and 90% of global GDP.

[36] Details on the framework and data are available on the website https://www.ascorproject.org/.

[37] See Scheer et al. (2024) for further details.

[38] Based on the indicators EP 2a, EP 2c, EP 3a, EP 3b, and the metrics EP 2ai, EP 3ai.

[39] Countries that are exempt from aligning their net zero emissions targets with the 1.5°C limit of the Paris Agreement are usually those not included in Annex I of the Agreement."

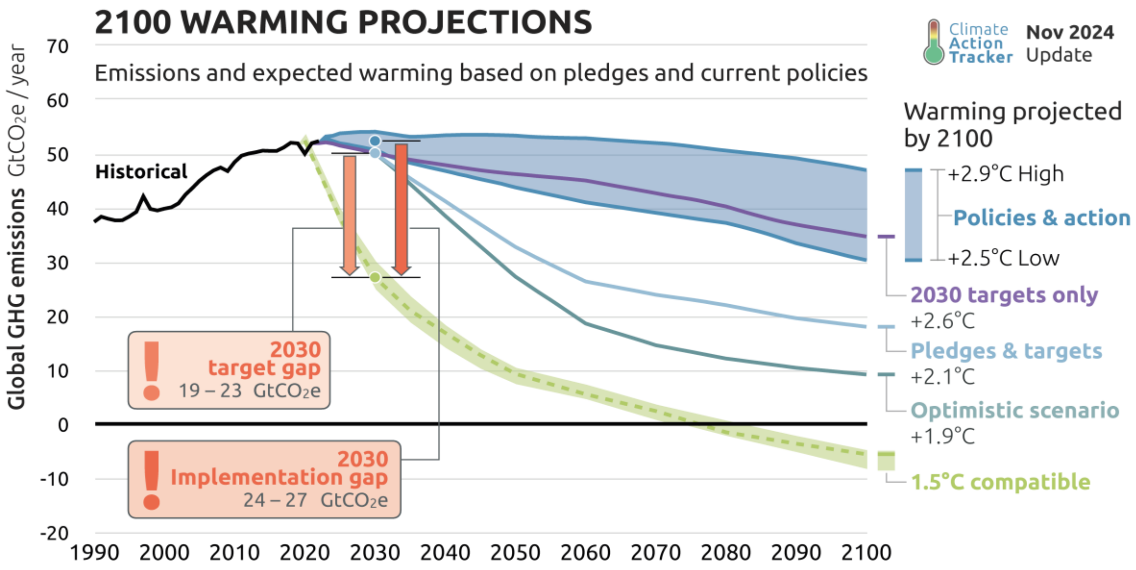
[40] More details and data are available on the website: https://climateactiontracker.org/

affect national emissions up to 2030. CAT covers the actions of 39 countries and the European Union, accounting for around 85% of global emissions. It assesses global emissions pathways consistent with government actions and identifies the gap between the Nationally Determined Contributions (NDCs), pledges, policies, and the emissions needed to comply with the Paris Agreement goal of limiting the increase in global average temperature to well below 2°C above pre-industrial levels.

Specifically, the tools developed by CAT include: i) a thermometer indicating the likelihood of goals being met or specific temperatures being exceeded, b) an assessment of the emissions gap between the expected absolute emissions in 2030 and the emissions consistent with the pathway aligned with the 1.5°C Paris Agreement goal, c) a 2035 climate NDCs target update tracker, and d) a net zero target evaluation through ten elements to assess whether the scope, architecture, and transparency meet what CAT defines as good practice.

According to CAT, current global policies are projected to result in a median warming of about 2.7°C, considering the combined low and high ends of current policy projections. Nationally Determined Contributions (NDCs) alone are expected to limit warming to 2.6°C. When binding long-term or net-zero targets are included, warming would be limited to about 2.1°C above pre-industrial levels. In probabilistic terms, this means there is a likely (66% or greater chance) limit of warming below 2.3°C. See Graph 7 and Climate Action Tracker (2024) for more details.

Graph 7. Climate Action Tracker: global emissions



Source: Climate Action Tracker (2024). Copyright ©2024 by Climate Analytics and NewClimate Institute.

They perform assessments for specific countries and for the EU. For the EU, CAT assigns an overall rating of “Insufficient” to its climate action and current 2030 emissions reduction target, considering that it is not fully on track to meet its goal of reducing emissions by at least 55% below 1990 levels (including LULUCF). CAT's assessment indicates that if the EU fully implements its planned policies under the Fit for 55 and REPowerEU initiatives, it will be close to achieving its 2030 NDC target. However, they point out that not all proposals have been adopted, and the targets and measures outlined in member states’ National Energy and Climate Plans would be also insufficient to meet the EU’s targets. Additionally, the EU’s 2030 NDC target lacks ambition according to CAT, meaning that more rapid and significant emission reduction measures will be necessary later to follow a 1.5°C compatible pathway and achieve climate neutrality by mid-century. Finally, CAT rates the EU’s net zero target as “Acceptable” in terms of its architecture, transparency, and scope, with a regular review and assessment process, although there is room for improvement. Specifically, there would be a need for separate reduction and removal targets and clarity on the fairness of targets regarding international aviation and shipping.

4. Puzzle pieces in the case of companies.

In the case of companies, various initiatives have been developed to create metrics and frameworks that gather information on how companies are setting and achieving their climate targets. Depending on the source data and methods used, the results of analyses may differ. Some examples include the Science Based Targets initiative (SBTi), Net Zero Tracker, Paris Agreement Capital Transition Assessment (PACTA), Transition Pathway Initiative (TPI), Carbon Tracker's 2 Degrees of Separation, and the. Additionally, private data providers are also developing metrics and forward-looking indicators. This article will focus on SBTi and Net Zero Tracker.

4.1. The Science-Based Targets initiative (SBTi)

One widely used framework is the Science-Based Targets initiative (SBTi) [41]. Launched in 2015, its goal is to create a critical mass of companies that set and implement science-based GHG emissions reduction targets aligned with the Paris Agreement. Goals are considered science-based if they align with what science determines is necessary to comply with the Paris Agreement. Fundamentally, the SBTi establishes three types of objectives, as shown in infographic 4.

Furthermore, the SBTi includes information on commitments that reflect an organization's intention to develop objectives. These commitments are reviewed by the SBTi within a maximum period of two years, and those that do not comply with their commitments will be identified with the status "Commitment removed." Additionally, there are three available target-setting methods: (i) absolute emissions contraction, (ii) the Sectoral Decarbonization Approach, and (iii) economic intensity contraction.

Infographic 4. SBTi types of objectives:

Short-term objectives

Objectives to reduce emissions in 5-10 years and aligned with the trajectory of 1.5C (scope 1 and 3) or well below 2C (scope 3). These targets set the action required for significant emissions reductions to be achieved by 2030.

Long-term objectives

Objectives to reduce residual emissions (scope 1, 2 and 3) aligned with the 1.5C trajectory by 2050 at the latest.

Net zero

In addition to short and long-term objectives, neutralize residual emissions

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[41] The SBTi was formed as a collaboration between CDP, the United Nations Global Compact, the World Resources Institute (WRI), and the World Wide Fund for Nature (WWF). The goal of SBTi is to ensure that companies have the tools to set goals aligned with climate science and that these methods are transparent, robust, and plausible. See https://sciencebasedtargets.org/about-us

4.1.1. SBTi data set

This framework contains primarily two types of datasets[42]:

- First, the annual Monitoring and Target Reports, in which the SBTi and its partners present the results of their review of companies that have set science-based targets by the end of the year (e.g., December 31st, 2022)[43]. Each review is based on publicly available information (questionnaires and other public documentation such as non-financial statements, corporate reports, websites, etc), excluding companies removed from the initiative. This annual report is made available to the public during the third quarter of the following year.

- Additionally, the SBTi allows users to explore and download the most up-to-date data through its dashboard[44]. This information is updated weekly and includes high-level details about each organization's targets or commitments. It presents information on short-term (ST) and long-term (LT) targets, along with the temperature alignment of the companies (1.5°C, well-below 2°C (WB2), and 2°C) and the net-zero (NZ) commitments, which demonstrate an organization's intention to develop targets and submit them for validation within 24 months.

The dataset includes 9,339 companies from 101 different countries across six regions: Africa, Asia, Europe, Latin America, North America, and Oceania. Over 80% of the companies are located either in Europe (51%) or Asia (31%), followed by North America (13%).. See Table 3 for more details.

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[42] Analysis based on SBTi Monitoring report (2022) and the detailed data file from https://sciencebasedtargets.org/companies-taking-action

[43] The latest publicly available annual Monitoring and Target Report is the 2023 version (only available in PDF). Compared to the 2022 version, the company progress data (in Excel file) for December 31st, 2023, is currently not available, and it is unclear whether it will be made publicly available. Therefore, our analysis of the annual Monitoring and Target Reports is based on the 2022 version. As of December 2023, more than four thousand companies had validated science-based targets, meaning that over two thousand companies set science-based targets during the year. It is worth mentioning that given the significant growth of companies joining the initiative (+102%) during the year 2023 findings from the 2022 report might be not very updated. To illustrate this, we will mention the most relevant figures from the 2023 report compared to the previous one.

[44] However, at that point in time, these data have not yet been reviewed by the SBTi or any other partner. A more up-to-date version of the data is available through the dashboard information. The analysis in this paper is based on data available as of August 26, 2024.

Table 3: Companies in dataset by region of location

Region	Number of companies	%
Europe	4,759	51%
Asia	2,858	31%
North America	1,254	13%
Latin America	229	2%
Oceania	158	2%
Africa	81	1%
Total	**9,339**	

Source: own elaboration based on SBTi data

Regarding the economic sectors of the companies within the sample, they belong to 57 different sectors. Ten sectors account for more than 55% of the total companies. The most represented sectors in this dataset are Professional Services, Electrical Equipment and Machinery, Software and Services, Food and Beverage Processing, Textiles, Apparel, Footwear and Luxury Goods, and Construction and Engineering.

In terms of company type, over 61% of the companies in the sample are non-financial corporations (5,733 companies), 36% are Small and Medium Enterprises (SMEs) (3,332 companies), and 3% are financial institutions (274 companies).

4.1.2 SBTi Results

Overall, the results of the dashboard align with those obtained from the Annual Monitoring Report. Additionally, both datasets complement each other[45]. Our analysis focuses on the targets set by the companies within the sample. We find that 64% of the companies have already set a ST target (see Table 4), 31% have "committed" to setting a ST target within two years, and a 5% of the companies' ST targets have been removed from the sample. Regarding LT targets, only 12% of the companies have already set such goals.

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[45] The dashboard shows the target classification (under which scenario the company is currently performing) and the company status on the targets (targets set, committed, etc.). The Annual Monitoring Report specifies the scopes involved, the percentage figures of reduction, which ultimately allows reaching a certain scenario (1.5°C, WB2, etc.), and even the target progress, which may indicate action towards the target, signaling plausible alignment with the Paris Agreement.

Table 4: Number of companies setting long and short term (ST) targets

Total number of Companies	***9,339***	
of which:	Short Term	Long Term
Targets set	*5,969*	*1,082*
Commited	*2,867*	
Removed	*503*	
NA		*8,257*

Source: own elaboration based on SBTi data

In terms of ST targets, nearly all (92%) are aligned with the 1.5°C scenario, while the rest are aligned with the Well Below 2°C (WB2) scenario (see Table 5 – column A). Additionally, among those with ST targets, only 18% have already set LT targets. By region, Europe is the most represented, with over 50% of the companies located there, followed by Asia (31%) and North America (12%).

Regarding LT goals, only 12% of companies have already set this type of targets (1,082 companies), and all of them are aligned with the 1.5°C scenario (see Table 5 – column B). Additionally, all these companies have also set ST targets.

Table 5. Scenario alignment for companies setting short and long term targets

Targets set	A. Short Term	B. Long Term
of which, scenario alligned:	*5,969*	*1,082*
1.5	*5,516*	*1,081*
WB2	*406*	
2	*47*	
NA		*1*

Source: own elaboration based on SBTi data

SBTi data reveals information regarding net zero (NZ) commitments, showing that almost 40% of companies in the total sample (3,427 companies) are committed to achieving NZ by 2050[46]. Of this sub-sample, more than 45% have set ST targets, mostly aligned with the 1.5°C scenario, while 25% have set LT targets, all aligned with the 1.5°C scenario (see Table 6).

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[46] This commitment will have to be reviewed by SBTi.

Table 6. Companies committed to Net Zero by type of target set.

Net-zero committed	**Yes (3,427)**	
of which:	Short Term	Long Term
Targets set (total)	*1,640*	*1,078*
1.5 ºC	*1,585*	*1,078*
WB 2ºC	*45*	-
2 ºC	*10*	-
NA	-	-

Source: own elaboration based on SBTi data

It is worth noting that only 10% of companies within the sample have set both ST and LT targets and are committed to NZ simultaneously (see table 7), and most of these companies have disclosed 2030 as the target year to achieve their goals. Among those committed to NZ and with LT targets, almost 70% are located in Europe.

Regarding the information contained in the Monitoring and Target Reports, main findings of the short-term targets include:

- Regarding the target type, most companies rely on absolute reduction targets.
- Regarding the scope of the targets: Scope 1+2 is the most predominant followed by Scope 3
- For those with Scope 1+2: The most relevant base years are 2019, 2020, and 2018, in that order. And the most common target years are 2030, followed by 2025.
- For all the most represented sectors in the sample, scope 1+2 is the most predominant scope in terms of number of companies disclosing, followed by scope 3.

Main findings of the long-term targets include:

- Regarding the target type, most companies rely on absolute reduction targets.
- Regarding the scope of the targets: Total emissions (Scope 1+2+3) is the most predominant followed by Scope 1+2
- For those with Scope 1+2+3: The most relevant base years are 2019, 2020, and 2021, in that order. And the most common target years are 2050, followed by 2040.

Table 7. Summary of setting short and long term targets and net zero commitments

Number of companies in the sample:	**9,339**					
Short- term (ST) targets:						
Targets Set	**5,969**	**64%**	of which, Scenario allignment:			
Comm	2,867	31%		1.5	5,516	92%
Rem	503	5%		WB2	406	7%
				2	47	1%
				NA		-
Long- term (LT) targets:						
Targets Set	**1,082**	**12%**	of which, Scenario allignment:			
NA	8,257	88%		1.5	1,081	100%
				WB2	-	-
				2	-	-
				NA	1	0%
Net-zero commited:						
Yes	**3,427**	**37%**		of which, ST targets:	**3,427**	
No	5,912	63%		Targets already set	1,640	48%
				Commited	1,520	44%
				Removed	267	8%
				NA	-	-
				of which, LT targets:	**3,427**	
				Targets already set	1,078	31%
				Commited	-	-
				Removed	-	-
				NA	2,349	69%
Number (and %) companies that have already set ST targets, LT targets and NZ commitments:	**925**	10%				

Source: own elaboration based on SBTi data

4.1.3 Constraints

Regarding the information contained in the Monitoring and Target Reports, there may be multiple lines for each company depending on various factors: the target (short-term, long-term, and net zero), the target type (absolute, intensity), the scope (1, 2, 3, or total), and within the indirect emissions (Scope 3), the categories included, base year, and target year. Obviously, all of this makes it difficult to properly process and summarize. Moreover, the lack of identifiers such as ISIN codes and LEI codes makes matching and comparing with other datasets difficult. Comprehensive identifying information would be ideal for merging these datasets with others containing, for instance, information on carbon emissions.

The relative importance of each scope within a company's total emissions varies depending on the company's main activity. Therefore, the distribution of emissions between direct and indirect emissions will depend on the sector to which the company belongs. However, some deviation in behavior among companies within a sector is to be expected. Another important point is that companies should disclose targets based on their main sources of emissions. For those whose primary source of emissions come from direct emissions should ideally disclose accordingly targets on scope 1+2.

4.2 Net zero tracker

Net Zero Tracker is an independent tool that provides a comprehensive view of net zero commitments across all nations and the world's largest regions, cities, and companies. They collect data on targets set and the factors that indicate whether those targets are robust—essentially, how serious companies and governments are about meaningfully cutting their net emissions to zero. It relies on publicly available data sources such as company websites, press releases, and other public information[47].

It includes several indicators on targets (interim, net zero) and their status, whether there is a published plan in place and/or a reporting mechanism, the gases covered, and the scopes involved (companies' direct and indirect emissions). In addition, for the identification of the companies the sector and the ISIN code are available, allowing for matching and comparison with other datasets.

Specifically, when considering the targets set by companies, it provides information on “interim” and “end” targets:

- interim targets refer to the earliest targets set by the company such as emissions reduction targets, emissions intensity targets, or absolute emissions targets.
- end targets refer to how the company describes its own target in the long run that can be described in multiple ways and the expert would try to find the best fit from various options: net zero, zero emissions, zero carbon, climate neutral, climate positive, carbon neutral, GHG neutral, carbon negative, net negative, 1.5°C targets, science-based targets, among others. Several assumptions are made if companies are members of Business Ambition for 1.5°C or SBTi.

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[47] They regularly capture input both manually and using machine learning techniques such as web scraping. The team then analyzes each entity following a guideline (codebook).

Alternatively, the company may disclose emissions reduction targets, emissions intensity targets, or absolute emissions targets.

To fully understand the information underlying the indicators, both types of targets need to be considered along with other variables, including target notes and other qualitative information[48]. Regarding the coverage of gases, the following alternatives apply: CO2 only, CO2 and other GHGs, and not specified[49]. Information on the scopes of gases (scope 1, 2 or 3) are also collected.

Some limitations of these database are: i) the analysis is limited to the 2.000 largest publicly-listed companies (according to the Forbes 2000 list) and the 100 largest privately-owned companies worldwide, ii) the timing of the information, since they exclusively rely on public disclosures the information contained might not be the most up-to-date

4.2.1 Net zero tracker data set

Half of the data in Net Zero Tracker comprises company level data. In total, there are more than 4000 observations including almost 200 nations, over 700 regions, almost 1,200 cities and over 2,000 companies. See table 8.

Table 8: Classification of entities

Entity type	**count**	**%**
Countries	198	5%
Regions	711	17%
Cities	1,186	28%
Companies	2,076	50%
Total	**4,171**	**100%**

Source: own elaboration based on Net zero tracker data

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[48] While interim targets need to be considered together with the interim target year and interim target text, end targets need to be examined along with the end target year, end target text, and end target status. Target years refer to the year in which the target is expected to be achieved. The target status indicates the current status of the target: achieved (externally or internally validated), included in the corporate strategy (in policy), pledged (announcement), or under discussion.

[49] If an important gas is missing, it is recorded in the relevant note field. For companies, information on the scopes of gases included in the targets may be disclosed. For Scope 1 and 2, only "Yes," "No," or "Not specified" may be answered. Additionally, for Scope 3, partial coverage can be answered.

Focusing on companies, the analysis is based on the data available as of November, 5th 2024. Starting with the location, nearly all the companies are in three main geographic regions: East Asia (35%), North America (34%), and Europe (22%) as it is shown in Table 9. The most prevalent countries within the sample are the United States of America (30%), China (14%), and Japan (11%), followed by Great Britain (4%) and France (3%).

Table 9: Companies in data set by region of location

Geographic region	**count**	**%**
East Asia	717	35%
North America	696	34%
Europe	466	22%
Western and Central Asia	57	3%
South Asia	51	2%
Latin America and the Caribbean	42	2%
Oceania	32	2%
Africa	15	1%
Total	**2,076**	**100%**

Source: own elaboration based on Net zero tracker data

4.2.2 Results from Net Zero Tracker

When considering the targets set by companies, of the 2,076 companies, less than half set interim targets (1,121 companies). Among these, 72% have set an emissions reduction target, while only 1% have set an absolute emissions target (see table 10). When referring to end targets, 75% of the companies (1,556) have them. More than half of these companies have set net zero end targets, making it the most common type of end target. This is followed by carbon neutral targets, which account for 19% of the sample. So we can see that the number of companies that have set an end target is higher than those with interim targets.

Table *10: Summary of the Net zero tracker data interim and end target types*

Number of companies in the sample:	**2,076**	
Interim targets:	**1,121 (54%)**	100%
Emissions reduction target	808	72%
Other	133	12%
Net zero	111	10%
Emissions intensity target	62	6%
Absolute emissions target	7	1%
End targets:	**1,556 (75%)**	100%
Net zero	832	53%
Carbon neutral	298	19%
Emissions reduction target	255	16%
Climate neutral	46	3%
Other: science-based targets, zero emissions, climate positive, zero carbon, etc.)	86	6%
Emissions intensity target	37	2%
Absolute emissions target	2	0%

Source: own elaboration based on Net zero tracker data

4.3. Comparison of results from two datasets: SBTi and Net zero tracker

Comparing the Net Zero Tracker data with the dashboard version of the SBTi data, we can examine the similarities and differences between the populations. Using the broader version of the SBTi data (Annual Monitoring Report) is not recommended for this purpose, as it is not as timely as the Net Zero Tracker. Given that many companies are joining the initiative lately it would imply missing many companies.

With regards to targets, it is possible to compare the Net Zero Tracker information with either the Monitoring Report or the dashboard version of the SBTi. However, comparing the former is more detailed in terms of the type of target set. We have observed that, when controlling for the company, there are discrepancies in the type of target reported [50]. See Table 11.

We select companies with a short-term (interim) target, resulting in 927, 1,625, and 1,091 unique companies, for the SBTi monitoring report, dashboard version, and Net Zero Tracker, respectively. When considering base and target years for interim targets we identify less discrepancies compare to targets. Besides, we observe wide ranges for both base and target years being 2019 the most frequent base year and 2030 the most common target years.

When merging the Net Zero Tracker dataset with the dashboard version, we find more matches than with the Monitoring Report (416 vs. 299). As mentioned in the previous section, there are differences in the population and methodology among the datasets. Therefore, when comparing the Net Zero Tracker with the Monitoring Report, we often find multiple targets in the SBTi dataset corresponding to a single target in the NZ Tracker.

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[50] The SBTi monitoring report includes 2,077 unique companies. However, the dashboard version contains 9,339 unique companies. The significant difference is due to the version of the data, with a one-year gap between them. The Net Zero Tracker contains 2,074 unique companies, which is significantly smaller compared to the dashboard version. This difference is explained by the fact that the Net Zero Tracker includes the 2,000 largest publicly-listed companies (according to the Forbes 2000 list) and the 100 largest privately-owned companies worldwide. Companies without an ISIN code are then discarded, reducing the three samples to 927, 2,495, and 1,971 unique companies for the SBTi monitoring report, dashboard version, and Net Zero Tracker, respectively.

Table 11: Main figures and comparison

Main figures	SBTI		Net Zero tracker
	Monitoring report	Dashboard	
Number of unique companies in the sample:	**2.077**	**9.339**	**2.074**
of which:			
with ISIN code	927	2.495	1.971
with interim target set	927	1.625	1.091
Base year (range)	2005-2022		1990-2030
most frequent value	2019		2019
Target year (range)	2020-2050		2016-2044
most frequent value	2033		2030
Comparisons			
SBTI Monitoring report v NZ tracker			
Concurrencies	299		
Target	258		
Base year (range)	216		
Target year (range)	239		
SBTi Dashboard v NZ tracker			
Concurrencies	416		
Target	416		
Base year (range)	na		
Target year (range)	267		
Version of the data:	August, 2023	August, 2024	October, 2024

Source: own elaboration based on SBTi and Net zero tracker data

5. Final remarks

Establishing a decarbonization pathway to achieve the Paris Agreement targets involves developing specific final and intermediate targets as part of a transition plan. This process must be grounded in both backward-looking and forward-looking data and metrics. The former helps understand past trends and serves as the foundation for forward-looking metrics that project into the future.

So far, the assessment of climate change risks has relied mostly on past or backward-looking data. However, new methodologies and indicators are needed to support the development of decarbonization pathways. Currently, several initiatives aim to provide transparency to the various available information, while others are developing specific metrics.

Results differ depending on the data sources used, and only a limited number of firms, mainly large ones, are currently disclosing forward-looking indicators. Differences in results can be partly explained by variations in methodology. These methodologies are not always easy to understand, nor are they always comparable or communicated transparently. Therefore, their appropriate usage depends on specific use cases.

At the same time, it is important to combine targets from countries and corporations to ensure coherence in a common path to achieve net-zero emissions and the Paris Agreement targets. Based on the analysis in this paper, it currently seems challenging to align the sum of targets and trajectories.

This document is intended to give an overview of current initiatives and selected publicly available data on forward-looking transition risk metrics. A deeper analysis of results is still needed going forward in order to gain a better understanding of methodologies and differences in results.

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IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

US banks' exposures to climate transition risks[1]

H Jung, J Santos and L Seltzer,
Federal Reserve Bank of New York

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

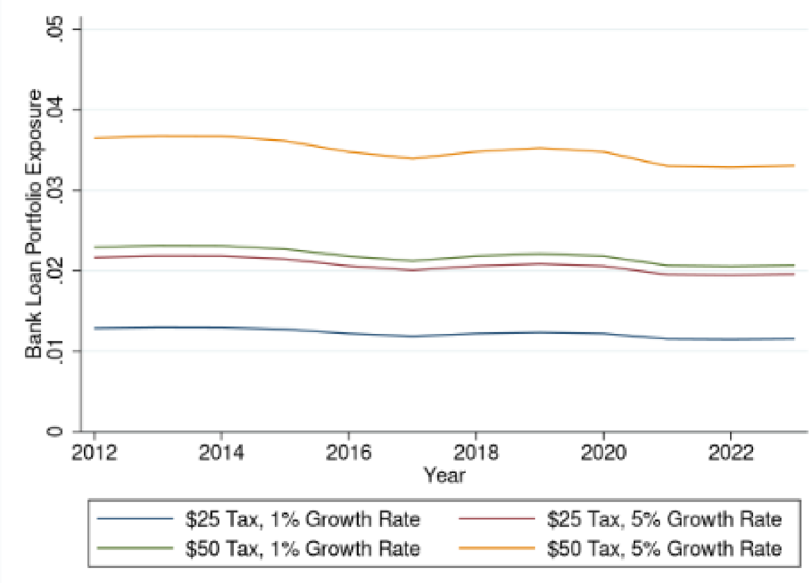
U.S. Banks' Exposures to Climate Transition Risks

Policymakers have grown increasingly concerned with understanding financial institutions' exposures to climate transition risks. However, while climate risk is a problem with forward-looking ramifications, most approaches to measure transition risk use backward-looking data, such as carbon emissions. In our paper "U.S. Banks' Exposures to Climate Transition Risks", we introduce a forward-looking approach to measure banks' exposures to specific climate transition policies using general equilibrium model estimates.

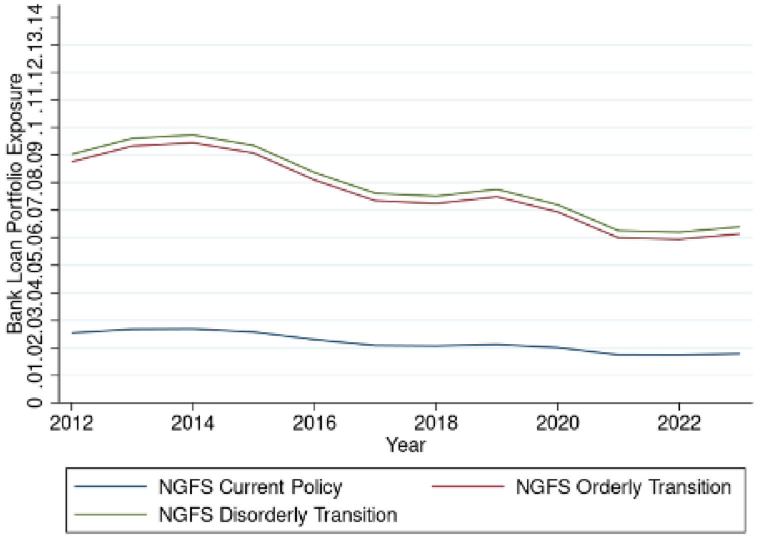
In our paper, we use estimates from three general equilibrium models, two of which we present here. Our first approach builds on the Jorgenson, Goettle, Ho and Wilcoxen (2018) model, which provides estimates of expected decreases in industry output due to carbon taxes. The authors consider four scenarios, with the least stringent being a $25 initial carbon tax and a 1 percent tax growth rate, and the strictest being a $50 initial carbon tax and a 5 percent tax growth rate. We also use the G-Cubed model estimates of expected changes in industry output for the Network for Greening for the Financial System (NGFS) scenarios, or NGFS (2022). The G-Cubed explores three different policy scenarios: (1) an orderly transition, where a carbon tax is immediately enacted to reduce carbon emissions to net zero by 2050, (2) a disorderly transition, where in 2030 a carbon tax sufficient to reduce end-of-century temperature rise to 2 degrees Celsius is passed, and (3) a status quo scenario where current climate policy is maintained.

For both of these approaches, banks' exposures are calculated as the decrease in the value of their loan portfolios. When calculating the measure, we assume that bank loan portfolio values drop proportionally to the change in output. However, the paper also includes alternative versions of the analysis, which account for loan probabilities of default, as well as assuming that loans to industries most adversely affected by transition risks lose their entire value.

The estimates of the bank loan portfolios from the Jorgenson et al (2018) model are shown below. In the most extreme case, where a $50 per ton carbon tax growing at 5% per year is enacted, the bank's loan portfolio exposure is no more than about 3.5%. In the least stringent scenario, where a $25 per ton carbon tax growing at 1% per year is enacted, the exposure is closer to 1%. In either case, the exposure of banks is relatively small. Similarly, when we produce alternative estimates accounting for loan probabilities of default, and potentially larger losses for industries more sensitive to climate transition risks. In fact, even when making the strong assumption that loans in industries with the top-two deciles of exposures lose their entire value, bank loan portfolios decrease by no more than 14% of their values as of 2023.



The conclusions are broadly similar when examining the estimates from the G-Cubed model, which are shown below. The estimates from the status quo scenario are relatively low, at about 2%. When examining the estimates of bank loan portfolio exposures under the disorderly and orderly transition scenarios, those are about 6% as of 2023.



To conclude, the analysis in this paper uses general equilibrium model estimates to provide a forward-looking approach to estimates banks' exposures to climate transition risks. The results show that at most, banks climate transition risk exposures are no more than about 14%. The measure introduced in this paper will be a useful tool for policy makers to examine how specific climate policies affect banks.

U.S. Banks’ Exposures to Climate Transition Risks

Addressing Climate Change Data Needs: The Global Debate and Central Banks’ Contribution

Hyeyoon Jung João Santos Lee Seltzer

Federal Reserve Bank of New York

May 6, 2024

Effects of Climate Transition Risk on Banks

- How does climate transition risk affect banks?
    - *Transition risk* arises from changes in policies as economies transition to less carbon-intensive environments.

- How much are banks exposed to a specific climate transition policy (e.g. \$50 carbon tax growing 5% annually)?

  ⇒ We develop a measure to assess banks' credit portfolio exposure to a specific set of climate transition policies.

Empirical Challenges

1. Existing approaches typically rely on backward-looking data (e.g. carbon emissions).
    - We propose a **forward-looking** measure that quantifies the effect of a specific set of climate transition policies on banks.
2. Reduced form approaches typically do not capture the general equilibrium effects.
    - We build on estimates from **general equilibrium** climate models.
3. Publicly available credit data may not accurately represent current exposure if the bank sells the loan after origination.
    - We employ a granular dataset (**Y-14**) that provides current loan-level credit exposure information for major U.S. banks.

Our Approach in Brief

General Equilibrium Climate Model Estimates

E.g., How much does each industry's output fall if a carbon tax gets introduced?

Industry	Change in Output
Coal	-30%
Renewable	+20%

Y-14 Data

E.g., Bank's credit portfolio:

Industry	Share of Lending
Coal	50%
Renewable	50%

Study bank exposure to transition risk
- across time
- across banks
- across policies

Investigate how banks manage transition risk

Key Findings

1. Banks' exposures to transition risk is generally manageable.
    - The average bank's credit exposure (as of 2023) does not exceed 14% under even the most severe scenario
2. Across policies, banks' transition risk exposure is larger under stricter policies.
    - Relative to a $25 carbon tax, a $50 carbon tax increases banks' exposures by 1%.
3. Carbon emissions explain at most 60% of variation in our measure.
4. Banks that signed the Net-Zero Banking Alliance appear to have reduced their exposures compared to non-signatories.

Climate Models: Overview

1. **Jorgenson et al. (2018)**
    - Estimates changes in industry-level output from 2015 to 2050, if a range of carbon tax policies are put in place in 2020.
    - e.g. Initial carbon tax rate of $50 and annual tax growth rate of 5%.
2. **NGFS G-Cubed Model (2022)**
    - Estimate changes in industry-level output from 2020 to 2050.
    - Considers NGFS scenarios (current, orderly, and disorderly transitions).

Climate Model (1)

Jorgenson et al. (2018)

- Estimates industry-level decreases in output for 36 industries conditional on a specific carbon policy.
- Assumes a carbon tax is put in place in 2020, and grows from 2020 until 2050.
    - Provides estimates of change in industry-level output from 2015 until 2050.
    - Model estimates produced for several initial tax rates ($25 or $50) and tax growth rates (1% or 5%).
- Also models the redistribution of the tax proceeds.
    - Model outputs produced for redistribution as a lump sum dividend, a capital tax cut, or a labor tax cut.

Example of Estimates from Jorgenson et al. (2018)

IGEM Industry	**$25 tax, 1% growth rate**	**$25 tax, 5% growth rate**	**$50 tax, 1% growth rate**	**$50 tax, 5% growth rate**
Agriculture	0.009	0.016	0.017	0.028
Oil mining	0.026	0.045	0.049	0.079
Gas mining	0.059	0.097	0.103	0.157
Coal mining	0.163	0.237	0.252	0.338
Nonenergy mining	0.016	0.028	0.028	0.046
Electric utilities	0.047	0.077	0.082	0.124
Gas utilities	0.049	0.087	0.092	0.154
Water and wastewater	0.016	0.026	0.028	0.046
...				
Health care and social assistance	0.003	0.006	0.006	0.010
Accommodation and other services	0.007	0.011	0.012	0.020
Other government	0.001	0.001	0.001	0.002

Climate Model (2)

NGFS G-Cubed Model (2022)

- Estimates industry-level decreases in output for 12 industries from 2020 until 2050.
- Unlike the other models, the policy scenarios set a certain carbon tax conditional on achieving a desired policy outcome.
    - Current Policy
    - Orderly Transition – sufficient policies to achieve net-zero emissions by 2050 is immediately adopted
    - Disorderly Transition – policy to limit end-of-century temperature rise to under 2 degrees adopted in 2031

Exposure Measure

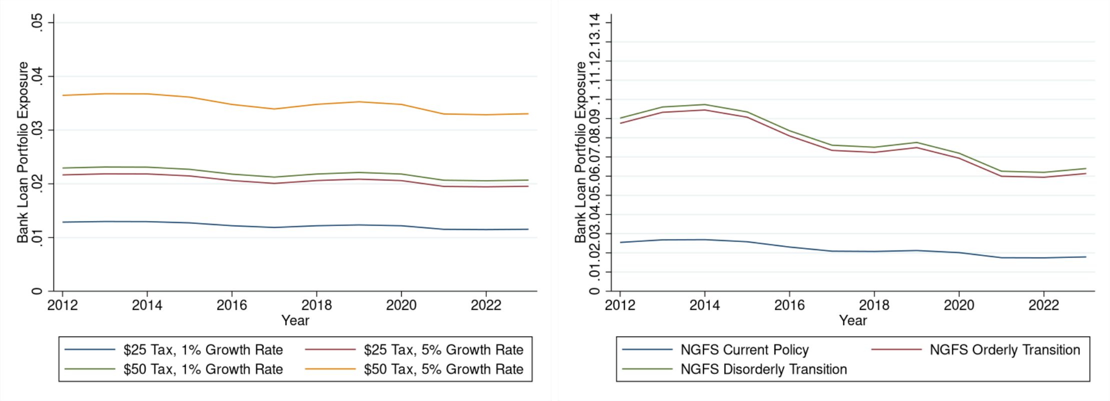
What proportion of bank b's loan portfolio value would be lost if policy P gets implemented?

$$Exposure_{b,t}^{P} = \sum_{j \in J} w_{b,j,t} \, Markdown_{j}^{P},$$

- $w_{b,j,t}$ is proportion of bank b's loan made to industry j at time t.
- $Markdown_{j}^{P}$ is the drop in the output or profits of industry j under policy P.

- **Key Assumptions:**
  1. Banks lose the value of loans proportionally to the drop in the output or profit of the borrower's industry.
  2. Bank b maintains their allocation of loans across industries as of time t.

Average Exposure over Time



(a) Jorgenson et al.

(b) NGFS

- The maximum average exposure is less than 4% based on Jorgenson et al., while it is 9.5% based on NGFS.

Exposure Measure under Stress

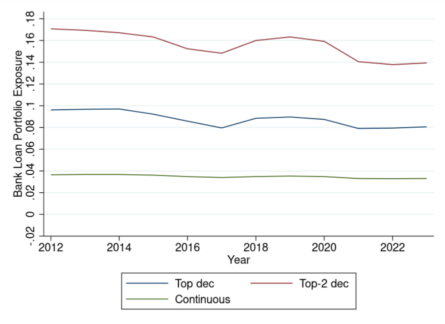
Considering potential non-linear effects: what if banks are *more severely affected* by the riskiest industries?

$$ExposureUnderStress^{P}_{b,t} =$$

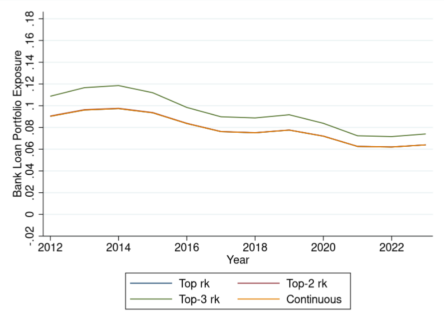
$$\sum_{j \in J} w_{b,j,t} \, \mathbb{1}(Markdown^{P}_{j} > x) + \sum_{j \in J} w_{b,j,t} \mathbb{1}\left(Markdown^{P}_{j} \leq x\right) \cdot Markdown^{P}_{j}$$

- w_{bjt} is proportion of bank b's loan made to industry j at time t.
- $Markdown^{P}_{j}$ is the drop in the output of industry j under policy P.
- x is a cutoff where if the drop in industry output is above x, we assume the industry goes "bankrupt".
- Pick x so we focus on either the top-decile or top-two-decile exposed industries.

Average Exposure Under Stress over Time



(a) Jorgenson et al.: $50 initial tax, 5% annual tax growth rate



(b) NGFS: Disorderly transition

- Based on Jorgenson et al., the average *exposure under stress* is 11% higher than the average exposure.
- Based on the NGFS model, the average *exposure under stress* remains similar as the NGFS scenarios are already severe.

Exposure Adjusted for Expected Loan Losses

1. Compute loan losses for each loan:

$$Loss_{l,t} = Loss\ Given\ Default_{l,t} \times Probability\ of\ Default_{l,t}$$

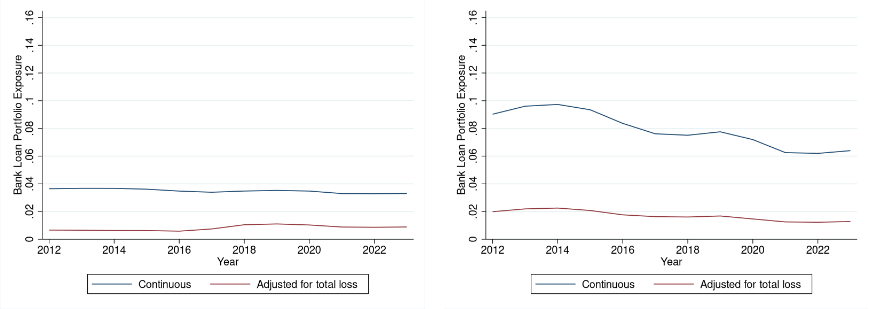
2. For each industry, exploit loan-level empirical relationship between loan losses and sales to obtain expected loss:

$$Loss_{l,t} = \alpha_j + \beta_j \log(Sales_{l,t}) + \varepsilon_{l,t}$$

3. Compute adjusted exposure:

$$\begin{aligned} AdjExposure^P_{b,t} = & \sum_{j \in J} w_{b,j,t}\ \mathbb{1}(Markdown^P_j > x)(\hat{\alpha}_j + \hat{\beta}_j Markdown^P_j) \\ & + \sum_{j \in J} w_{b,j,t} \mathbb{1}\left(Markdown^P_j \leq x\right)\left(\hat{\alpha}_j + \hat{\beta}_j Markdown^P_j\right) Markdown^P_j \end{aligned}$$

Average Exposure Adjusted for Expected Loan Losses over Time

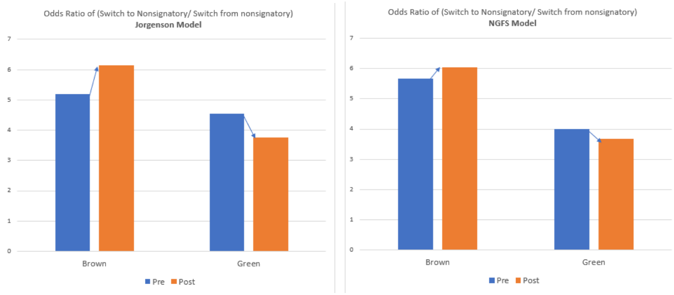


(a) Jorgenson et al (2018) $50 initial tax, 5% annual tax growth rate

(b) NGFS disorderly transition

- Adjusting for the loss given default (LGD) and probability of default (PD) reduces exposures.

Brown Borrowers are Switching to non-Signatories



(a) Jorgenson et al. (b) NGFS

- Examine whether brown borrowers switched lenders after the announcement of the Net-Zero Banking Alliance in April 2021
- Brown borrowers became more likely to switch to non-signatories and green borrowers were more likely to switch to signatories

How Much of Exposure is Explained by Carbon Emissions?

Model Scenario	I	II	III	IV
Panel A: Jorgenson et al (2018) Tax and Growth Rate Scenarios				
	$25 Tax, 1% Growth Rate	$25 Tax, 5% Growth Rate	$50 Tax, 1% Growth Rate	$50 Tax, 5% Growth Rate
Emissions R2	0.572	0.577	0.582	0.588
Panel B: Jorgenson et al (2018) Redistribution Scenarios				
	Lump Sum Redistribution	Capital Tax Cut	Labor Tax Cut	
Emissions R2	0.577	0.595	0.577	
Panel C: Goulder and Hafstead (2018) Redistribution Scenarios				
	Lump Sum Redistribution	Corporate Tax Cut	Payroll Tax Cut	Individual Income Tax Cut
Emissions R2	0.257	0.257	0.257	0.258
Panel D: NGFS Scenarios				
	Current Policy	Disorderly Transition	Orderly Transition	
Emissions R2	0.496	0.411	0.416	

- Much of the variation in exposures is *not* driven by emissions.
- Based on the industry-level emissions data, R^2 is even smaller.

Conclusion

- We develop a novel measure of US banks' exposure to transition risk building upon general equilibrium model estimates.
- We find that the estimated exposures are generally modest, and are no higher than 14% relative to current loan balances even in the most severe scenario.
- Banks' exposures to the riskiest industries appear to be mildly decreasing over time.
- Banks decreased lending for highly exposed industries in recent years.

IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

A framework for macro-financial analysis of climate risks[1]

C Schmieder,
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[1] This contribution was prepared for the workshop. The views expressed are those of the authors and do not necessarily reflect the views of the Central Bank of the Republic of Türkiye, the BIS, the IFC or the other central banks and institutions represented at the event.

A framework for macro-financial analysis of climate risks

Christian Schmieder, Abhishek Srivastav and Miroslav Petkov[1]

Abstract

This paper presents an accessible top-down framework to evaluate the forward-looking impact of climate risk vulnerabilities on bank credit losses and capital ratios at the country level. By incorporating key transmission channels of climate risk—both physical and transition risks—we build upon the scenario analysis framework established by Hardy and Schmieder (2013). The framework enables the simulation of short-, medium-, and long-term scenarios through 2100, providing insights into both immediate and structural vulnerabilities that could affect bank solvency. Additionally, the framework allows exploring the compounded impact of climate-related risks coinciding with conventional banking crises.

Keywords: Scenario Analysis, Climate Vulnerabilities, Bank stability, Macro-financial analysis, Physical Risks, Transition Risks

JEL classification: Q54, G21, G32

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[1] The authors would like to thank Ryan Banerjee, Fiorella De Fiore, Benoît Mojon, Ilhyock Shim, Hyun S Shin and the BIS seminar participants on 18 April 2024 as well as the participants of the IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution" on 6-7 May 2024 in Izmir (Türkiye). The views expressed in the paper are those of their authors and not necessarily the views of the BIS, the FSB or the IAIS. The usual disclaimer applies.

Contents

1. Introduction

Insurance companies have long been concerned about weather- and climate-related risks. In recent years, climate risk analysis in general, and scenario analysis in particular, has extended to other financial institutions, notably banks (eg BCBS 2021, ECB 2023, Federal Reserve Board 2023/2024, Financial Stability Board 2025). Extreme weather conditions observed around the world in recent years have reinforced this interest (see Figure 2).

This paper introduces a framework for macro-financial analysis of climate risks. We offer an accessible top-down scenario analysis approach to evaluating banks' exposure to climate-related financial risks. The framework allows for forward-looking simulations of potential outcomes of credit losses and capital ratio levels under different climate scenarios across countries and over time. Additionally, it enables assessments of the relative contribution of climate risk to potential overall solvency risk faced by banks under adverse short-term adverse conditions.

Two core components of our framework are:

- the climate risk scenarios established by the Network of Central Banks and Supervisors on Greening the Financial System (NGFS) and
- a "traditional" scenario analysis concept for banks (Hardy and Schmieder, 2013), which maps GDP trajectories into bank solvency metrics.

Traditional financial stability analyses assess financial vulnerabilities, ie imbalances arising from exposures of financial institutions that give rise to potential losses driven by different levels of economic and financial shocks as observed in the past. These exercises are characterised by a fairly stationary loss distribution function, whereby one can establish proxies for the magnitude of losses, say in a ‘1-in-20’ or ‘1-in-100’ years scenario.

By contrast, climate risk is a growing structural risk factor, exposing banks to increasing levels of "average" vulnerabilities (akin to the expected loss concept), and, in parallel, more extreme tail events (akin to potential unexpected losses). Tail events can occur short-term (especially the materialisation of physical risk), but also involve adverse structural trends with lasting effects, which can be reinforced by tipping points. Our contribution encompasses two main aspects:

1. We offer an accessible framework for conducting forward-looking macro-financial analysis of climate risks across a wide range of countries, building upon the "traditional" bank scenario analysis framework developed by Hardy and Schmieder (2013). This allows one to capture cross-country evidence to identify potential vulnerabilities that are common to the specific types of economies, advanced and emerging market economies. Given the substantial modelling complexity involved by default, we believe our work is a valuable complement to the intricate frameworks established by central banks and regulatory authorities.
2. Introducing a novel element, we enable the simulation of potential vulnerabilities transmitted through cross-border channels. This provides insights on how an increasingly financial interconnectedness could have the potential to engender material cross-border spillovers.

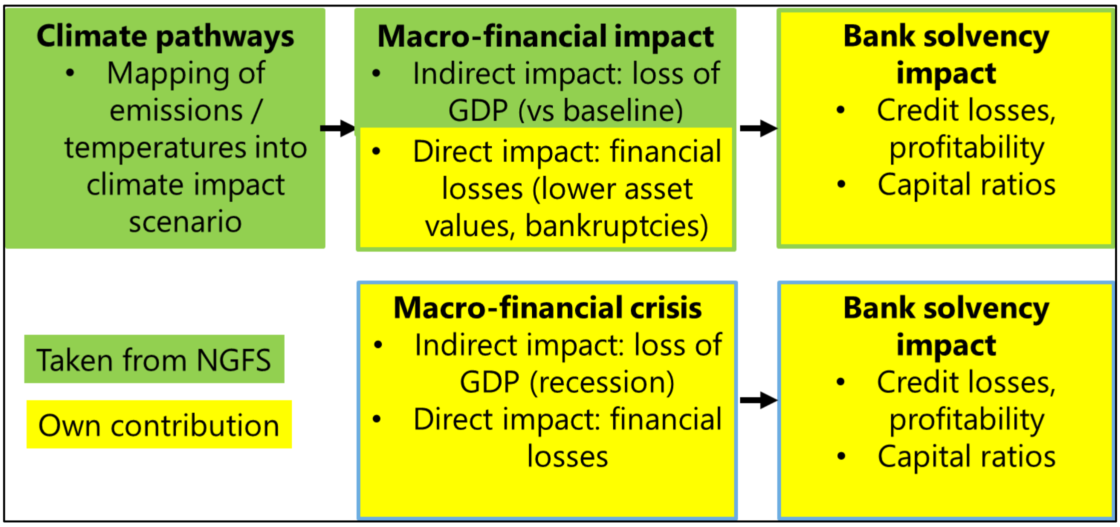
Our paper highlights that climate risk scenario analysis presents a distinct complexity compared to traditional scenario analyses. In addition to the challenge to simulate the impact of macro-financial scenarios on solvency outcomes at the bank level (second row in Figure 1), climate scenario analysis involves an additional third element, namely to translate climate scenarios into bank level parameters (first row in Figure 1). To keep the framework manageable, it is based on a mapping of GDP trajectories (which are available for both the climate and macro-financial scenarios) to key bank solvency parameters.

The framework serves several key policy purposes, which will be assessed in a follow-up paper focussing on outcomes:

1. To monitor bank vulnerabilities over time, across countries, and to assess the relative importance of physical versus transition risks on bank solvency.
2. To assess the relative importance of climate risk vis-à-vis other key solvency risk factors, most importantly macro-financial conditions.
3. To conduct reverse stress tests to assess the capacity of the banking sector to withstand adverse conditions.

Figure 1: Scenario analysis concept

Scenario analysis for climate risks is more complex than "traditional" scenario analysis for banks, which is already intricate in itself



Note: Our own contribution is strongly based on Hardy and Schmieder (2013)

Source: Authors

Our insights underscore several caveats, highlighting the urgency for further research:

- First, the framework foresees static bank balance sheets and will typically focus on the most severe NGFS scenario, current policies, thereby establishing an upper bound for the impact at the country level. We note that tipping points could significantly alter our findings, especially in the long(er) term, which are not reflected in the current NGFS scenarios. However, newly emerging scenarios can be readily captured by the framework.

- Second, we assume that historically calibrated GDP elasticities of bank solvency parameters (credit losses, capital ratios) serve as meaningful predictors for the cause-and-effect relationships for indirect climate risk-related losses materialising through economic output.
- Third, we assume that we implicitly capture at least some of the feedback loops and second-round effects using the integrated NGFS scenarios and GDP elasticities of bank solvency observed during past banking crises.

The remainder of this paper is structured as follows: Section 2 reviews related studies. In section 3, we outline our framework and section 4 concludes.

2. Related work

As the available data will improve, the focus of climate risk analysis will gradually shift from assessing vulnerabilities (ie exposure to climate risk) to investigating actual risks (ie an assessment how climate risk could materialise and affect institutions) (FSB 2025). Risk analysis involve comprehensive and high-quality granular data, as well as complex concepts. Our framework tries to fill a gap, namely to run meaningful climate risk scenario analysis that focus on identifying the impact via macro-financial risk transmission channels using less granular data. Our approach provides high-level macro insights on the main channel, which can then be used to conduct a focused deep dive with more granular data.

Climate risk scenario analysis focussing on the ultimate risks of financial institutions is undergoing rapid development, propelled by public initiatives aimed at mitigating potential financial stability risks associated with climate change (BCBS, 2024; FSB, 2025; NGFS, 2024;). These evolving frameworks typically built upon established bank solvency frameworks (eg Acharya et al., 2023; Adrian et al., 2022; Bank of England, 2024; Baudino and Svoronos, 2021; BCBS, 2022; ECB, 2023; Federal Reserve, 2023/2024; FSB, 2025; NGFS, 2023; Reinders et al., 2023). Incorporating climate risk into these frameworks requires two key adjustments: expanding the framework to encompass relevant transmission channels through which climate risks can impact bank solvency, and extending the time horizon covered by the analysis to include medium- to long-term risks.[2]

Scenario analysis carried out by central banks and regulatory authorities (eg NGFS, 2021; ECB, 2023; Federal Reserve Board, 2023/2024) suggests that at the aggregate level, near-term risks tend to be contained for most banks, at least on a stand-alone basis, although they could be noteworthy under tail risks conditions, and will grow over time. There is consensus (eg Acharya et al., 2023; NGFS, 2022) that transition risks, particularly regulatory and technological risks, will mainly matter in

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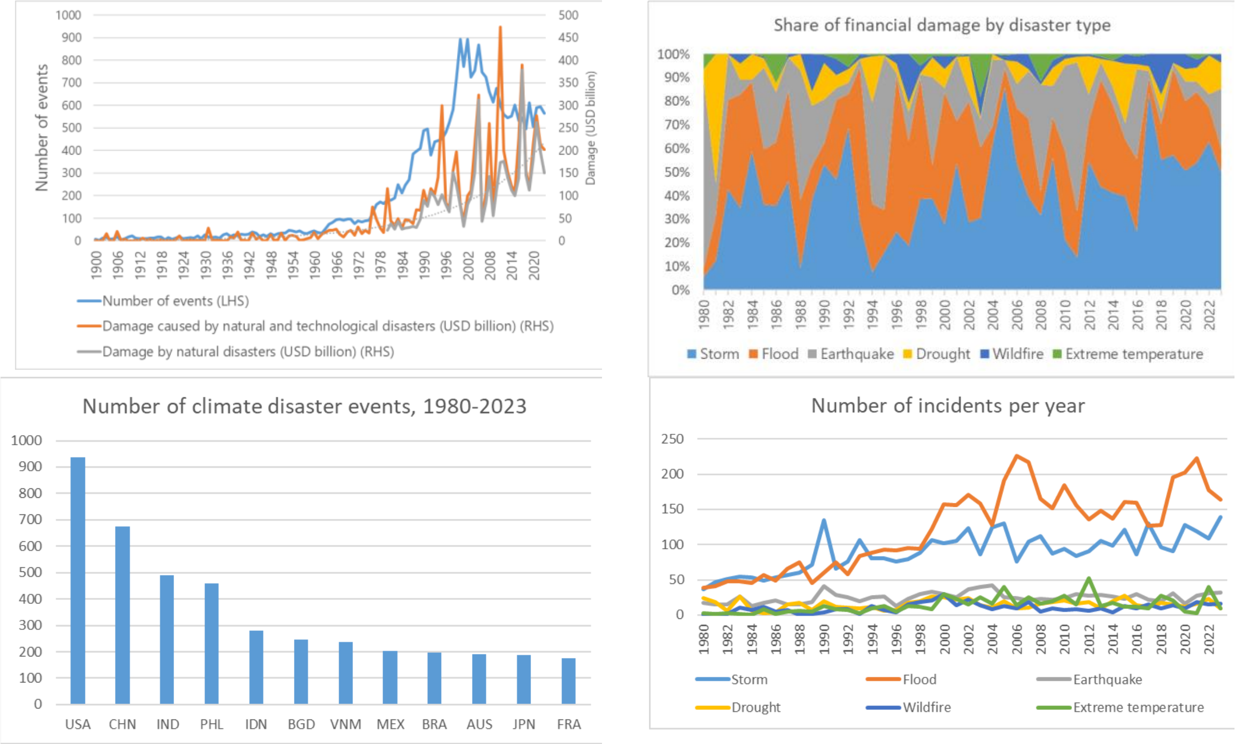
[2] The IPCC refers to a medium-term horizon of 2025-2074 and a long-term one from 2070-2099.

the near term (ie the next 25 years)[3], both through the market risk and credit risk channel, at least for the advanced economies. At the same time, physical risks are expected to gradually become the most critical climate risk type over the next three decades, especially through the credit risk channel.

Figure 2: Evolution of natural disasters over time

The financial impact of natural disasters has increased over time (1900-2023)[4] and some countries are more affected

The bulk of financial damage caused by natural disasters relates to storms and floods



The natural disasters included in the left graph are storms, floods, drought, wildfire and extreme temperature, while earthquakes were left out. The data on the financial impact is adjusted for inflation, with 2015 as the base year.

Source: EM-DAT.

At the same time, studies quantifying the potential impact of climate risk on capital requirements are still rare. Moreover, the ECB (2022) found that only a handful of frontrunners had voluntarily allocated economic capital for climate risks as part of their Internal Capital Adequacy Assessment Process (ICAAP).

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[3] This assumes that climate policies are put forward during the coming years, which is the baseline for most scenarios.

[4] EM-DAT contains data on the occurrence and impacts of over 26,000 mass disasters worldwide from 1900 to today, but is more representative since 2000. The database is compiled from various sources, including UN agencies, non-governmental organisations, reinsurance companies, research institutes, and press agencies.

Climate risks encompass chronic or acute physical risks[5] stemming from climate-related hazards as well as transition risks (i.e., changes in climate policies and regulation, consumer preferences, or technological adjustments). The financial impact of adverse natural disasters measured in USD terms has been on a steep upward trend in recent years, which is, however, at least partly owed to more systemic recording (see Figure 2, upper left graph). While financial losses from storms and floods have been dominant physical risk materialisations until today (see Figure 2, right graphs), NGFS scenario analysis suggests that the impact from droughts and heatwaves will also increase substantially over time. The crossing of tipping points (a Minsky moment or Green Swan[6]) could result in steeper loss trends at shorter time horizons, also increasing the unexpected component of climate risk. The exposure of countries and financial institutions to physical risks varies widely (Figure 2, bottom left graph), and (smaller) banks with concentrated regional assets are therefore particularly exposed to climate risks.

3. Concept

The focus of this paper is on bank solvency in general, and the implications of climate risk on bank solvency more specifically, with a focus on credit risk. We recognise that other risk types also matter, including market risks (eg for transition risks) or liquidity risks (eg in case of a materialisation of severe physical risk scenarios affecting a large share of the balance sheet of specific banks).

Unlike in the case of "common" solvency risks faced by banks, such as bank credit losses, which are fairly stationary over time (Figure 3, top left), historical benchmarks for assessing the impact of climate change on bank solvency are not available. Moreover, to the extent they are accessible, they may not be representative due to the steep upward trend in the climate impact (Figure 3, bottom left). However, we can extrapolate potential future losses through scenario analysis, leveraging the work conducted by the NGFS on the macro-financial impact of climate risk scenarios. These extrapolations consider the evolving relationships between climate pathways and macro-financial conditions on the hand and the realised upward trend in the impact of natural disasters on the other. A comparison of aggregate numbers for the losses from natural disasters in the US with credit losses vis-à-vis non-public sector counterparties shows that the former could become relevant for banks (Figure 3, right graph)., especially if risks are concentrated in regions and/or institutions.

To simulate the potential impact of climate risk on bank losses and capital ratios, we integrate relevant transmission channels into the scenario analysis framework developed by Hardy and Schmieder (2013). This allows us to model both an isolated climate risk-related shock and an adverse event that may occur simultaneously with

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[5] Physical risk are direct manifestations of climate change on economic activity and asset values, including from floods, storms, heat waves and wildfire. Rising sea levels and flooding can cause economic damage by destroying housing and factories, heat waves can jeopardise agricultural activities (eg crop production), depress worker productivity and lead to an escalation of energy expenditure.

[6] See Green Swan 2023: Climate transition in the real economy: what should central banks know about it? (bis.org).

a "traditional" macro-financial shock and/or financial crisis, with or without international spillovers.

Climate risk scenario analysis presents a distinct complexity compared to traditional scenario analyses. Our framework is designed to enhance comprehension of the fundamental elements at play, acknowledging that the lack of granular data used for our simulations (by design of our framework which is meant to be candid) may limit the precision of outcomes. As depicted in Figure 1, analysing climate risks on bank solvency involves three primary components and two translations of impact (see also Adrian et al., 2022):

- The first component involves establishing climate impact scenarios, which entails mapping emission and temperature pathways into physical and transition risk scenario realisations. For this aspect, we rely on NGFS input[7].
- The second component is to map climate impact scenarios into macro-financial scenarios, distinguishing between indirect effects on bank solvency through macroeconomic conditions and direct effects on losses and profitability. We draw upon NGFS analysis, which discerns between chronic and acute physical risk outcomes (i.e., their frequency and severity) and transition risks (determined by climate policies, technology, and evolving user behaviour).

The third component involves translating macro-financial scenarios into bank solvency parameters, utilising the work by Hardy and Schmieder (2013), as further elucidated below. We use the climate risk and macro-financial impact of different climate risk scenarios provided by the NGFS as key inputs for our work. Related work by the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA) are important benchmarks for the NGFS, but mainly focus on the possible evolution of greenhouse gas emissions (IPCC)[8] and are limited to the impact of transition risk until 2050[9] (IAE). Alternative modelling approaches find a similar GDP impact, including some scenarios which suggest more conservative outcomes than the NGFS (Kotz et al, 2024).

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[7] We note that NGFS machinery builds upon other frameworks, given the complexity of the subject matter and multidisciplinary nature of the issue.

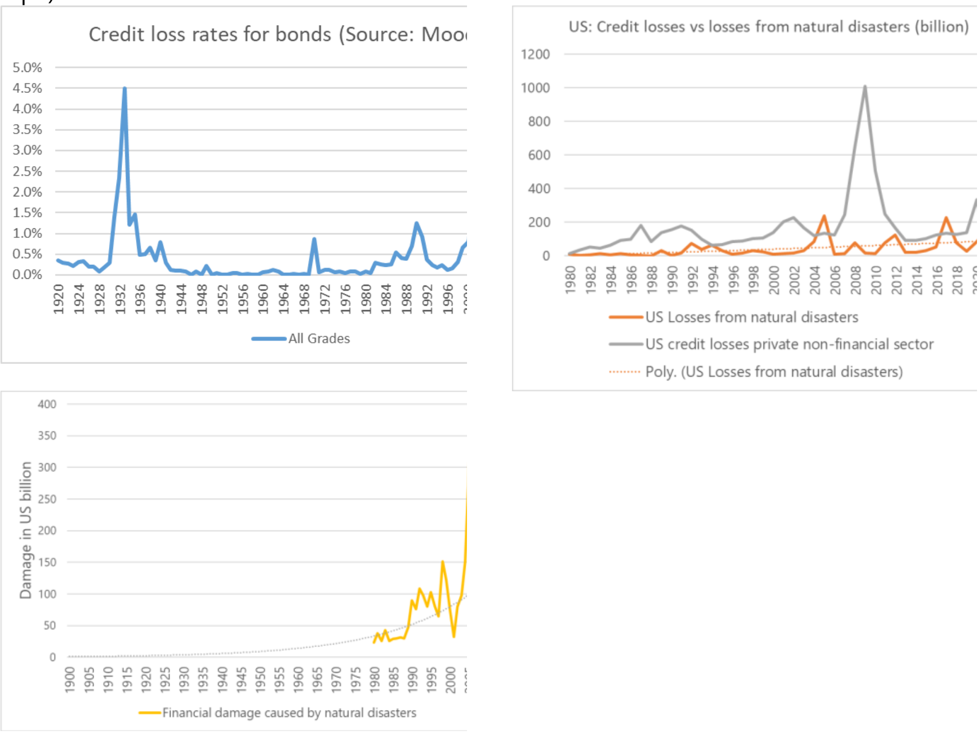
[8] Regarding assumptions on socio-economic drivers, the NGFS scenarios are based on IPCC work, while the IPCC frameworks uses input from the NGFS modelling.

[9] Ie the IEA does not project physical risk impacts and does not provide an outlook beyond 2050.

Figure 3: Climate risk related vulnerabilities are different from traditional solvency risks

Credit losses, the main driver for bank solvency, are fairly stationary (upper graph), while the financial impact of natural disasters has increased substantially over time (bottom graph)

Hence, over time, financial losses from climate risks could become a significant contributor to bank losses, at least at the regional level



The natural disasters included in the bottom left graph are storms, floods, drought, wildfire and extreme temperature, ie earthquakes were left out. The data on the financial impact is adjusted for inflation, with 2015 as the base year. Right hand graph: the two series are not directly related to bank exposures, but are meant to provide context of the magnitudes in general.

Source: Moody´s (2023) and EM-DAT.

The NGFS distinguishes between seven hypothetical scenarios, simulating potential low, median and high climate and macro-financial impacts through 2100 (Figure 4) to capture the distribution of outcomes. A main distinction is between orderly (Figure 4, bottom left scenarios in top left graph) and disorderly scenarios (Figure 4, upper left in top left graph). In the former case, climate risk policies are assumed to be implemented decisively early on, while disorderly scenarios assume delayed and divergent policy implementation. The hot house world scenarios (bottom right) assume decisive action in some jurisdictions but insufficient global efforts, whereby critical tipping points are exceeded, resulting in irreversible chronic physical risk (sea-level rise) and higher acute risks, too. The fragmented world scenario (top right) simulates the impact of a combination of delayed policy action and international divergence. The current policy scenario simulates a scenario without further measures, the most conservative benchmark. Key characteristics of the scenarios in terms of policy ambition, policy reaction, assumed technology paths, mitigation policies and regional variations is provided in Annex 2.

The NGFS uses a combination of models to simulate – with an attempt towards an integrated and consistent approach – transition and physical risks as well as macro-financial impact (Figure A1.2):

- Transition pathways are simulated based on three integrated assessment models[10],
- Physical risks are modelled using Earth System Models and Climate Impact Models and
- A macro-financial model (NiGEM[11]) uses the outputs of the other models as well as information from the international disaster database Emergency Events Database (EM-DAT) to project a series of macro-financial variables at the regional and country levels (Figure A1.3).

As acknowledged by the NGFS and documented by others (e.g., Acharya et al., 2023; Adrian et al., 2022), there exists a certain trade-off between the costs of mitigation policies (i.e., transition risk) and the realisation of physical risks, which would greatly benefit from internationally coordinated agreements and actions (Figure 4, top left graph). Key outputs of the NGFS machinery are temperature pathways (Figure 4, top right graph), the projected increase of carbon prices (Figure 4, bottom left graph) and the cumulative loss of GDP growth (bottom right graph).

The transmission channels from climate risks to financial risks are illustrated in Figure A2.4: the materialisation of climate risk vulnerabilities is projected to gradually worsen economic conditions at the macro-level and micro level, which has implications on bank solvency (credit, market and operational risk), including through cross-border contagion and liquidity risks. The ultimate impact will depend on banks´ exposure to climate risks.

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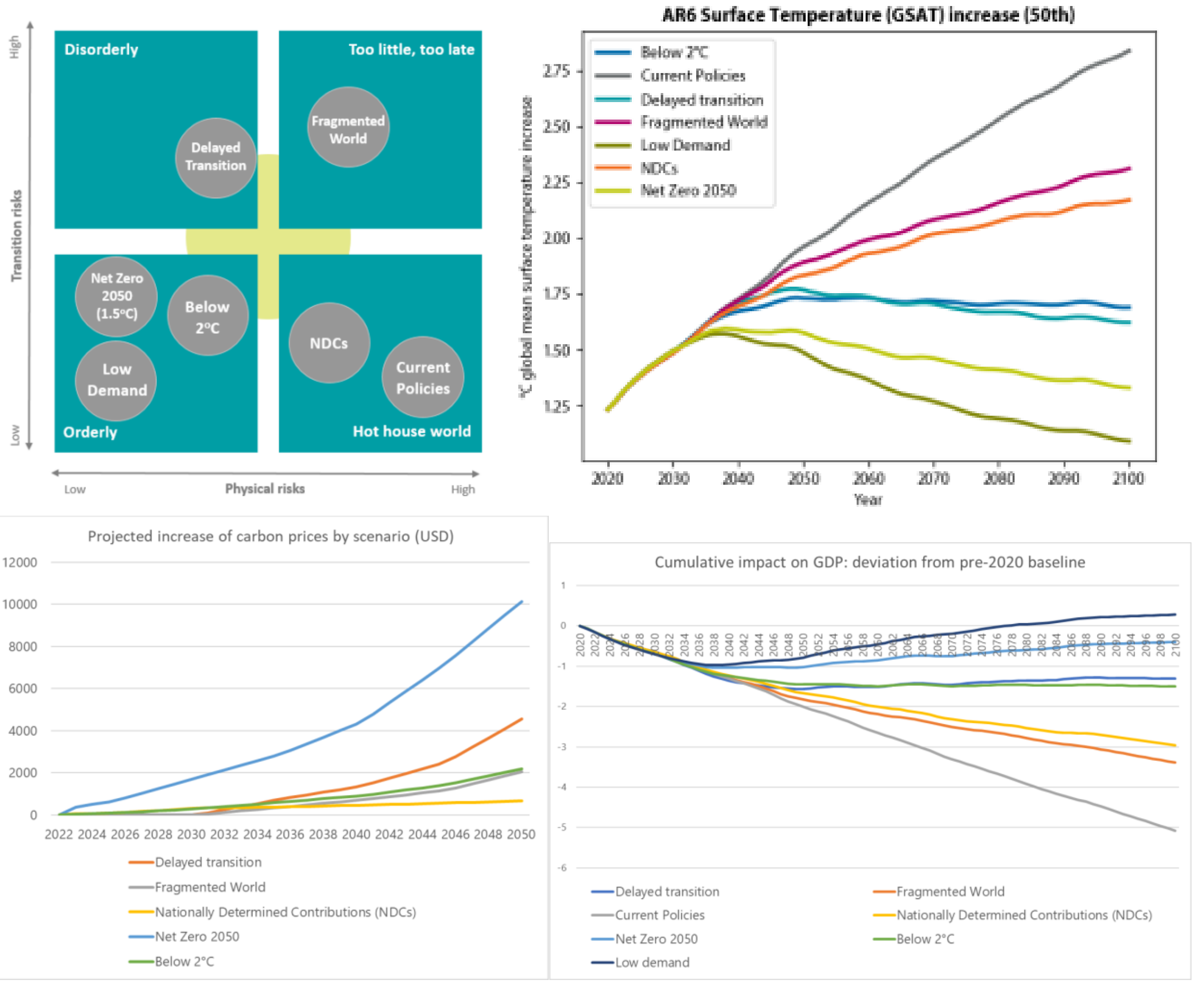
[10] REMIND-MAgPIE, MESSAGE-GLOBIOM, and the GCAM models. We use outputs from the first model, which are most comprehensive in terms of the available variables, observing that their outcomes are generally fairly similar, at least at the aggregate level.

[11] The National Institute Global Econometric Model (NiGEM).

Figure 4: NGFS climate scenarios

NGFS scenarios (Phase IV)



Note: NDCs: Nationally Determined Contributions; right graph: temperature increase relative to preindustrial conditions

Source: NGFS (2024)) [the scenarios have been updated sligthly since then]

The NGFS scenarios suggest the following main conclusions on the impact of climate risk on GDP growth paths:

1. There is substantial variation across countries, reflecting different exposure to climate related vulnerabilities (physical risks) and different levels of exposure of the industry to fossil fuels and trade (transition risk).

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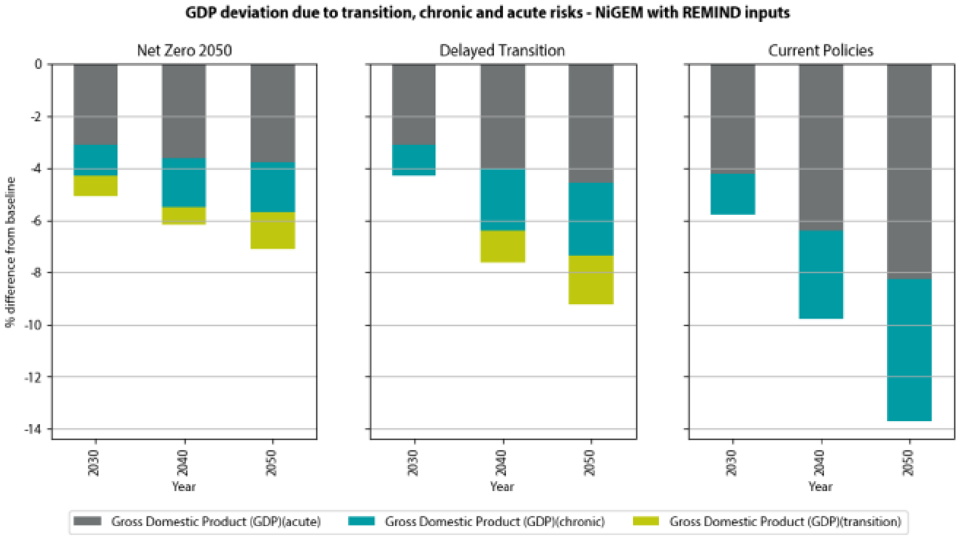
[12] Climate change's impact on economic output should be a significant area of focus, as highlighted by Acharya et al. (2023). Structural Dynamic Integrated Climate-Economy (DICE) models, as used by the NGFS for its scenarios, simulate climate change as a tax on consumption. This means that the economic damage is most severe when changes in GDP are highest, ie during boom periods. On the other hand, climate disaster models, such as those proposed by Weitzman (2012/14) and Barro (2015), assume that substantial physical risks from climate change and low GDP growth can coincide. In this model, low GDP states are the result of climate disaster realisations.

2. Vulnerabilities from chronic physical risks (modelled based on temperature pathways) are the dominant driver on GDP trajectories in the long-term and have a growing impact, while acute physical risk are the dominant structural driver until 2050 (Figure 5). Moreover, physical risks can have a strong short-term impact in case of a major acute climate risk event (eg storm, flooding).
3. Transition risks tend to impact GDP trajectories particularly in the near time, especially for the more ambitious climate scenarios (such as Net Zero 2050), but clearly lose relative impact vis-à-vis physical risk over time.
4. At the global level, GDP by 2050 is projected to be about 5-7 percentage point below a world with climate risk conditions frozen today, while GDP would be 14 percentage points below for the current policies. By 2100, the cumulative GDP loss is projected to be more than 20%.
5. In the near term (until 2030), the more ambitious climate risk scenarios may be more costly in terms of economic output, but they are associated with a net benefit from 2040.

It is important to note that the macro-financial impact provided by the NGFS does not incorporate the short-term impact of acute physical risk, costs related to sea-level rise or wider societal impacts from migration or conflict.

Figure 5: Impact of NGFS scenarios – aggregate outcome by scenario

GDP variation due to transition risks and physical risks (chronic vs acute)



Source: [NGFS (2024)](#) [the scenarios have been updated sligthly since then]

We differentiate between three steps to simulate the climate impact on bank solvency: in the first step, climate impact scenarios are established; second, those scenarios are translated into macro-financial impact; in the last step, the macro-financial scenario is mapped into bank solvency parameters, including credit losses and capital ratios. For steps 1 and 2, we mostly leverage NGFS work, while step 3 is based on the Hardy and Schmieder (2013) framework.

By contrast, traditional scenario analysis "only" requires a partial element of step 2 (establishing macro-financial scenarios) and step 3, which in itself is already a very complex undertaking (see Annex 1).

As illustrated in Figures 1 and A2.4, our contribution is three-fold:

1. We provide a framework to map the NGFS outputs into bank solvency, complementing the GDP trajectories provided by the NGFS with short-term scenarios for acute physical and transition risks.
2. We allow for the simulation of potential vulnerabilities transmitted through cross-border channels.

We establish findings on the relative impact of key drivers of climate risk vulnerabilities for banks, their evolution over time and variation across countries. We also allow for a simulation of a joint materialisation of a climate risk scenario with financial crises. Table 2 compares our approach with other frameworks used for climate scenario analysis, including by the Central Banks of France, the United Kingdom, and the ECB as well as the IMF in its Financial Stability Assessment Programmes (FSAPs). Moreover, the NGFS (2021) compared the approaches of 31 members, for which we have summarised relevant parameters in the table.

Our framework has the following features:

- To our best knowledge, it is the only one which is publicly available, using public data sources, but at the expense that the modelling is top-down at the aggregate, country-wide level, rather than informed by more granular, restricted data.
- It allows for a comprehensive modelling of risk types, ie
  - both climate risk and "traditional" solvency risks,
  - projects credit losses and capital ratios, and
  - distinguishes between structural medium/long-term risks vs short-term risks on the one hand and physical vs transition risks on the other (Box 1, Table 1). We attempt to avoid double-counting of potential impact, eg through direct and indirect channels.
  - allows to explicitly consider the impact of potential distress transmitted through cross-border channels, which may be an important transmission channel going forward, originating from trade (ie supply chains) and financial networks (Box 2).
- It enables simulations of the impact of climate risk and traditional financial risks for five-year periods for all decades until 2100, using the seven NGFS scenarios for long-term structural risks; the projection of short-term risks is based on a simplified approach (Table 1).
- We distinguish between banks based in advanced economies and emerging market economies, and – for the simulation of capital ratios – by the regulatory approach for credit risk (standardised approach or IRB).

- For the scenario analysis of financial risks, we distinguish between three scenarios – moderate, adverse and severely adverse, corresponding the worst in 15-20/30/50 year stress periods (Annex 1).

Box 1

Physical and transition risk modelling

For the modelling of physical and transition risks, we distinguish between structural and short-term (acute) risks on the one hand, and indirect vs direct impact channels on the other. The main transmission channels are as follows:

- Acute physical risks:
    - Floods and wildfires can reduce homeowners' capacity to pay back their mortgages, while negatively affecting banks´ collateral values and risk weights, exhibiting both direct and indirect elements.
    - Floods and wildfires can disrupt firms' value chains and production processes, reducing their ability to service loans and increasing banks´ risk weights, exhibiting both direct and indirect elements.
- Chronic and acute physical risks can lead to negative economic consequences, lower growth, and further impact both firms and households. This impact will be transmitted indirectly.
- Transition risk: A significant increase of the carbon tax could weaken banks' solvency profiles in carbon-intensive sectors, associated with defaults (direct impact) and lower GDP growth (indirect impact).
- Public policies: We capture public policies through the NGFS scenarios and the calibrated GDP elasticities for the banks solvency parameters, consisted with past practices during financial crises.

All structural risks, ie chronic and changes in "average" acute physical risks and transition risks, are inferred from the GDP trajectories projected by the NGFS scenarios, ie modelled through the indirect channel. These projections provide a range of potential scenario severities, depending on modelling assumptions, resulting in lower or higher GDP losses. In the tool, we provide users with the option to simulate the full range of scenarios, while our reported results are limited to general patterns and tendencies.

For the short-term scenarios, we use a combination of heuristics inferred from the projected GDP growth paths (ie the indirect channel) and realised outcomes for natural disasters (direct channel), consistent with the exposure of the different countries to physical risks. The calibration used for these scenarios is only meant to be indicative and will be refined as more studies become available. We provide users of the tool with options to change the calibration based on their own calibrations. For transition risks, we allow for a simulation of an abrupt increase in carbon prices.

Complementary information is provided in Annex 3.

Comparison of different climate scenario analysis frameworks[13]

Table 1

Element	*NGFS (2021): Cross-country overview*	*BdF/ACPR (2021)*	*IMF Mexico FSAP (2022)*	*BoE/PRA (2021)*	*"Best practice" (ECB 2022)*	*ECB (2023)*	*IMF (2024)*	*Our framework*
Integration of solvency and climate risk	Depends	Credit risk and market risk, but not solvency risk	Yes	No	Yes	Credit risk and market risk, but not solvency risk	Credit risk	Yes, and also including cross-border spillover risks
Outcome (Impact ratio)	Capital ratios and/or losses	Loss provisions scaled by total exposures; Changes in fair value of trading book	Capital adequacy ratio	Projected credit losses	Expected credit losses	Expected credit losses on loan and bond portfolios	Potential loan losses from acute physical risks; Share of loans at risk (transition risk)[14]	All bank solvency components on capital ratios, focus on credit losses and capital ratios
Approach	Mix of top-down and bottom-up	Top-down	Top-down	Top-down	Bottom-up	Top-down	Top-down	Top-down
Time horizon	1 to 30 years (30 years most common)	30 years	5 years	30 years	Also use scenarios with longer time horizons	Short-to-Medium term (until 2-23-30)	10 year intervals (2030-2050)	5 year period, up to 2100
Scope of climate scenario analysis	Majority: macroeconomic, some sectoral analysis, Specific countries: counterparty level	All portfolios that are materially impacted	Credit portfolio of banks	All bank portfolios that are materially impacted	All portfolios that are materially impacted by climate risk	Loan and bond portfolio	Loan portfolio	Aggregate approach, ie no differentiation by asset type

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[13] We also note that the Federal Reserve has conducted a pilot climate scenario analysis exercise for the six largest US banks, simulating physical risks (like a major hurricane hitting the northeast U.S.) and transition risks under different economic scenarios. These results will not affect capital adequacy assessments yet, but will refine future scenario assumptions.

[14] Loans at risk is defined as loans extended to borrowers that may not be able to service outstanding debt obligations due to deteriorating earnings. The study uses interest coverage ratio (EBIT/interest expenses) and classifies borrowers with ICR<1 as firms-at-risk.

	NGFS (2021): Cross-country overview	*BdF/ACPR (2021)*	*IMF Mexico FSAP (2022)*	*BoE/PRA (2021)*	*"Best practice" (ECB 2022)*	*ECB (2023)*	*IMF (2024)*	*Our framework*
Climate scenario specification	Varies, NGFS scenarios important benchmark		Five-year scenarios drawn from long-term NGFS scenarios	NGFS scenarios	In line with scientific climate change pathways	Short-to-medium term scenarios compatible with long-term temperature targets	Medium-to-long term scenarios (2030-40-50)	All NGFS scenarios
Number of scenarios		Three for transition risk, one for physical risk	Two for transition risk, multiple physical risk scenarios	Three	At least two for transition risk and one for physical risk	Three	One for physical risk, Two for transition risk	Integrated scenarios for all risk types; specific modelling for short-term scenarios
Physical risk	Majority of countries: yes	Yes	Yes (floods and tropical cyclones)	Yes	Scenario relevant for the respective geographical region	Yes	Yes (acute physical risks)	All types (structural risks), short-term scenarios for flooding risk
Transition risk	Majority of countries: yes	Yes	Yes	Yes	More than one transition risk scenario	No	Yes	Structural impact via GDP paths, plus short-term scenario
Static / dynamic balance sheet	Majority: static	Static for five years, re-assessed every five years	Static	Static for five years, re-assessed every five years	Both static and dynamic balance sheet	Static	Static	Static, reflecting today´s situation, to allow for comparisons and due to limited asset maturities

Sources: Authors based on Baudino and Svoronos (2021) and other references listed above

As documented in Table 2, the use of the "traditional" scenario analysis framework by Hardy and Schmieder (2013) framework (see Annex 1) is the main element of our framework to derive bank solvency outcomes. Specifically, it allows for a mapping of the manifestations of different combinations of physical and transitional risks as per the NGFS scenarios through 2100 (NGFS, 2023) into bank solvency outcomes through their respective GDP trajectories.

As banking crises have tended to last up to 5 years, we simulate short-term climate risk scenarios with and without a simultaneous occurrence of financial crises, for today´s conditions and vs potential climate risk conditions until 2100 (Table 1).

We establish the potential direct and indirect impact of climate risk events. This encompasses direct financial losses encountered by banks, as well as losses incurred indirectly through macro-financial downturns, into trajectories for banks' credit losses and capital ratios. When considering the indirect impact, our approach operates on the assumption that historically calibrated GDP-elasticities—quantifying the non-linear impact of changes in GDP growth rates—on banks' credit losses and capital ratios during banking crises serve as meaningful predictors for climate-related economic output losses.[15] For assessing the potential short-term direct impact, we use a combination of losses extrapolated from observed disaster events and tail risks inferred from the Network for Greening the Financial System (NGFS) scenarios.

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[15] Relevant factors for this assumption encompass the extent of policy support provided to mitigate the repercussions of stress, structural characteristics of the economy (e.g., distinguishing between advanced and emerging market economies), and the resilience of the financial system, among others.

Overview of our scenario analysis: climate risk and traditional risks Table 2

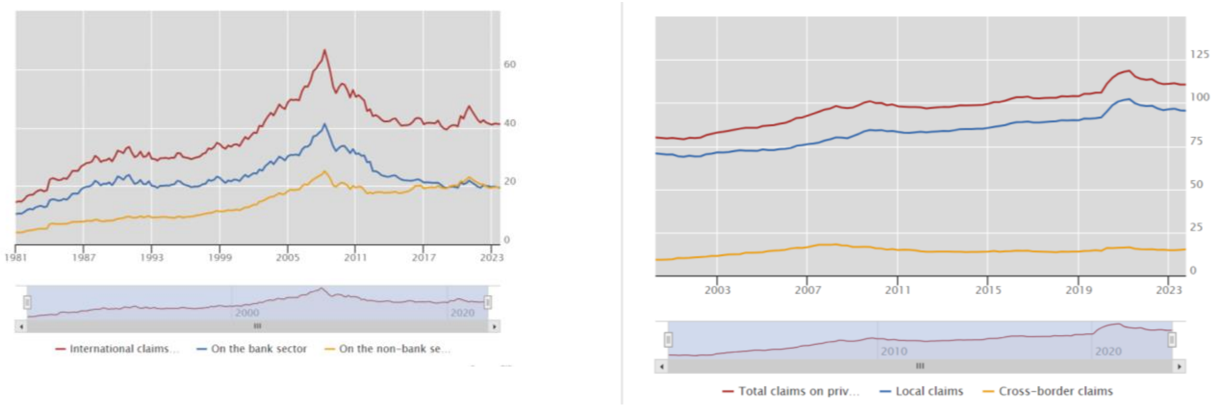
	Scenarios	Outcome	Horizon	Bank impact
Climate risk	7 NGFS scenarios (Figure 4), covering structural risks, plus short-term shocks and cross-border impact	(a) Structural impact only, (b) structural impact and short-term impact on credit losses and capital ratios	Forward-looking short-term scenarios, simulating climate risk situation for the forthcoming decades until 2100	Average impact by country
Traditional financial risks	Moderate, adverse and severely adverse scenario observed in past financial crises & user defined scenarios and cross-border impact	Credit losses and capital ratios for banking crises scenarios	Scenarios for 5 years, based on past crises evidence	Average impact observed during past crises

Source: Authors

Existing climate change studies tend to confine their focus to impacts within the same geographical location, ignoring the cross-border impacts of climate shocks, and the same often applies to scenario analysis for "traditional" solvency risks. Besides the conceptual modelling complexity, data accessibility across jurisdictions is another important challenge impairing the analysis of cross-border transmission of climate shocks (FSB-NGFS, 2022). However, not considering international transmission channels (see Box 2) may result in underestimating the financial stability implications of climate change. For instance, some EMDEs that may face the most adverse effects of climate change are dependent on cross-border bank lending (FSB, 2021).

The materiality of cross-border claims between banks and bank lending to non-banking sectors reinforces the case to bring those into the picture: the volume of cross-border claims measured against GDP has more than doubled during the past 40 years (Figure 6, red line in left chart). Much of the increase came from lending to non-banks (yellow line in left graph, right graph), while interbank claims have been at around 20% of GDP on average, after a spike to 40% in 2008.

Figure 6: Evolution of cross-border claims



Total cross-border claims are about 40% of global GDP, half of which are interbank claims and claims to non-bank sectors

The claims to the private non-financial sector are growing proportional to GDP and are equivalent to about 15% of global GDP, ie about 14% of total bank claims, but with a substantial variation across countries

Source: BIS banking statistics

As further outlined in Box 2 and Annex 4, we simulate international scenarios to determine the inward- and outward-spillovers of recession scenarios depending on the intensity of the trade and financial network relationships.

- For the impact of recessions in one country on credit losses and capital ratios in other economies we use the GDP elasticities from Hardy and Schmieder (2013) along with the share of cross-border claims in total credit assets. As documented by Cerutti and Schmieder (2014), cross-border claims can make up a material share of bank assets.
- To mitigate the impact of stress, banks will try to reduce their exposure to countries affected by crises. To gauge this impact, we established econometric results (Annex 4), suggesting that banks have substantially reduced their cross-border claims around crises, especially during severe crises.

Box 2

Modelling of cross-border spillover risk

While cross-border claims can facilitate risk sharing and diversify idiosyncratic risks, they can give rise to systemic risk concerns (Claessens and van Horen, 2014; Bruno and Shin, 2015; Karolyi et al., 2022), amplify losses if shocks occur simultaneously in several countries or are clustered in one geographical region. Interbank claims are a channel through which vulnerabilities of one institution can be rapidly transmitted through the system, as evidently shown during the GFC. Hale et al. (2020), for example, show that non-bank cross-border exposure to simultaneous crises causes significant profitability losses for banks and influences their lending behaviour; banks decrease new business loans and raise interest rates (spreads) on such loans due to crisis-related risks. Higher interconnectedness could also raise challenges to handle the resolution of financial institutions and pitch home and host supervisors against each other.

Given the global nature of climate change, transition and physical shocks can affect multiple countries simultaneously or in quick succession. Such shocks could also be transmitted across borders through the global network of financial claims, triggering global financial stability concerns. These effects could give rise to global contagion that further amplifies the consequences of these shocks through the real and financial channels.

Climate shocks and financial shocks more generally can be transmitted through cross-border claims via the following transmission channels (FSB, 2021):

- Credit Risk: Banks extend credit to borrowers in foreign countries through various instruments like loans, bonds, and derivatives. If the creditworthiness of these borrowers deteriorates due to economic or political shocks, banks may incur losses on their cross-border claims (e.g., higher write-downs on non-performing exposures). These losses can erode the capital of the lending banks, reducing their ability to lend and potentially triggering a broader credit squeeze in the home and host country.

- Market risk: Banks may face valuation losses on securities and, to the extent that these are "held for trading", mark-to-market losses can further affect bank net income and profitability (Hale et al., 2020).

- Liquidity Risk: Shocks can lead to sudden changes in market conditions, making it difficult for banks to access funding or sell assets. If banks have significant cross-border claims that they need to liquidate to raise cash, this can put further downward pressure on asset prices and disrupt financial markets.

- Funding risk: Information contagion, where the market discounts banks that have more cross-border exposures to affected jurisdictions, may face higher funding costs. Prior literature documents how borrower defaults or bankruptcy result in adverse equity market reaction for lending banks and their ability to syndicate loans (Dahiya et al., 2003; Gopalan et al., 2011).

Annex 4 details our modelling approach.

4. Conclusion

This paper introduces an accessible framework to evaluating banks´ climate vulnerabilities using scenario analysis.

During the coming years, the field of climate scenario analysis will likely benefit from conceptual advancements, along with better data, to narrow down potential outcomes for the various scenarios. Work by the FSB (2023/2025), the NGFS (2024) and the BCBS (2024) will be key elements to further both concepts and outcomes. Market-based scenario analysis approaches could also become a useful complement and benchmark for balance-sheet based approaches (Acharya et al 2023), especially for transition risks.

Given the flexibility of our framework, it can be adjusted to reflect the evolving findings of other, more detailed scenario analysis work, with the overarching principle to keep the concept as simple as possible. Adjustments to bank behaviour over time will be a crucial dimension to be captured, ie whether banks continue to lend in areas exposed to climate risk, how they adjust prices in such cases and how competition might affect such trends.

Besides climate risks, banks will face a number of structural changes during the years to come, including socio-economic (aging) and technological change. Using scenario analysis to take a holistic perspective on potential vulnerabilities affecting their business models, associated profitability and risk profiles, will be very important.

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Annexes

Annex 1: Scenario analysis for banks

Scenario analysis for banks and other financial institutions have gained significant prominence in the aftermath of the 2007-2008 global financial crisis. The European Banking Authority's (EBA) stress test and the Dodd-Frank Act Stress Test in the United States (now complemented by the Comprehensive Capital Analysis and Review, CCAR) have played a pivotal role in shaping the evolution of bank stress testing.

It has become a critical tool for regulators, policymakers, and banks themselves to assess the resilience of financial institutions to adverse economic and financial cycle conditions. While the analyses vary in their design (concept, time frame, top-down or bottom-up approach) and scope (risk types, types of scenarios, number of banks), the ultimate objective is the same: to establish an understanding of potential vulnerabilities faced by banks to inform policy work (for authorities) or management decisions (for banks themselves) (see Ong and Jobst 2020, for example).

Our framework relies on Hardy and Schmieder (2013), who have established – based on a wide range of evidence from previous banking crises – GDP elasticities on critical solvency components of banks, including credit losses, pre-impairment income (ie including valuation changes etc), asset growth patterns, risk-weighted assets and overall capital ratios.

The calibration is Hardy and Schmieder (2013) suggests a GDP elasticity of bank capital ratios ranging from 0.1 to 0.5, depending on the severity of the shock (which has a non-linear impact), the type of the economy (advanced vs emerging) and regulatory approach to credit risk (Standardised Approach vs Internal rating-based approach, IRB). For adverse banking crisis (one in 20-40 years), a bank based in advanced economies using the IRB, a scenario with a cumulative deviation of GDP growth by 8.5 percentage points over four years would lead to a reduction in its capital ratio at the trough by about 2.5 percentage points (=8.5 percentage point loss of GDP growth times 0.3 GDP elasticity of capital ratios). Under the same scenario, the bank would have to expect its credit loss rate to peak at 1.5% (=0.3% + 8.5 percentage point loss of GDP growth times -0.15 GDP elasticity of credit loss rates), five times the 0.3% under "normal" conditions.

Annex 2: NGFS Scenarios and modelling framework

Figure A2.1: NGFS scenarios by key assumption

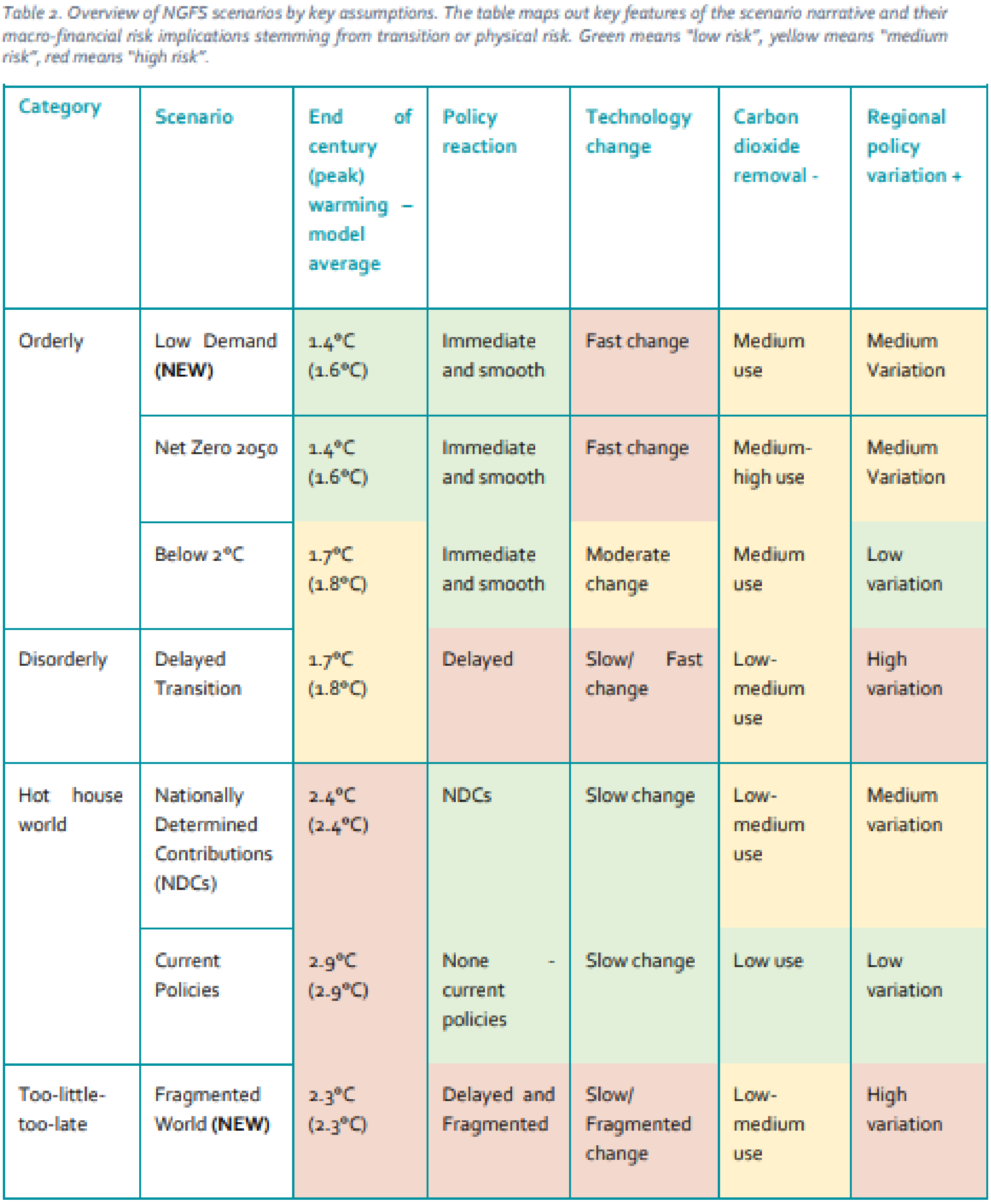


Table 2. Overview of NGFS scenarios by key assumptions. The table maps out key features of the scenario narrative and their macro-financial risk implications stemming from transition or physical risk. Green means "low risk", yellow means "medium risk", red means "high risk".

Category	Scenario	End of century (peak) warming – model average	Policy reaction	Technology change	Carbon dioxide removal -	Regional policy variation +
Orderly	Low Demand **(NEW)**	1.4°C (1.6°C)	Immediate and smooth	Fast change	Medium use	Medium Variation
	Net Zero 2050	1.4°C (1.6°C)	Immediate and smooth	Fast change	Medium-high use	Medium Variation
	Below 2°C	1.7°C (1.8°C)	Immediate and smooth	Moderate change	Medium use	Low variation
Disorderly	Delayed Transition	1.7°C (1.8°C)	Delayed	Slow/ Fast change	Low-medium use	High variation
Hot house world	Nationally Determined Contributions (NDCs)	2.4°C (2.4°C)	NDCs	Slow change	Low-medium use	Medium variation
	Current Policies	2.9°C (2.9°C)	None - current policies	Slow change	Low use	Low variation
Too-little-too-late	Fragmented World **(NEW)**	2.3°C (2.3°C)	Delayed and Fragmented	Slow/ Fragmented change	Low-medium use	High variation

Source: NGFS

Figure A2.2: NGFS suite of models approach

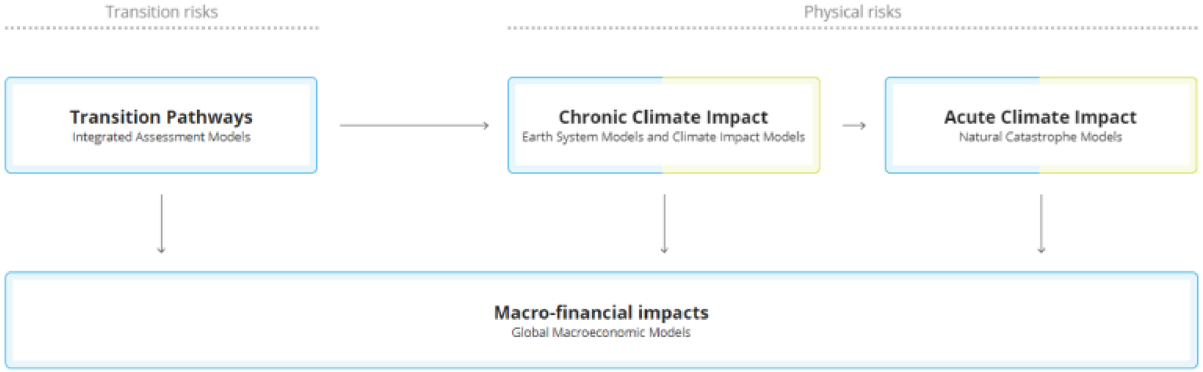
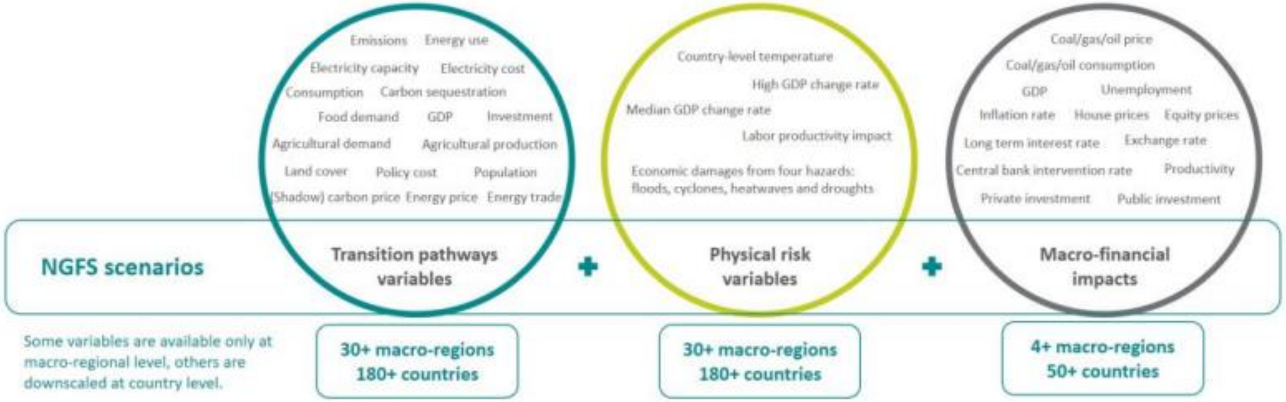


Figure 1. NGFS suite-of-models approach

Source: NGFS

Figure A2.3: Overview of NGFS output variables



Some variables are available only at macro-regional level, others are downscaled at country level.

Figure 2. Overview of the range of data provided by NGFS scenarios.
Note: this visual does not contain the full list of variables and is for illustrative purposes only. The names of the variables do not necessarily correspond to the ones used in the databases. The number of countries/regions available varies significantly depending on the variable. Downscaled climate-related and macro-financial variables are available for 180+ and 50+ countries, respectively.

Source: NGFS

Figure A2.4: Overview of transmission channels

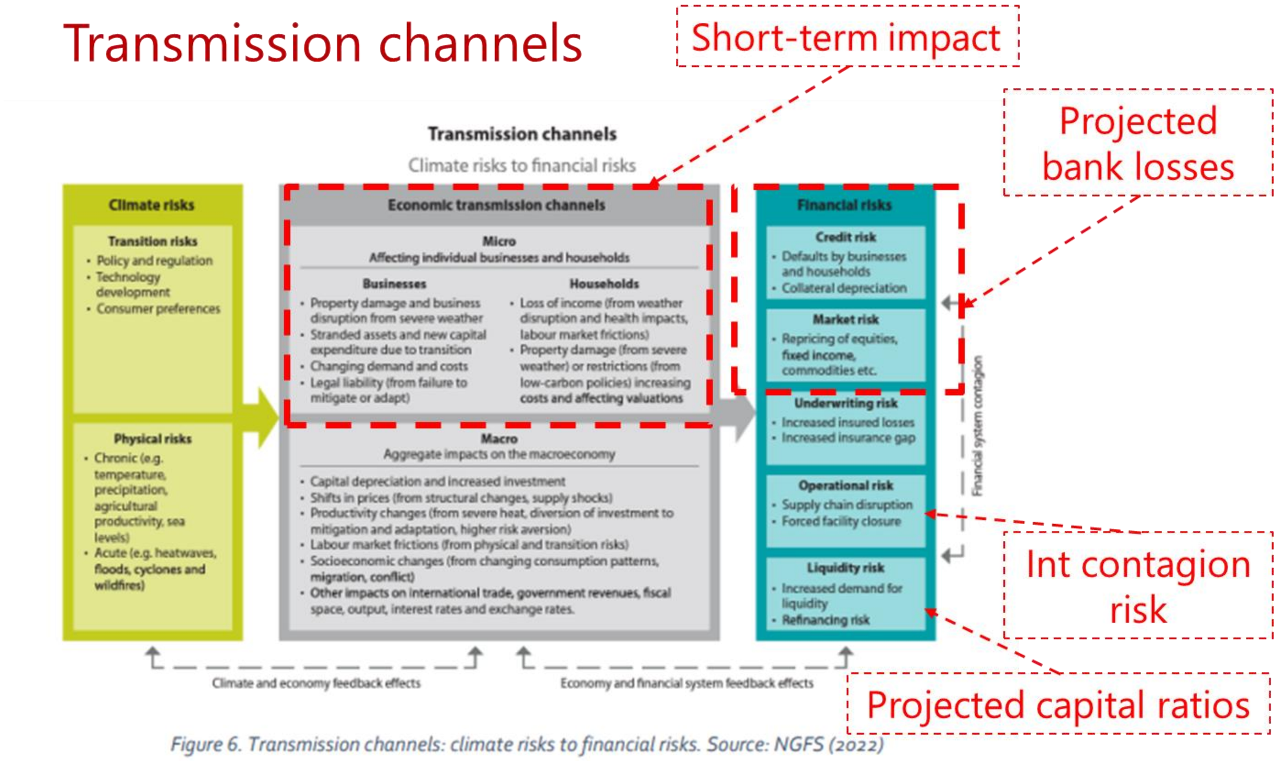


Figure 6. Transmission channels: climate risks to financial risks. Source: NGFS (2022)

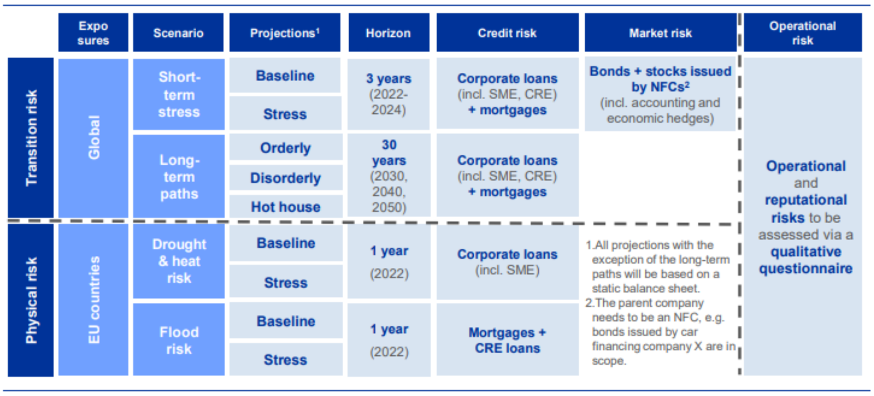
Source: NGFS

Annex 3: Scenario analysis modelling

Figure A3.1: Climate risk scenarios used by the ECB in their 2022 bottom-up exercise

Chart 2

Module 3 scenarios and risk dimensions



	Exposures	Scenario	Projections[1]	Horizon	Credit risk	Market risk	Operational risk
Transition risk	Global	Short-term stress	Baseline	3 years (2022-2024)	Corporate loans (incl. SME, CRE) + mortgages	Bonds + stocks issued by NFCs[2] (incl. accounting and economic hedges)	Operational and reputational risks to be assessed via a qualitative questionnaire
			Stress				
		Long-term paths	Orderly	30 years (2030, 2040, 2050)	Corporate loans (incl. SME, CRE) + mortgages		
			Disorderly				
			Hot house				
Physical risk	EU countries	Drought & heat risk	Baseline	1 year (2022)	Corporate loans (incl. SME)		
			Stress				
		Flood risk	Baseline	1 year (2022)	Mortgages + CRE loans		
			Stress				

1. All projections with the exception of the long-term paths will be based on a static balance sheet.
2. The parent company needs to be an NFC, e.g. bonds issued by car financing company X are in scope.

Source: ECB, climate risk stress test 2022, methodology, October 2021.
Notes: CRE stands for commercial real estate; NFC stands for non-financial corporation; SMEs stands for small and medium-sized enterprises.

ECB (2022)

Navigating Climate Vulnerabilities: Scenario Analysis for Banks

Christian Schmieder, Abhishek Srivastav and Miroslav Petkov

6 May 2024

Preview of results

- Attempt to establish forward-looking top-down estimates of climate risk impact on banks until 2100
- Conservative estimates under static balance sheets across countries and over time, for loan pricing and bank capital
- Bird’s view of evolving climate risks in the global banking system and how such risks, when realised, could be transmitted and amplified
- Outcome: Short-term and structural impact of climate shocks growing over time, especially in countries that are more exposed to climate risk

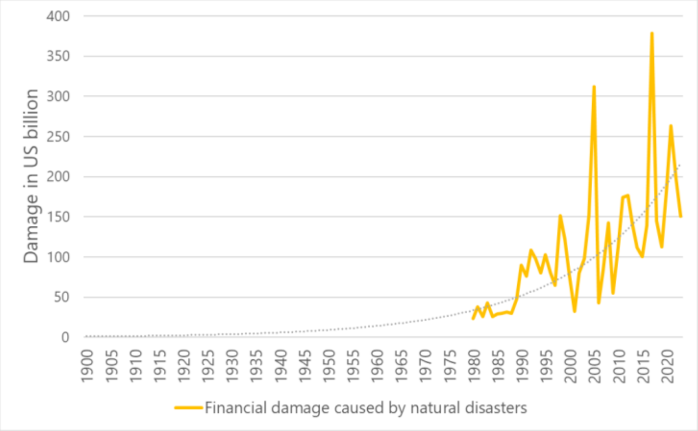
Motivation

- FSB Roadmap for Addressing Financial Risks points to a need for…
  - better data (firm disclosure, aggregate data) and
  - improving conceptual frameworks to assess Financial Stability risks

  … to inform regulatory and supervisory policy work
- Many central banks and IMF are conducting climate scenario analysis
- This work fills a gap
  - Accessible top-down concept to run climate risk scenario analysis for banks at the country level for a wide range of countries
  - Helps understanding transmission channels and illustrates sensitivities of outcomes over time and across countries, including through cross-border channels

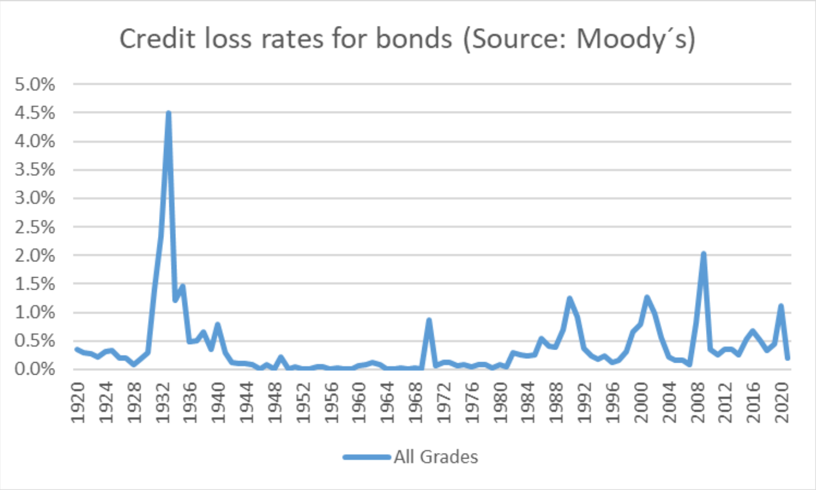
Climate risk vs macro-financial bank solvency risks

- Climate risks are expected to grow over time (→ no historical benchmarks)



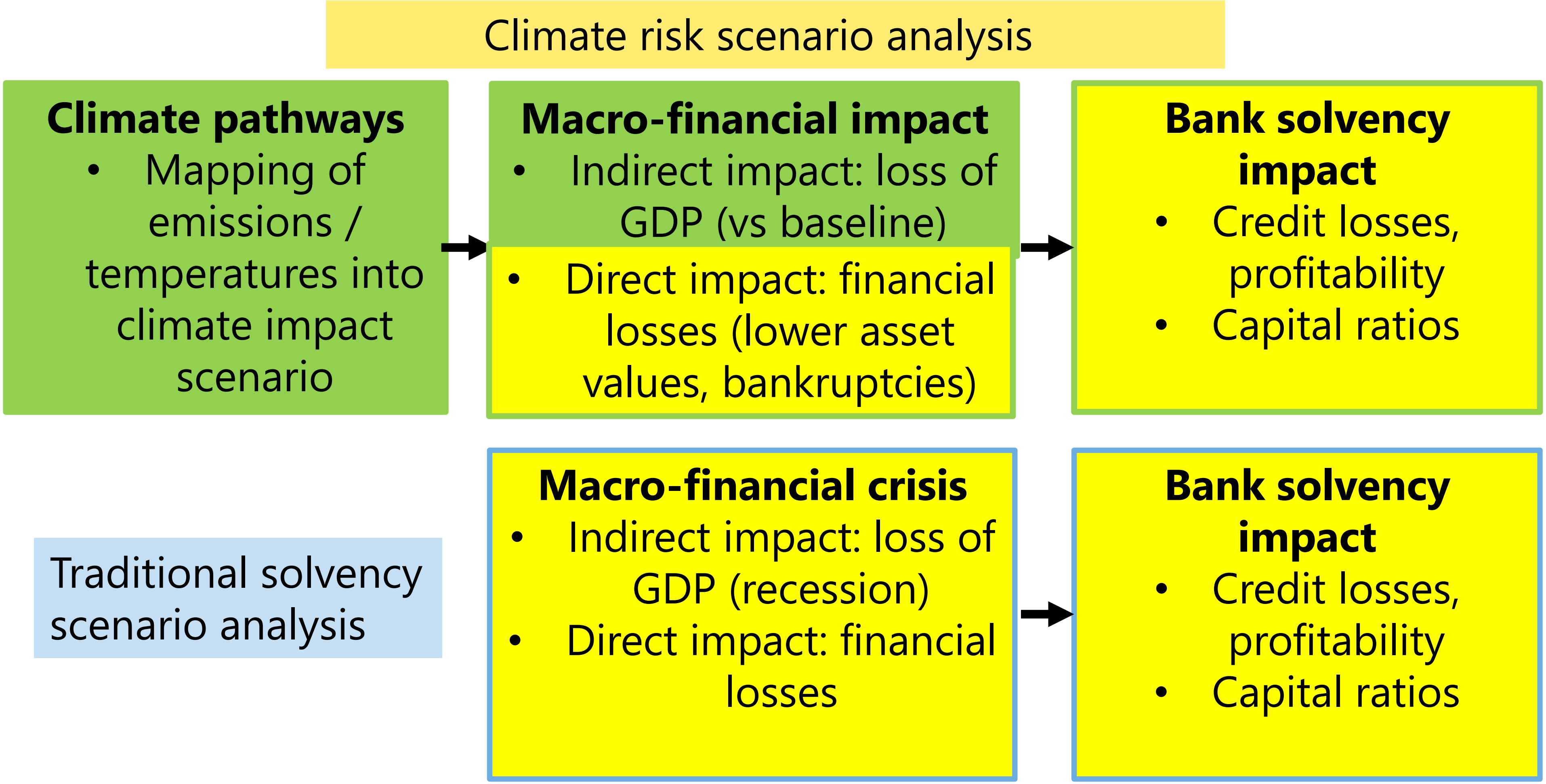
Source: EM-DAT

- Bank solvency risks are fairly stationary, all else equal (→ historical benchmarks)



- Similar concept: expected impact vs unexpected tail risk

Concept: Climate risk scenario analysis is much more complex than traditional scenario analysis



Climate risk scenario analysis

Climate pathways
- Mapping of emissions / temperatures into climate impact scenario

Macro-financial impact
- Indirect impact: loss of GDP (vs baseline)
- Direct impact: financial losses (lower asset values, bankruptcies)

Bank solvency impact
- Credit losses, profitability
- Capital ratios

Traditional solvency scenario analysis

Macro-financial crisis
- Indirect impact: loss of GDP (recession)
- Direct impact: financial losses

Bank solvency impact
- Credit losses, profitability
- Capital ratios

Source: Authors

🟩 Taken from NGFS

🟨 Own contribution

Concept: cross-border transmission

- Climate shocks can have international spillovers due to
    - trade and financial interlinkages and
    - climate event affecting multiple jurisdictions
- We capture cross-border credit risk transmission channel:
    - Indirect and direct impact of climate risk event in host countries on credit losses through cross-border exposures
    - Sensitivity of cross-border bank claims to economic downturn of host countries affected by shock (may mitigate impact)
    - Impact will depend on intensity of economic and financial linkages

Scenarios: Climate risk vs "traditional" risks

	Scenarios	Outcome	Horizon	Bank impact
Climate risk	7 NGFS scenarios, plus short-term shock scenarios (user-defined)	Impact on credit losses and capital ratios	Forward-looking short-term scenarios (5 years), simulating climate risk situation for the forthcoming decades until 2100	Average impact by country
Traditional financial risks	Moderate, adverse and severely adverse & user defined scenarios, calibrated based on past crises evidence	Impact on credit losses and capital ratios	Scenarios for 5 years	Average impact observed during past crises
Combined scenarios	Any combination of the climate risk and traditional financial risk scenario (the marginal impact of the climate risk scenarios increase based on the severity of the underlying macro-financial scenario)			

Source: Authors

Scenarios: Potential bank behaviour

	Potential impact on pricing	Potential impact on bank capital	Caveats
Structural Climate risk	Higher solvency risk (expected loss) of bank customers reflected in higher loan prices	Indirect impact, since tail risk scenarios may get worse, see below	Difficult to model long-term trends; static balance sheet assumption
Short-term tail risk	Banks may disengage from specific sectors or pass on costs for higher capital consumption to their customers	Banks may face direct losses (eg on their collateral) and could decide to allocate more capital, which may increase credit prices and reduce banks' lending capital, which has macroeconomic implications	Difficult to extrapolate tail events; managerial and regulatory developments will play an important role; static balance sheet assumption

Source: Authors

Conclusion and caveats

- Our framework:
    - Accessible approach to establish global perspective of climate risk impact on bank solvency at the country level, both short- and long-term
    - Flexible to modify elements and update parameters using incoming evidence and new concepts (eg BCBS 2024)
- Besides climate risks, banks will face aging risks and technological change

- Assumptions / caveats
    - Static projection (eg balance sheets)
        - Duration of bank assets are short relative to climate risk horizon; adjustment of bank behaviour will matter greatly (upper bound)
    - Use of aggregate data and simplified, but comprehensive modelling
    - Reliance on historical relationship between GDP and solvency
    - Scenarios: Tipping points could have substantial impact on climate outcomes and thus bank solvency

IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

Measures of sustainable finance in the international standards for macroeconomic statistics[1]

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Organisation for Economic Co-operation and Development

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

Measures of Sustainable Finance in the International Standards for Macroeconomic Statistics

Sarah Barahona
Head of National Accounts Division
CBRT-IFC Workshop - Izmir, Türkiye - May 2024

What this presentation will cover

- Background:
    - Measuring the volume of climate finance – why is it important?
    - Updates of the international standards for macroeconomic statistics
- What will change in the 2025 System of National Accounts (SNA) and the 7th Balance of Payments Manual (BPM7)
- Linking up with the work of the third G20 Data Gaps Initiative (DGI-3) Recommendation 4
- Principles and definitions

Background

Measuring the volume of climate finance – why is it important?

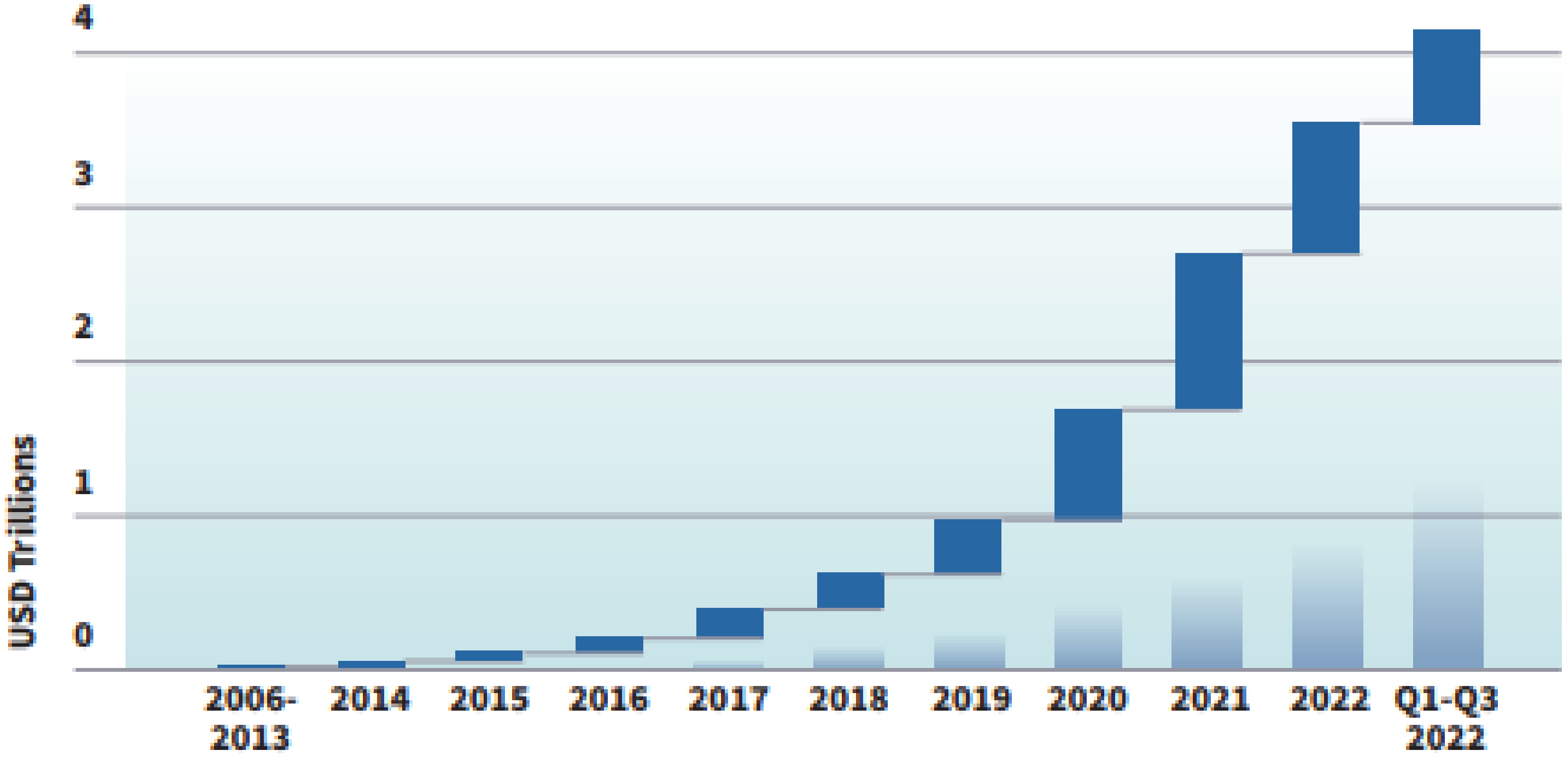
- Sustainable finance (or climate finance) is about funding activities that actively contribute to sustainable economic outcomes, for example the transition to low-carbon economies

- The 2015 Paris Agreement led to rapid growth in demand for sustainable finance, especially green bonds

- Policy makers need to know how much is being invested (availability of finance) to inform decisions in this area

- At present, we have no official estimates of how much of total debt securities, loans, equities (including listed shares) and investment fund shares on countries' balance sheets is 'sustainable' or 'green'

Cumulative ESG* debt securities at the end of 2023-Q3 – USD 4.2 trillion



* ESG = Environment, Social and Governance –
or, in the CBI source: "Aligned GSS+ debt"

Source: Climate Bonds Initiative (CBI)

Scorecard: GSS+ debt recorded by Climate Bonds

	Q3 2023		2023 YTD		Cumulative since 2006	
	USDbn	% total	USDbn	% total	USDbn	% total
Green	110.6	65	415.0	67	2613.0	62
Social	27.4	16	95.8	16	762.7	19
Sustainability	22.1	13	88.8	14	764.2	18
SLB	8.6	5	16.8	3	42.5	1
Transition	0.7	0.4%	1.7	0.3	12.7	0.3
Total	**169.5**	**100**	**618.2**	**100**	**4228.1**	**100**

Source: CBI Summary 2023-Q3

Updates of the international standards

- The international standards provide a set of accounts for countries and produce estimates of (for example):
  - Economic growth (measured by GDP)
  - Trade and investment between countries
- The manuals for the SNA and BPM were last updated in 2008
- The current update began in 2020 and the UN Statistical Commission is expected to endorse the revised standards in March 2025
- A key aim of the update is to make sure the standards address the big policy questions of today such as environment and climate change, and more specifically their interplay with countries' economies

Updates of the international standards

- The SNA 2025 will provide more information on land and other natural resources such as oil and gas, renewable energy and biological resources - measuring Natural Capital stocks and answering questions like:
    - How much of a country’s energy stocks is non-renewable (e.g. oil and gas) vs. renewables and how is the balance changing over time?
    - What is the impact on economic growth of depletion of natural capital?
- The OECD has established an **Expert Group on Natural Capital*** to produce implementation guidance for the 2025 SNA – it is looking at sub-soil assets, biological resources (e.g. timber), renewables, estimation methods

What will change in the 2025 SNA and BPM7?

Agreement to include official estimates of sustainable finance

- On 20th February, the Advisory Expert Group on National Accounts (AEG) – the body that agrees the changes for the SNA update – and the IMF Balance of Payments Committee (BOPCOM), in a joint meeting, **endorsed** the final proposal asking countries to report ESG and green financial instruments (debt securities, loans, equities and investment fund shares) as separate lines in the accounts

- In the 2025 SNA, ESG and green financial instruments will appear in the **core** financial accounts (flows) and balance sheets (stocks) as '*of which*' lines

- For the BPM7, they will appear in a **supplementary table** in Annex 14

AF	Financial assets and liabilities (National Accounts)
AF.3	**Debt securities**
	Of which: ESG debt securities
	Of which: Social debt securities
	Of which: Green debt securities
	Of which: Sustainability debt securities
	Of which: Sustainability-linked debt securities
	Of which: Other ESG debt securities
AF.4	**Loans**
	Of which: ESG loans
	Of which: Green loans
AF.5	**Equity and investment fund shares**
AF.51	**Equity**
	Of which: ESG equity
	Of which: Green equity
AF.52	**Investment fund shares**
	Of which: ESG investment fund shares
	Of which: Green investment fund shares

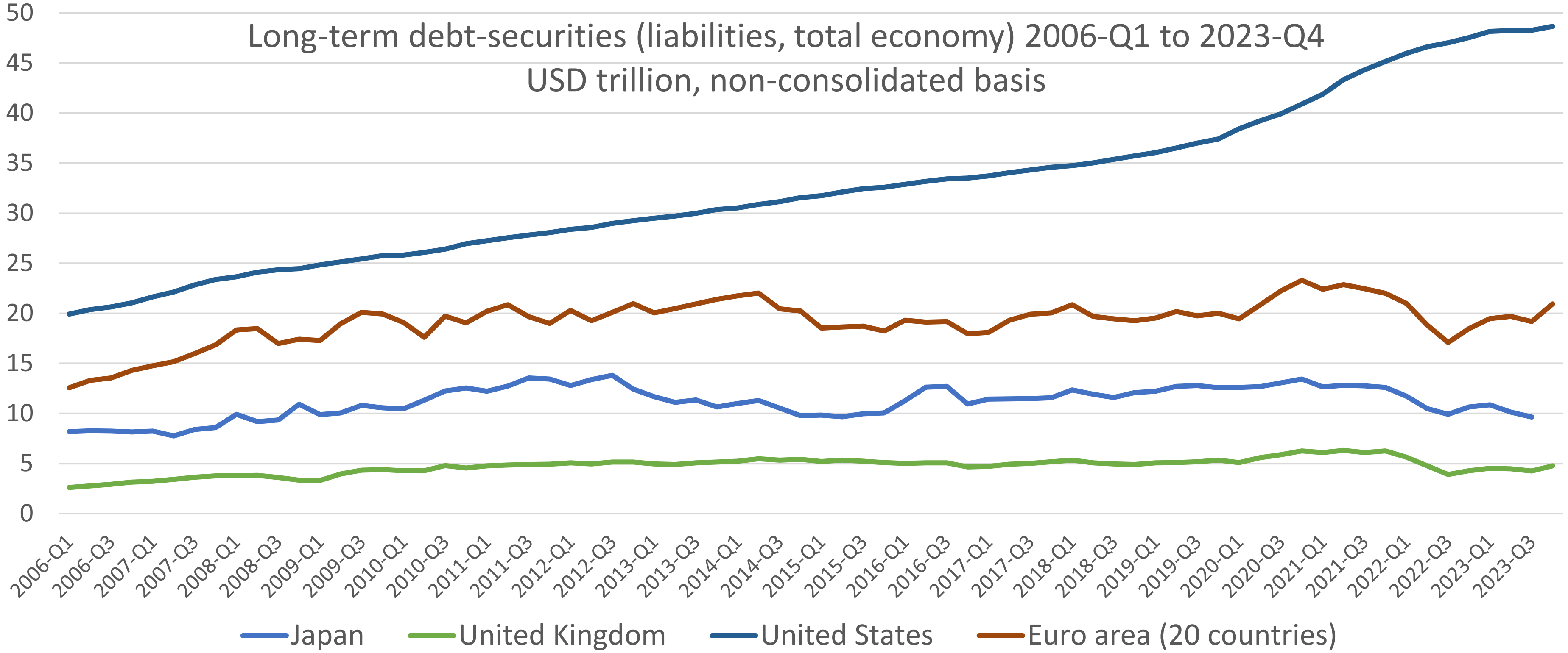
1	**Direct Investment (BOP and IIP)**
1.1	**Equity and investment fund shares**
	Of which: ESG equity/investment fund shares
	Of which: Green equity/investment fund shares
1.2	Debt Instruments
1.2.0.1	**Debt Securities**
	Of which: ESG debt securities
	Of which: Social debt securities
	Of which: Green debt securities
	Of which: Sustainability debt securities
	Of which: Sustainability-linked debt securities
	Of which: Other ESG debt securities

2	**Portfolio Investment (BOP and IIP)**
2.1	**Equity and investment fund shares**
	Of which: ESG equity/investment fund shares
	Of which: Green equity/investment fund shares
2.2	**Debt Securities**
	Of which: ESG debt securities
	Of which: Social debt securities
	Of which: Green debt securities
	Of which: Sustainability debt securities
	Of which: Sustainability-linked debt securities
	Of which: Other ESG debt securities

4	**Other Investment (BOP and IIP)**
4.3	**Loans**
	Of which: ESG loans
	Of which: Green loans

What will this look like in official statistics?

- In the national accounts balance sheets for example, in future there will be time series for ESG and green financial instruments *in addition to the* ***totals*** *that are currently available*:



Linking up with the work of DGI-3 Recommendation 4

DGI-3 Recommendation 4: Climate Finance

- Task Teams of the third G20 Data Gaps Initiative started work in early 2023
- The DGI-3 Recommendation 4 Task Team is coordinated by the BIS, ECB and IMF and is working with countries to produce estimates (by end-2025 and end-2027) on:
  - ✓ Green debt securities
  - ✓ Sustainability debt securities
  - ✓ Sustainability-linked debt securities
  - ✓ Green listed shares
- This data collection will be a primary source for many statistical producers to start populating the new lines in the 2025 SNA and BOP/IIP
- The DGI-3 Recommendation 4 approach to collecting securities data and the requirements of the 2025 SNA and BPM7 are well aligned, as both sides have worked together on the principles and definitions

Principles and definitions

General principles

- **ESG** finance is finance for “activities or projects that sustain or improve the condition of the environment or society or governance practices” (this is deliberately a broad concept)
- **Green** finance is finance for “activities or projects that sustain or improve the condition of the environment”
- The general principle for establishing greenness is a positive contribution to the environment (rather than ‘do no harm’)
- What is the *perspective* used to assess whether something is ESG or green?
  - Most debt securities: the use of proceeds raised with the financial instrument
  - Equity: the corporate revenues generated by the financing transaction
  - Loans: revenue approach (business loans)/proceeds approach (household loans)
  - Sustainability-linked debt securities, investment fund shares: achieving certain objectives or performance targets

Taxonomies, labelling and certification

- There will **not** be a single taxonomy for sustainable finance activities in all countries, although the development of official taxonomies is encouraged
- Both public and private standards may be used
- ESG and green instruments may be included on the basis of:
  a) Self-labelling, where the issuing entity decides on the appropriate ESG or green classification (no second party opinion or SPO, and no certification)
  b) Second Party Opinion (SPO), where a trusted entity provides the ESG or green label (but no certification)
  c) Certification, where, in the presence of standards, a specialised entity grants the ESG or green status
- Compilers **should** provide information (metadata) on whether the figures include *self-labelled* and/or *SPO* and/or *certified* financial instruments

Definitions

- *ESG [green]* ***debt securities*** are debt securities where the use of proceeds is restricted to (or where the issuer agrees to achieve performance objectives that) improve the condition of the environment or society or governance practices [of the environment].

- *ESG [green]* ***loans*** are funds lent by creditors to debtors in which **50% or more** of the debtor's activities improve the condition of the environment or society or governance practices [of the environment].

- *ESG [green]* ***equity*** are equity investments by investors to institutional units in which **50% or more*** of the institutional unit's revenue comes from activities improve the condition of the environment or society or governance practices [of the environment].

- ESG *[green]* **investment funds** are funds investing in financial instruments, companies, projects or other funds that intend to achieve performance objectives that improve the condition of the environment or society or governance practices [of the environment].

Thank you!

SNA update Issues Note endorsed by the AEG and BOPCOM on 20 Feb 2024:
Issues Note: Sustainable Finance in the 2025 SNA and BPM7
(final version, May 2024)

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IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

Compiling climate finance statistics from security-by-security data[1]

F Fusero, J Kleibl and D Theleriti,
European Central Bank

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

Compiling climate finance statistics from security-by-security data[1]

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Abstract

Over the past years, large-scale security-by-security (s-b-s) databases with multiple input data sources have become increasingly relevant for producing official statistics in the central banking world. Such databases also offer significant potential for compiling new reliable and comparable statistical indicators, including on climate finance. These climate finance statistics would improve policymakers' understanding of the volume, usage and sources of funds available for financing the green transition. This paper contributes towards closing this key data gap by providing a general framework for the compilation of climate finance statistics from s-b-s data on debt securities issuances and holdings in a consistent and automated manner. In addition, the paper explores a new approach for measuring the role of equity for climate finance using s-b-s data, an area that because of its complexity has so far been neglected by existing attempts to quantify the volume of climate finance via securities markets. To showcase the usefulness of the climate finance indicators for debt securities and the applicability of the newly proposed concepts for equity securities, the paper uses s-b-s data from the European System of Central Banks' Centralised Securities Database (CSDB) and Securities Holdings Statistics Database (SHSDB) for the euro area.

Keywords: Climate finance statistics, sustainable finance, environmental social and governance (ESG), official statistics, security-by-security databases, compilation, data quality management, multi-source data, debt securities, listed shares.

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[1] The views expressed are those of the authors and do not necessarily reflect those of the ECB.

1. Introduction

In the wake of the climate crisis and the growing need for funds to finance the green transition in economies around the world, climate finance securities have become one of the fastest growing market segments in the global securities market. These financial instruments, including green bonds, sustainability bonds, sustainability-linked bonds or green shares, today constitute a main source to finance climate and other sustainable projects and the transition to a sustainable economy in general. The issuance of climate finance debt securities in the global market has risen from negligible amounts to over USD 500 billion per year over the last decade (see International Monetary Fund 2024).[2] An increasing number of major stock exchanges has been introducing separate market segments for green listed shares (see, e.g., London Stock Exchange 2023; NASDAQ 2023). Investment funds with environmentally, socially and governance-oriented (ESG) investment strategies (i.e. that are investing in companies with ESG objectives) are mushrooming (Capotă et al. 2022).

Following the increasing relevance of climate finance in the global securities markets, also central banks, international institutions and other compilers of securities statistics have been trying to track the volume of climate finance globally or in different regions or countries (see, e.g., International Monetary Fund 2024; ESCB Statistics Committee Expert Group on Climate Change and Statistics and Working Group on Securities Statistics 2024). At the same time, there is so far no standardised methodology for the compilation of harmonised climate finance statistics from security-by-security (s-b-s) data. This paper aims at addressing this gap by presenting a general framework for compiling harmonised statistics on issuances and holdings of climate finance debt securities, and by exploring a new approach for measuring the volume of issuances and holdings of green equity securities.[3] The paper makes three contributions. First, it provides compilers of securities statistics with practical guidance on the key steps for producing harmonised statistics on climate finance debt securities based on s-b-s data. Second, the paper makes a first attempt of exploring a general and simple methodology for measuring the volume of green shares, an area that because of its complexity has so far been neglected by existing attempts to quantify the volume of climate finance via securities markets. In doing so, it identifies specific issues that require further consideration for developing a general harmonised compilation approach for statistics on green equity securities. Third, it directly contributes to the work of the Group of 20 Data Gaps Initiative (G20 DGI) on developing harmonised indicators for measuring climate finance in the G20 and Financial Stability Board (FSB) member economies in the context of G20 DGI Recommendation 4 on Climate Finance (Working Group on Securities Databases 2023). Thus, the paper ultimately supports the broader goal of improving policymakers' understanding of the volume, usage and sources of funds available for financing the green transition.

The remainder of the paper proceeds as follows. Section 2 describes a general compilation framework for securities statistics using s-b-s databases. Section 3 shows how this framework can be used for the compilation of climate finance statistics for debt securities, while section 4 showcases the usefulness of this compilation approach by presenting an overview of recent developments in climate finance via debt securities for the euro area economy. Section 5 explores the use of this framework for compiling statistics on green listed shares, suggesting a simple methodology for identifying green shares. Based on this, section 6 uses this methodology

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[2] Debt securities consist of short-term and long-term debt instruments.

[3] While for debt securities the contribution of green, sustainability and sustainability-linked bonds to financing the green transition is immediate due to the use of proceeds for climate change adaptation and mitigation projects or their linkage to climate-related key performance indicators, for green equity this link is less clear. In the case of green equities, the related funds may have been raised long time in the past to finance non-green activities, while their issuers may have only transformed into green businesses at a later stage. This caveat should be considered when interpreting the experimental statistics on green listed shares presented in this paper.

to provide an overview of recent trends in green listed shares for the euro area economy. Section 7 concludes and identifies avenues for further work on establishing a general compilation methodology for statistics on green listed shares.

2. Compilation using security-by-security databases

Compiling climate finance statistics from s-b-s data first requires setting up a general compilation process. As prerequisites, compilers need to have in place an s-b-s data collection framework on securities issuances, securities holdings and related reference data (e.g., from reporting financial institutions, commercial data providers, government agencies, and other sources); an s-b-s database that stores and processes these data; and robust processes for the regular production, data quality management, revision and possible dissemination of such data (see Kleibl and Micheler 2022; 2023). For the remainder of this paper, we assume that aforesaid basic infrastructure has been put in place.

Setting up a process for compiling aggregates on securities statistics from s-b-s data requires following four basic steps and answering four related questions:

- *Availability of required s-b-s data attributes*: Which attributes are required for identification, calculation and aggregation?
- *Identification of relevant securities*: Which individual securities need to be part of the aggregates for a given reference date?
- *Calculation of statistics at individual security level*: How should the required statistical quantities (e.g., outstanding stocks, gross issuances, redemptions, revaluations, and other changes) be calculated at the level of the individual securities?
- *Aggregation by relevant breakdown categories*: For which breakdowns should aggregates be compiled based on the statistical quantities calculated at the level of the individual securities?

The following subsections briefly describe each of these steps for the example of compiling securities issues statistics on stocks of outstanding debt securities at nominal value.

Availability of required s-b-s data attributes

As a first step, compilers need to ensure that the required s-b-s data attributes are available in their database. These include the attributes needed for the identification of the securities that should be part of the aggregates, the calculation of the relevant statistical quantities at individual security level, and the aggregation of such quantities calculated at individual security level.

For example, to compile basic aggregates on stocks of outstanding debt securities at nominal value, the s-b-s data that would be required for the identification and calculation of statistical quantities at individual security level will comprise at least the following attributes: System of National Accounts (SNA) instrument classification, issue date and maturity date, security status (e.g. alive, redeemed, in default, etc.), relevant instrument flags (for excluding instruments out of scope or instruments creating duplications such as depository receipts), outstanding amount (stock face value), nominal currency, issue price, coupon rate, coupon frequency, and coupon dates. In addition, further attributes will be needed for assigning individual securities into different breakdowns when performing the aggregation of the statistical quantities at individual security level, such as the SNA issuer sector or the interest rate type of the securities. Finally, for compiling aggregates on climate finance statistics for debt securities, additional attributes are needed to identify climate finance debt securities including green bonds, sustainability bonds, and sustainability linked bonds. As described in greater detail in section 3, these will include at least the classification of the type of climate finance debt security, the "assurance" level, and the standards with which each security is aligned.

The availability of all these attributes in the s-b-s database is usually achieved via a combination of direct reporting, input provision by commercial data providers, and reliance on additional data sources such as government agencies, stock exchanges, or internal sources.

Identification of relevant securities

In a second step, compilers need to define the filter conditions that are required for the identification of individual securities that should be part of the aggregates for a given reference date. This involves filtering for the relevant types of securities, for those securities that are in the relevant status (e.g., "alive" in the case of aggregates on outstanding stocks) or that experience the relevant event (e.g., an issuance or redemption in the case of aggregates on transactions), and for securities that are out of scope and should be excluded from the aggregates for specific reasons (e.g., to avoid duplications such as in the case of depository receipts).

For example, to identify the securities that should be included in the outstanding stocks of debt securities at a specific reference date the following attributes and filters are required:

- SNA instrument classification = F.3 (i.e., debt securities)
- Reference date >= issue date
- Reference date < maturity date
- Security status = alive (i.e., not early redeemed, converted, etc.)
- Instrument flags (for excluding instruments out of scope or instruments creating duplications) = blank

Compared with this simple example for outstanding stocks, the identification and filtering are much more challenging when identifying the securities that should be part of aggregates on transactions such as gross issuances (including full issuances, tap issuances, intra-month issuances, and accrual of interest) and redemptions (including full redemptions, partial redemptions, intra-month redemptions, and paid coupon), revaluations, or other changes in volume.

Calculation of statistics at individual security level

In a third step, compilers need to define the rules for calculating the outstanding stocks, gross issuances, redemptions, revaluations and other changes in volume at the level of individual securities. To ensure that the aggregates that result from these calculations are harmonised and comparable across economies, the calculation rules applied should follow to the extent possible the methodological principles defined in the SNA and the Handbook on Securities Statistics (HSS).[4]

For example, outstanding stocks of debt securities at nominal value can be calculated at individual security level by using the following simplified formula (based on HSS 5.51):

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[4] The HSS provides a methodological framework for the compilation of securities statistics, but does not provide a detailed compilation guide.

Stocks at nominal value = *Stock face value x issue price +*

stock face value x next coupon rate x coupon accrual period +

stock face value x discount rate x discount accrual period

These calculation rules for stocks of debt securities would in many cases require further refinements, e.g., when calculating accruals in a continuous manner, for securities denominated in foreign currency, for securities issued in tranches, or for hybrid debt securities quoted in currency units, and would be more complex when calculating other quantities such as transactions or revaluations.

Aggregation by relevant breakdown categories

In a fourth step, compilers need to define the breakdowns used for the aggregation of outstanding stocks, gross issuances, redemptions, revaluations and other changes in volume calculated at individual security level. For example, breakdowns for the regular publication of aggregates on debt securities issues could involve slicing the aggregates down by SNA issuer sector, currency of denomination, original/residual maturity, and interest rate type.[5] For each of these categories, compilers can then aggregate up the statistical quantities calculated at individual security level to compile the final output aggregates.

As described in greater detail in section 3, the compilation of climate finance statistics will require further breakdowns, e.g., by type of climate finance debt security, by assurance level, or by standard.[6] Moreover, by combining the statistical quantities calculated at individual security level with additional breakdown attributes, compilers and users can flexibly create on-demand aggregations that are not part of the “standard” breakdown categories.

3. Compiling climate finance statistics from s-b-s data for debt securities

The four steps described in the previous section also apply to the compilation of climate finance aggregates on securities issuances and holdings using s-b-s information. For the compilation of further breakdowns for climate finance debt securities, additional requirements need to be applied for the first and fourth steps, i.e., “*availability of required s-b-s data attributes” and “aggregation by relevant breakdown categories”*.[7] Climate finance debt securities can be broken down into at least three dimensions. First, to distinguish the different types of climate finance debt securities, the classification by type of climate finance debt instruments is required as a minimum. The broader climate finance debt securities market consists of instruments which fully or partially aim at funding projects contributing to environmental objectives and thus support the transition to a sustainable, net-zero economy. It is thus composed of three main types of instruments: green, sustainability, and sustainability-linked bonds. Green bonds are negotiable debt instruments where the proceeds are used to finance green projects; sustainability bonds are negotiable debt instruments where the proceeds are used to finance a combination of both green and social projects; and sustainability-linked bonds are negotiable debt instruments where the issuers are committed to future improvements in sustainability outcome(s) within a

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[5] These attributes would allow creating the breakdowns applied in the reporting templates of DGI-2 Recommendation 7 on Securities Statistics.

[6] These attributes would allow creating the breakdowns applied ink the reporting templates of DGI-3 Recommendation 4 on Climate Finance.

[7] No additional modifications are needed for steps 2 and 3.

predefined timeline, but with no restrictions on how the proceeds may be used. For this type of bonds, the financial and/or structural characteristics such as coupon rates may vary, depending on whether the issuers achieve the predefined sustainability objectives.[8] Second, in order to better understand the reliability of the classification of the different climate finance products and whether the issuer's bond framework is aligned to accepted market principles and the use of proceeds are aligned to market practises, information about the type of climate finance debt security can be complemented with its "assurance" level. Climate finance debt securities can be self-labelled as such by their issuer, or, in addition, they can be externally reviewed with a (pre-issuance) second party opinion (SPO) or can even be certified by an independent and recognised authority. Third, due to the lack of a common, internationally accepted, definition of the types of climate finance debt securities, it is equally important to know to which standard(s) the bonds are aligned with. These standards include, e.g., the CBI Climate Bonds Standards, ICMA Green, Social, Sustainability-linked Bond Principles, ICMA Sustainability Bond Guidelines, or European Union Green Bond Standard.

These additional attributes that describe the classification of the type of climate finance debt security (minimum requirement), the "assurance" level, and the standard(s) with which each climate finance debt security is aligned need to be available in the compilers' s-b-s databases. For climate finance statistics, aggregates by type of climate finance debt security (i.e., green, sustainability and sustainability-linked) are considered fundamental and as such are recommended to be part of the regular publications. Further, "of which" breakdowns by assurance level (e.g., self-labelled, with a second party opinion, or certified) and by standard can be compiled. This helps ensuring the reliability and transparency of the compiled data as well as serve users' needs for assessing the credibility of the claims of the issuers. The aggregates on climate finance debt securities issuances (as any other securities aggregates) can be further broken down for example by SNA issuer sector, currency of denomination, original/residual maturity, and interest rate type, while the aggregates on debt securities holdings can be broken down by similar dimensions as well as by holder sector and issuer residence. Applying these breakdowns for issuances and holdings of climate finance debt securities will allow the compilation of all breakdowns required in the reporting templates of G20 DGI-3 Recommendation 4 on Climate Finance. At the same time, limitations in the compilation of climate finance statistics for debt securities arise from a lack of internationally accepted and harmonised definitions of certain key concepts, such as what qualifies as "green", and the still relatively small size of the market that may not allow the publication of specific breakdowns (e.g., due to statistical confidentiality), particularly for the climate finance aggregates on holdings of debt securities.

4. Results for the euro area climate finance debt securities market

Building on the general compilation framework outlined in the previous two sections, this section illustrates the usefulness of this framework for compiling statistics on climate finance debt securities issuances and holdings for the euro area by using s-b-s data from the European System of Central Bank‘s (ESCB‘s) Centralised Securities Database (CSDB) and Securities Holdings Statistics Database (SHSDB) (see Cornejo Pérez and Huerga 2015; Amann et al. 2015). To do so, we will use the sustainable finance indicators developed by the ESCB in the context of the ECB Governing Council's action plan on climate change (ESCB Statistics

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[8] The market of environmental, social and governance (ESG) securities also covers social debt securities, which are negotiable debt securities instruments where the proceeds are used to finance social projects. These securities are not in the scope of this paper due to its focus on climate finance statistics. However, the framework described in sections 2 and 3 of this paper is also fully applicable to compiling statistics on social debt securities (see, e.g., ESCB Statistics Committee Expert Group on Climate Change and Statistics and Working Group on Securities Statistics 2024).

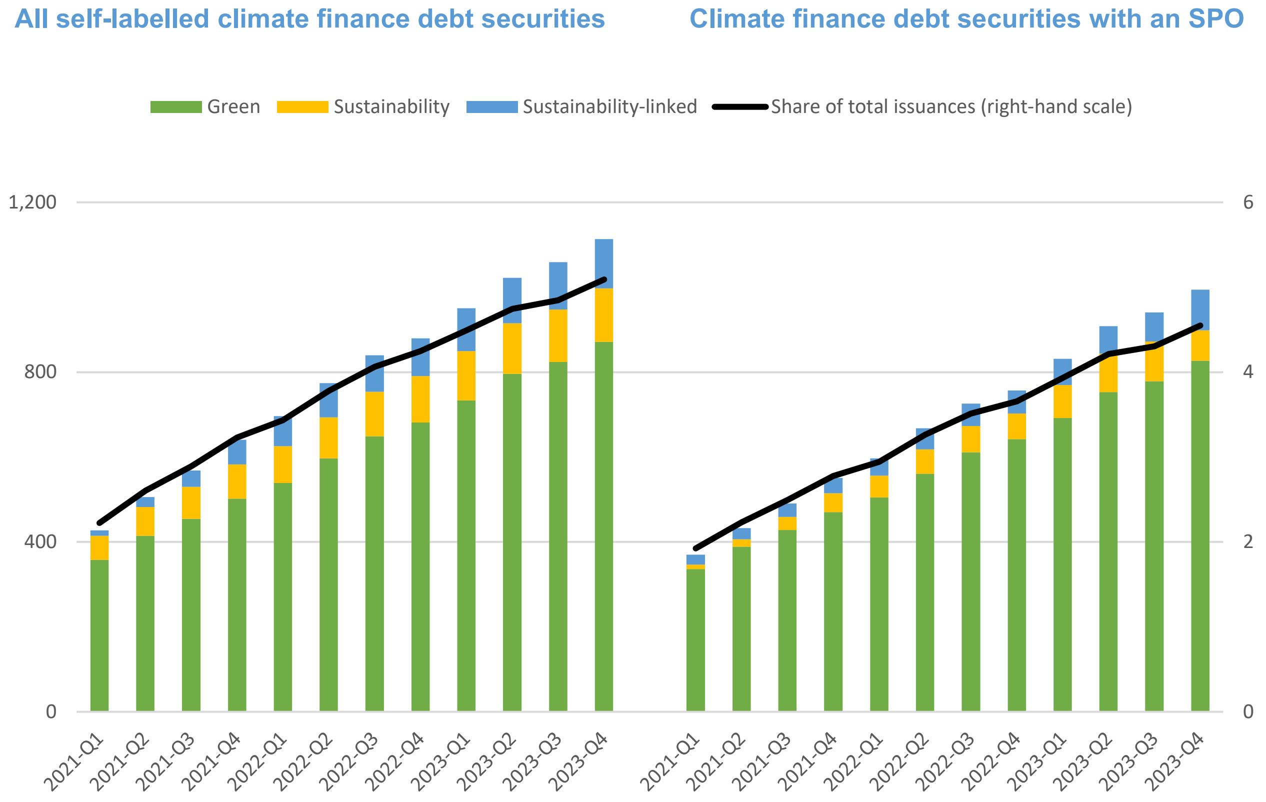
Committee Expert Group on Climate Change and Statistics and Working Group on Securities Statistics 2024). These indicators provide insights into the issuance and holding of climate finance debt instruments (green, sustainability, and sustainability-linked) by residents in the euro area. Aggregates are made available for two levels of assurance. For the "broader" assurance level, all climate finance debt securities, irrespective of the level of assurance, also including those that are only self-labelled, are considered. For the "stricter" level of assurance, the universe of climate finance debt securities is limited to those instruments that have been externally reviewed with a second party opinion or certified. No restriction is yet applied based on the underlying standard/framework against which the classification of the climate finance debt security is aligned with (although this information is available at s-b-s level).

Issuances of climate finance debt securities in the euro area

The outstanding amount of the climate finance debt securities issued in the euro area has almost tripled in the last three years, reaching more than EUR 1.1 trillion (Chart 1). Green debt securities account for the majority, representing close to 80% of the outstanding amount of all climate finance debt securities issued at the end of 2023.

Over the last three years, green bonds have recorded a particularly strong increase reaching outstanding amounts of almost EUR 900 billion in Q4 2023. Sustainability-linked bonds recorded the highest growth rate over the same period. Despite the constant increase, climate finance debt securities still account for a relatively small part of the wider debt securities market, representing 5% of total issuances in Q4 2023.

Chart 1
Euro area issuances of climate finance debt securities



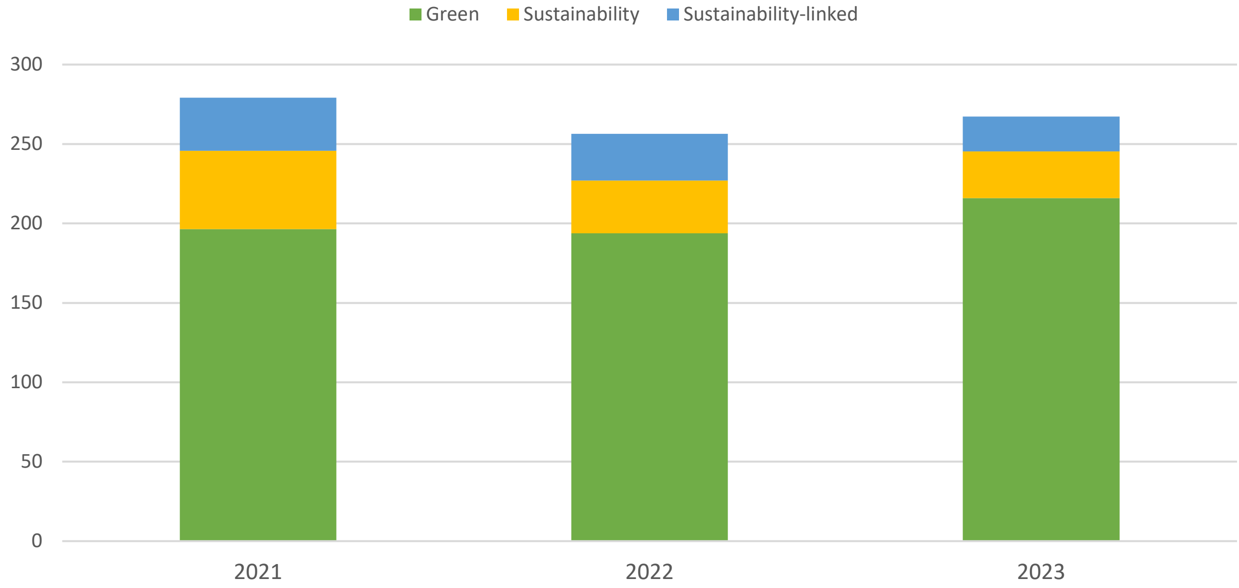
All self-labelled climate finance debt securities

Climate finance debt securities with an SPO

Left-hand scale: EUR billions, outstanding amounts at face value; right-hand scale: percentages.
Notes: The share of total issuances refers to the amount of all climate finance debt securities as a share of all debt securities issued in the euro area (left graph) and to the amount of the climate finance debt securities with a second party opinion as a share of all debt securities issued in the euro area (right graph).

New issuance of climate finance debt securities in the euro area dropped on a year-on-year basis in 2022 (Chart 2), with green debt securities materialising only a marginal decrease (of 1%). Although the newly issued sustainability and sustainability-linked debt securities further declined in 2023, the total new issuances of all climate finance debt securities in the euro area increased, as a result of the high amount of newly issued green bonds that outperformed even the 2021 green bond issuances.

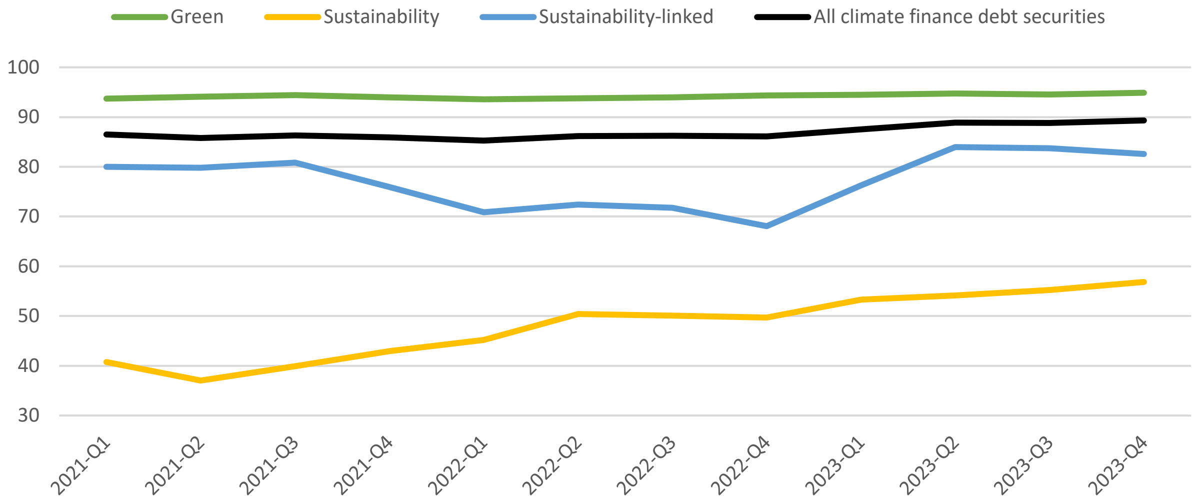
Chart 2
Issuances of climate finance debt securities



Left-hand scale: EUR billions, outstanding amounts at face value.

Overall, euro area issuers of climate finance debt securities deem to seek for external review of their issuances, with around 90% of them having obtained at least a SPO at the end of 2023 (Chart 3). This way issuers provide investors with further assurance of meeting certain international standards and alignment with accepted market principles. When focusing on each specific type of climate finance bonds, we observe that most green debt securities issued in the euro area have obtained a second party opinion (95%). Similarly, more than 80% of the sustainability-linked debt securities have been reviewed by an external provider (SPO), while sustainability bonds have significantly lower SPO assurance levels (only slightly above 55%).

Chart 3
Share of euro area issuances of climate finance debt securities with a second party opinion

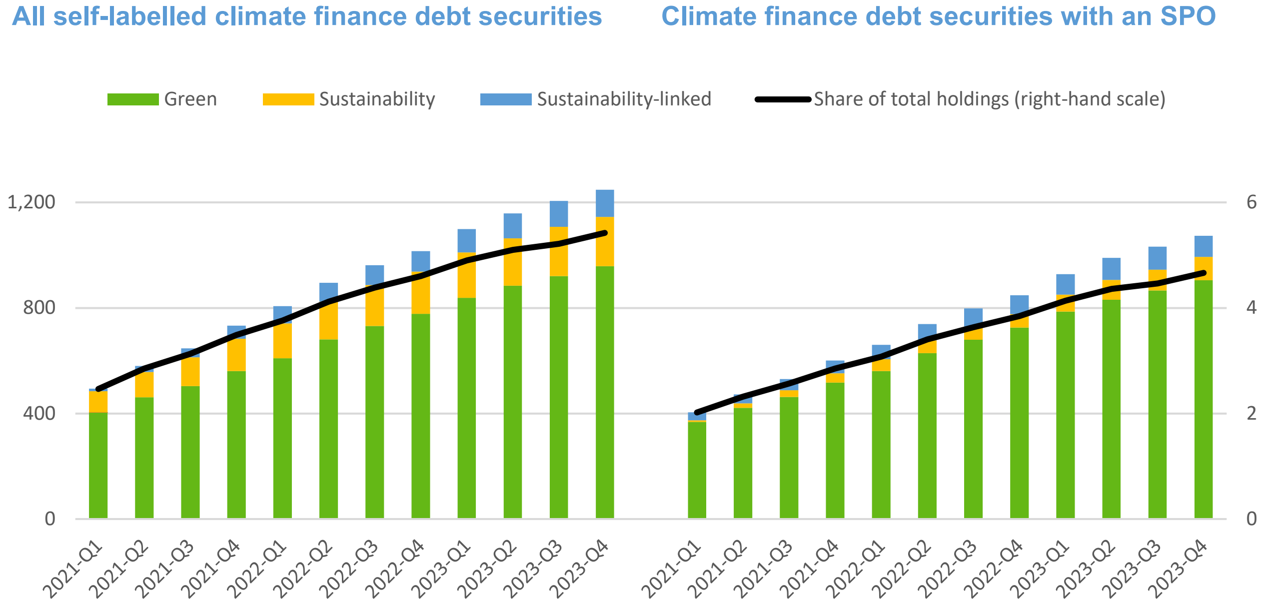


Left-hand scale: percentages.
Notes: The share of issuances with a second party opinion refers to the climate finance debt securities with a second party opinion as a share of all climate finance debt securities issued in the euro area.

Holdings of climate finance debt securities in the euro area

Euro area holdings of climate finance debt securities have grown continuously since the beginning of 2021, reaching almost EUR 1.3 trillion. Thus, euro area holdings of climate finance debt securities exceed the issuances, making the euro area a net buyer of these instruments. While these debt securities are becoming increasingly relevant investment alternatives (they more than doubled in the last three years), they are still a relatively minor portfolio item, accounting for 5.4% of total euro area debt securities holdings in Q4 2023 (Chart 4).

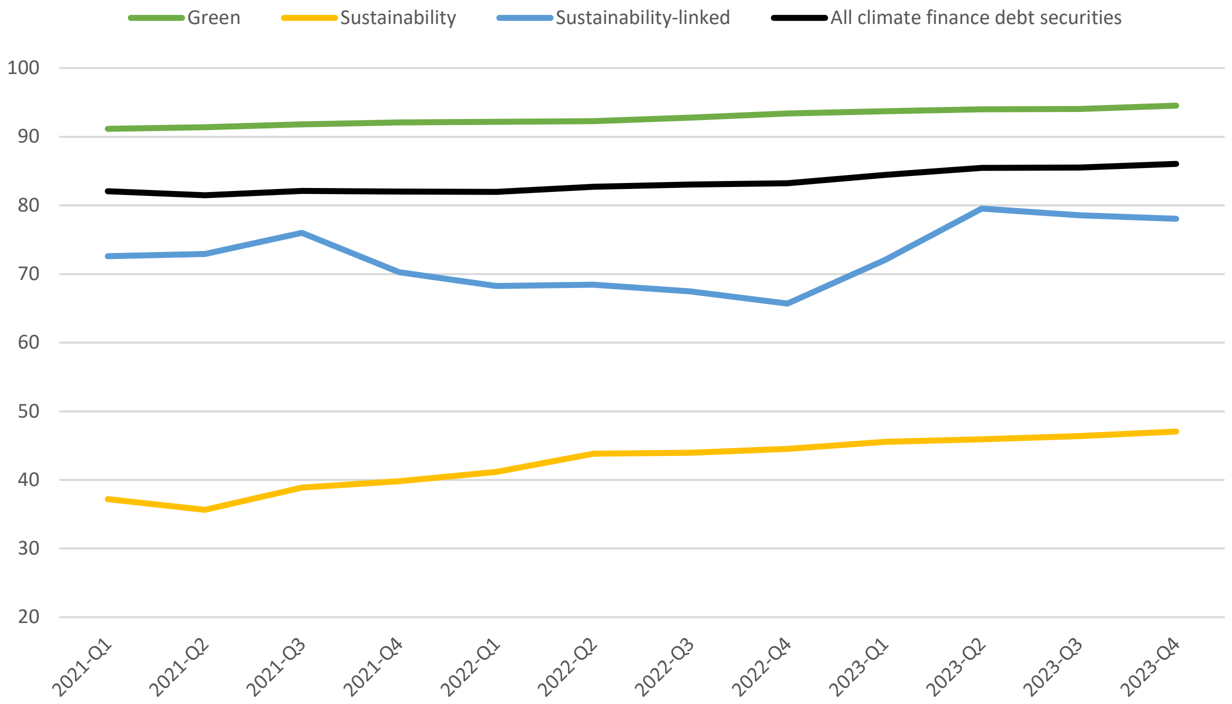
Chart 4
Euro area holdings of climate finance debt securities



Left-hand scale: EUR billions, outstanding amounts at face value; right-hand scale: percentages.
Notes: The share of total holdings refers to the amount of all climate finance debt securities as a share of all debt securities held in the euro area (left graph) and to the amount of the climate finance debt securities with a second party opinion as a share of all debt securities held in the euro area (right graph).

Most (86%) euro area holdings of climate finance debt securities have obtained a second party opinion (Chart 5). When focusing on the different types of securities, we can observe that holdings of sustainability bonds with a second party opinion are significantly lower (below 50%) than holdings of green and sustainability-linked bonds with a second-party opinion. This is because euro area investors buy a large proportion of sustainability bonds issued by non-EU residents, which have not obtained a second party opinion. On the contrary, euro area investors invest mainly in domestically issued green and sustainability-linked bonds that have been externally reviewed.

Chart 5
Share of euro area holdings of climate finance debt securities with a second party opinion



Left-hand scale: percentages. Notes: The share of holdings with a second party opinion refers to the climate finance debt securities with a second party opinion as a share of all climate finance debt securities held in the euro area.

5. Compiling climate finance statistics from s-b-s data for listed shares

As in the case of climate finance debt securities, the general framework described in section 2 can also be fruitfully applied to compiling aggregates for green listed shares based on s-b-s data. In this case, steps 2 and 4, i.e., "*availability of required s-b-s data attributes" and "aggregation by relevant breakdown categories"* require an additional attribute for the identification of green listed shares, which could then be used to break down listed shares into green and non-green shares.

Identifying green shares poses additional difficulties compared to debt securities. Most importantly, while for debt securities the financing of climate finance objectives is quite immediate when the "use of proceeds" principle is used, for green equity securities this link is less clear if at all meaningful, as the shares that are considered green nowadays may have been non-green at the time the capital was raised. Thus, strictly speaking only new issuances of shares of already green corporations in the primary market can be considered as funds contributing to climate finance. This caveat should be considered when applying the approach described in the following paragraphs, which de facto measures the volume of investment opportunities on green shares available in the secondary market.

Moreover, in contrast to debt securities, where the criteria for identifying green, sustainability and sustainability-linked bonds are nowadays well established in the financial markets, there are currently no generally accepted criteria for identifying green shares. Recently however, some stock exchanges developed specific methodologies, largely based on the green equity principles developed by the World Federation of Exchanges (WFE) (see World Federation of Exchanges 2023). As a minimum, for issuers that generate revenue, the WFE proposes that “listed issuers will need to generate more than 50% of their total annual revenues from activities that contribute to the green economy”. Additional criteria on governance, assessment, and disclosure are also brought forward. For example, the London Stock Exchange (LSE) and NASDAQ are respectively offering a “green mark” (London Stock Exchange 2023) or “green designation” (NASDAQ 2023) to issuers who satisfy certain criteria. Both stock exchanges require that 50% of the issuer’s revenue is generated by activities considered green (according to an approved external reviewer). Additionally, NASDAQ requires that less than 50% of revenue is generated by fossil fuel activities, and that more than 50% of the issuer’s investments is allocated to activities considered green.

The simple “50% of green revenues” criterion applied by the WEF and several of its member exchanges seems well suited for identifying green listed shares in the context of compiling statistical aggregates on green shares, as it provides a relatively easy-to-operationalise criterion for determining whether most economic activities of an issuer of listed shares can currently be considered as green.[9] Several other criteria for measuring the climate performance of issuers have been considered in other contexts such as monetary policy implementation (see, e.g., Aubrechtová et al. 2023), which however are not well suited for applying them in the statistical compilation context. For example, assessing the climate performance of companies based on improvements compared to past data (backward-looking metrics) might overestimate the greenness of a brown company just because it can reduce emissions very easily. On the other hand, relying on future emission targets (forward-looking metrics) could penalize companies in an already green sector. Similarly, relying on best-in-class approaches compared to other companies in the same sector might be biased by the fact that some sectors are naturally browner than others. Finally, criteria based on qualitative assessments cannot easily be applied to a large number of issuers as it is typically required for the automated compilation of aggregates based on s-b-s data. As a consequence, the simple “50% of green revenues” criterion seems conceptually to be the most suitable and at the same time easy-to-operationalise indicator for compiling statistics on green listed shares.[10]

Applying the breakdown into green and non-green listed shares, aggregates on listed shares issuances can be further broken down by SNA issuer sector and currency of denomination, while aggregates on listed shares holdings can be broken down by similar dimensions as well as by holder sector and issuer residence. Applying

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[9] Due to the fungible nature of funds raised via equity financing, a use of proceeds approach as used for climate finance debt securities cannot be meaningfully applied for green shares.

[10] Future work should explore further refining this simple indicator by making it more robust to possible greenwashing, e.g., by complementing it with a threshold for the share of revenues from brown (i.e., fossil fuel) activities, as for example done for the Nasdaq Green Equity Designation.

these breakdowns for issuances and holdings will allow the compilation of all breakdowns required in the reporting templates of DGI-3 Recommendation 4 on Climate Finance.

6. Results for the euro area green listed shares market

As an example of the general framework described in sections 2 and 5, we propose a simple approach for compiling experimental aggregates on issuances and holdings of green listed shares. Following the recommendations by the World Federation of Exchanges, we employ an identification method based on revenues, identifying as green shares those issued by issuers whose revenue share coming from activities aligned to the EU Taxonomy[11] is greater than 50%. To this aim, we use data sets from Institutional Shareholder Services (ISS) and Carbon4Finance (C4F)[12] and consider as green those shares that are green according to either ISS or C4F. To allow for the compilation of time series data, for each issuer, we select the latest data on green revenues from both data sets, and backpropagate the “green flag” to past periods. It should be noted that, given the natural delay with which climate data become available, the data should be considered provisional and is likely to be subject to revisions in the future. For the calculation step, for issuances, using the CSDB, we calculate the market capitalisation by multiplying the number of outstanding shares by the closing market price at the end of the reference period. For holdings, we calculate the holdings at market value using the SHSS database. Finally, we aggregate the indicators at euro area level.

At end-2023, we identify 62 green listed shares issued in the euro area, accounting for a market capitalisation of 308 EUR billion (Chart 6). This is about 3.1% of the total market capitalisation of euro area issuers for the same period (which is 9,967 EUR billion according to CSEC). As for holdings, the market value of green listed shares (as issued by the whole world) in the euro area investors’ portfolio amounts to 297 EUR billion as of end Q4 2023, issued by 125 companies. This accounts for about 2.9% of the total market value of listed shares in their portfolio (which is 10,096 EUR billion according to SHSS).

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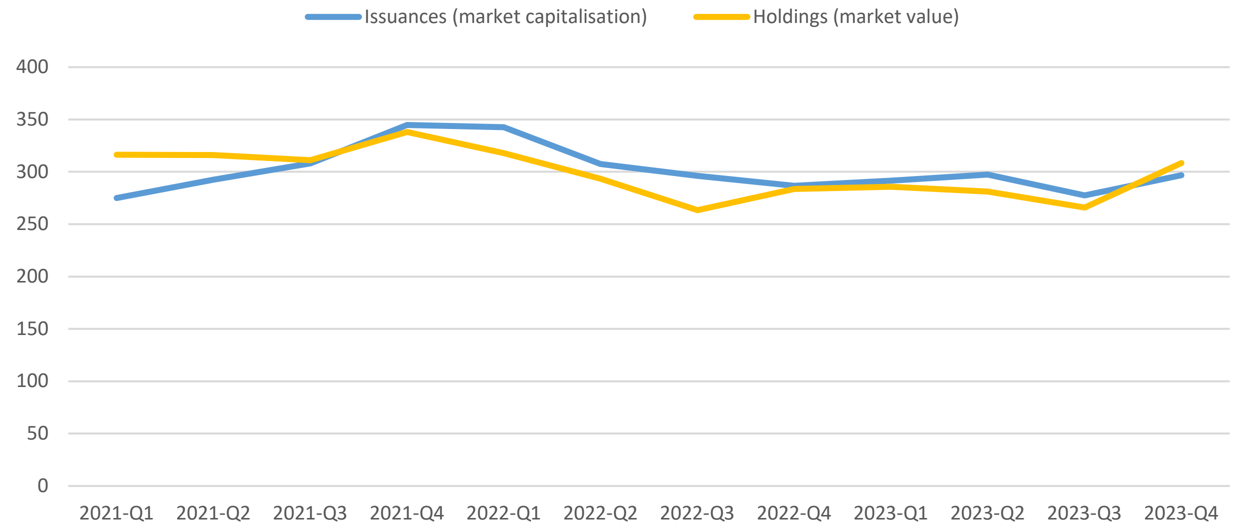
[11] See the EU Taxonomy Regulation of 18 June 2020 available at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32020R0852.

[12] ISS: https://www.issgovernance.com, C4F: https://www.carbon4finance.com. Other climate data sources available in the field include S&P Shades of Green: https://www.spglobal.com/ratings/en/products-benefits/products/second-party-opinions, and FTSE Russell Green Revenues Classification System: https://www.lseg.com/content/dam/ftse-russell/en_us/documents/policy-documents/ftse-green-revenues-classification-system.pdf.

Chart 6
Issuances and holdings of green listed shares by euro area issuers and investors

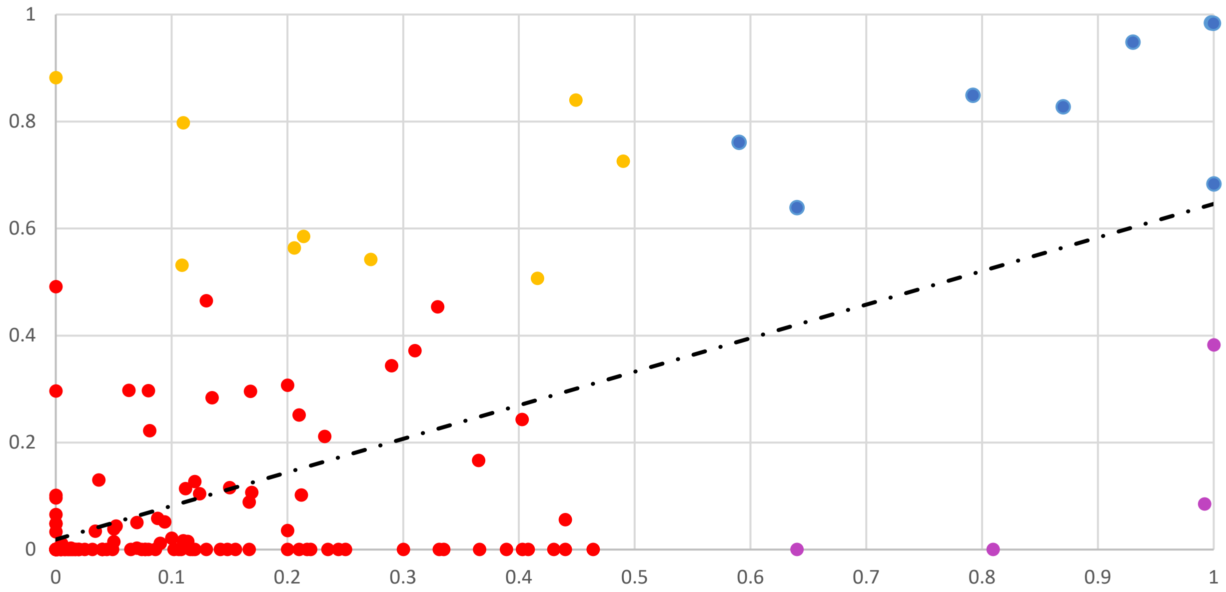


Left-hand scale: EUR billion. For the holdings series, all green shares are considered, including those not issued in the euro area.

It should be noted that, in the above examples, we considered as green all listed shares which are green according to either ISS or C4F. However, the two datasets exhibit some relevant differences, as illustrated in Chart 7. For example, at end-2023, ISS identifies 52 green listed shares, accounting for a total market capitalisation of 143 EUR billion, while C4F identifies 18, with a total market capitalisation of 217 EUR billion. For holdings, considering only ISS, we obtain a total market value of 106 EUR billion, while C4F gives 238 EUR billion. The below scatterplot (Chart 7) shows a positive correlation between the share of green revenues according to the two datasets. These discrepancies caution against the use of only one single data source on green revenues and highlight the need for further analysis of the methodologies and data collection approaches applied by different commercial providers of green revenue information.

Chart 7

Comparison of the share of green revenues in ISS and C4F data sets



X axis: share of green revenues over total (ISS); Y axis: share of green revenues over total (C4F). The trendline is depicted in black.

The colours represent shares which are green according to both ISS and C4F (blue), ISS only (yellow), C4F only (pink), or neither (red). Only issuers which are present in both datasets are plotted. The Pearson correlation coefficient is 0.62.

7. Conclusions

This paper presents a general framework for compiling harmonised statistics on issuances and holdings of climate finance debt securities and explores a new approach for measuring the volume of issuances and holdings of green equity securities. In doing so, it directly contributes to the work of the G20 DGI on developing harmonised indicators for measuring climate finance in the G20/FSB member economies by providing a framework for compiling the statistics on climate finance debt securities and supporting the work on defining a framework for compiling the statistics on green listed shares that are disseminated in the context of G20 DGI Recommendation 4 on Climate Finance (Working Group on Securities Databases 2023).

In applying this compilation framework to the euro area, the paper shows that climate finance debt securities present a rapidly growing market segment in the euro area debt securities market, with outstanding amounts and holdings of climate finance debt securities having almost tripled to EUR 1.2 trillion over the last three years. At the same time, the results underscore the key importance of external assurance in the euro area climate finance debt securities market, as highlighted by the high share of close to 90% of climate finance debt securities issued and held in the euro area that have at least a second-party opinion from an external reviewer. In contrast to climate finance debt securities, the euro area market for green listed shares is still in a more infant stage with official designations of green shares still not in place in the major euro area stock exchanges. However, the results based on the general framework presented in this paper show that – applying a classification approach modelled on the one of the WFE principles and of major non-euro area exchanges – a small market for green listed shares already exists that is likely to grow in the future when official labels and designations of green shares become more widely available.

While the compilation framework for climate finance debt securities presented in this paper can be readily applied for the compilation of globally harmonised and comparable aggregates on climate finance debt securities, the compilation process for harmonised aggregates on listed shares would benefit from additional data sources and from a robust data quality framework, to deal with inconsistencies such as those evidenced by comparing the ISS and C4F data sets. Based on this, future research should further benchmark these different data sources and carefully assess the underlying differences in methodologies and data collection approaches that are causing relevant differences. In this regard, the future introduction of green share designation in other major stock exchanges as well as the application of the EU Corporate Sustainability Reporting Directive (CSRD) will hopefully strengthen the availability of data on green shares in the future, allowing for more consistent and reliable aggregates. In addition, future work on measuring the volume of climate via green shares should also shift its focus to specifically measuring the new funds raised via initial public offerings and capital increases of already green corporations to quantify the actual contribution of new green shares to overall climate finance, and explore further refining the indicator presented in this paper by making it more robust to possible greenwashing (e.g., by complementing it with a threshold for the share of revenues from brown activities). Finally, considering the framework suggested in this paper, future methodological work – e.g., in the in the context of DGI Recommendation 4 and currently ongoing updates of the System of National Accounts and Balance of Payments Manuals – should provide more specific guidance on the measurement and compilation rules for climate finance statistics on both debt securities and shares to promote a harmonised basis for further research on the volume, determinants and effects of climate finance.

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Compiling climate finance statistics from s-b-s data

CBRT-IFC Workshop on "Addressing Climate Change Data Needs: The Global Debate and Central Banks' Contribution"

Izmir, Türkiye
6-7 May 2024

Flavio Fusero, Johannes Kleibl, Dimitra Theleriti
European Central Bank

Overview

Introduction

Introduction

- Climate finance securities are one of the fastest-growing segments in global securities market
  - ► Compilers of securities statistics have started trying to track the volume of climate finance to support policymakers' understanding of funds available for financing the green transition ...
  - ► ... but so far no standardised methodology for compiling climate finance statistics from s-b-s data

- Our paper aims at addressing this gap and makes three contributions:
  1) Provides practical guidance on key steps for producing harmonised statistics on climate finance debt securities based on s-b-s data
  2) Explores possible methodology for measuring the volume of green shares
  3) Directly contributes to work on G20 DGI Rec. 4 on Climate Finance

- We use s-b-s data for the euro area to showcase the usefulness of the indicators for debt securities and the applicability of the proposed concepts for shares

Compilation using s-b-s databases

Compilation using s-b-s databases

- Compiling securities statistics based on s-b-s data generally requires four steps:
  1) Availability of required s-b-s data attributes → Ensure that attributes are required for identification, calculation and aggregation are available in the s-b-s database
  2) Identification of relevant securities → Filter for individual securities that need to be part of the aggregates for a given reference date

     Example: *Instrument classification == F.3 & reference date >= issue date & reference date < maturity date & security status == alive & instrument flags == ""*
  3) Calculation of statistics at individual security level → Calculate statistical quantities (e.g., outstanding stocks, gross issuances, redemptions, revaluations, and other changes) at the level of individual securities

     Example: *Stocks at nominal value = Stock face value x issue price + stock face value x next coupon rate x coupon accrual period + stock face value x discount rate x discount accrual period*
  4) Aggregation by relevant breakdown categories → Apply breakdowns for which aggregates should be compiled based on the statistical quantities calculated at the level of individual securities

► Generic approach can be easily applied to compilation of climate finance statistics from s-b-s data by integrating climate finance breakdowns in steps 1 and 4

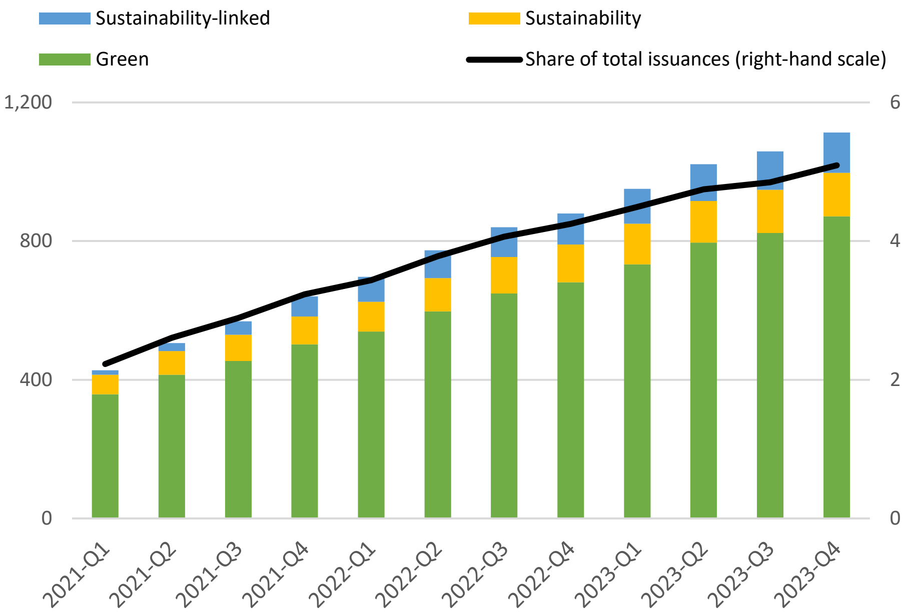
Compiling climate finance statistics from s-b-s data: debt securities

Compiling climate finance statistics from s-b-s: debt securities

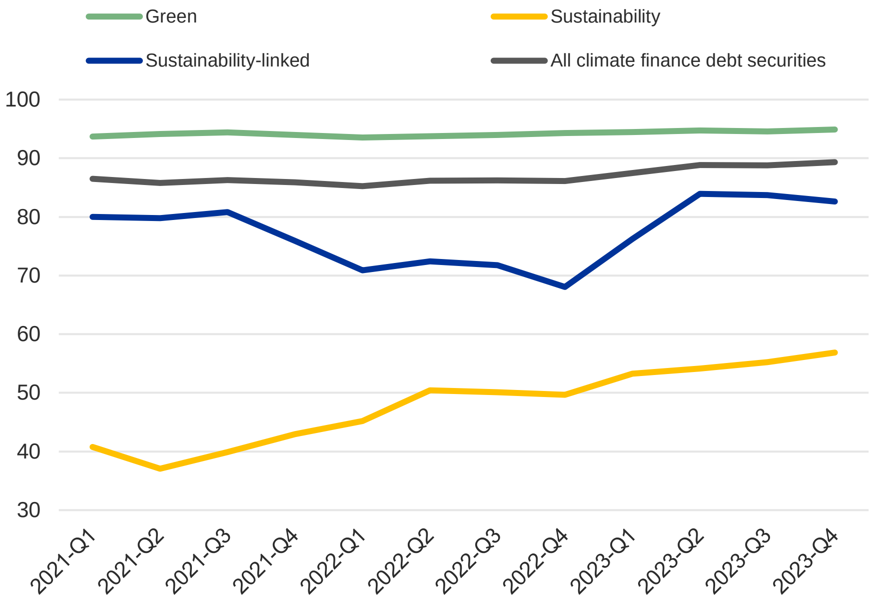
- Compilation of climate finance statistics from s-b-s for debt securities:
  - Additional requirements for steps 1 and 4 of the generic compilation approach:
  - *1) Availability of required s-b-s data attributes*
    - Classification of climate finance debt securities: green, sustainability, and sustainability-linked ⇦ Minimum
    - "Assurance" level: self-labelled, with (pre-issuance) SPO, certified
    - Standards: e.g. CBI Climate Bonds Standards, ICMA Green / Sustainability-linked Bond Principles, European Union Green Bond Standard
  - *2) Aggregation by relevant breakdown categories*
    - Aggregates by type of climate finance debt securities ⇦ Basic
    - Further "of which" breakdowns by assurance level and by standard
    - Further breakdowns by e.g. issuer (or holder) sector, maturity, etc.

} Suitable for G20 DGI-3 Rec. 4 on Climate Finance

Results for EA climate finance debt securities market

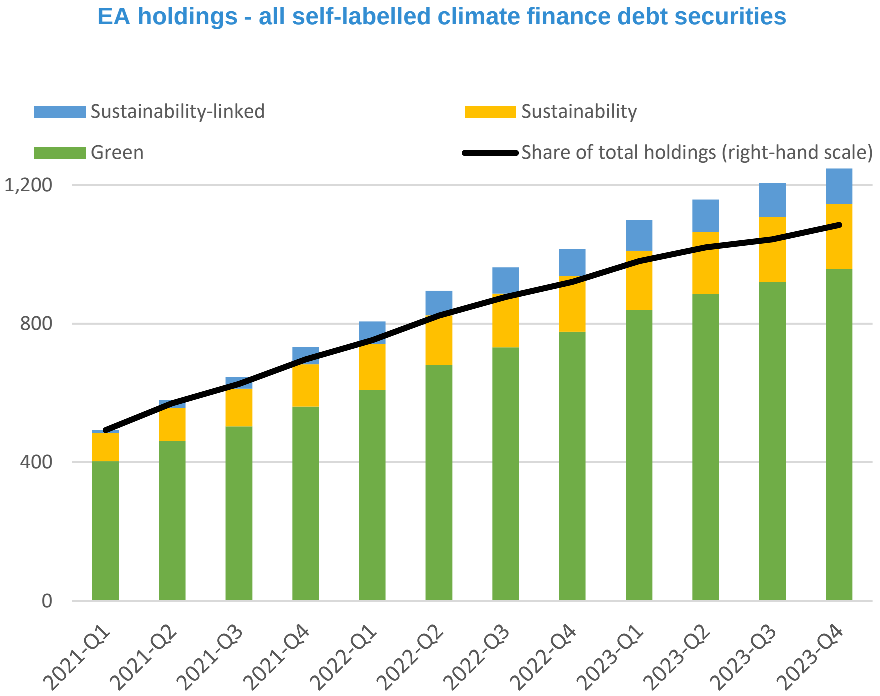

EA issuances - all self-labelled climate finance debt securities

Left-hand scale: EUR billions, outstanding amounts at face value; right-hand scale: percentages.

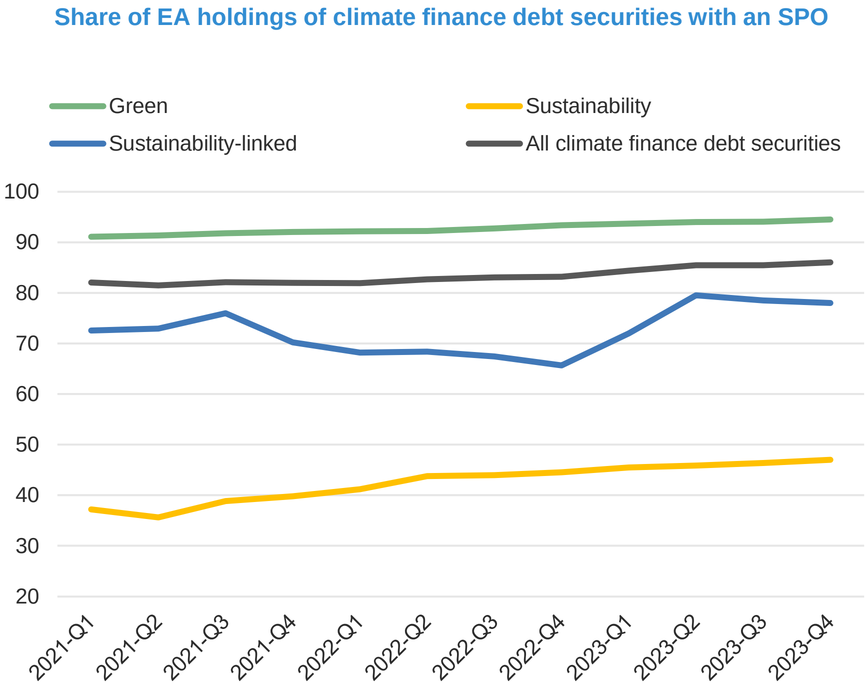

Share of EA issuances of climate finance debt securities with an SPO

Left-hand scale: percentages.

Results for EA climate finance debt securities market



Left-hand scale: EUR billions, outstanding amounts at face value; right-hand scale: percentages.



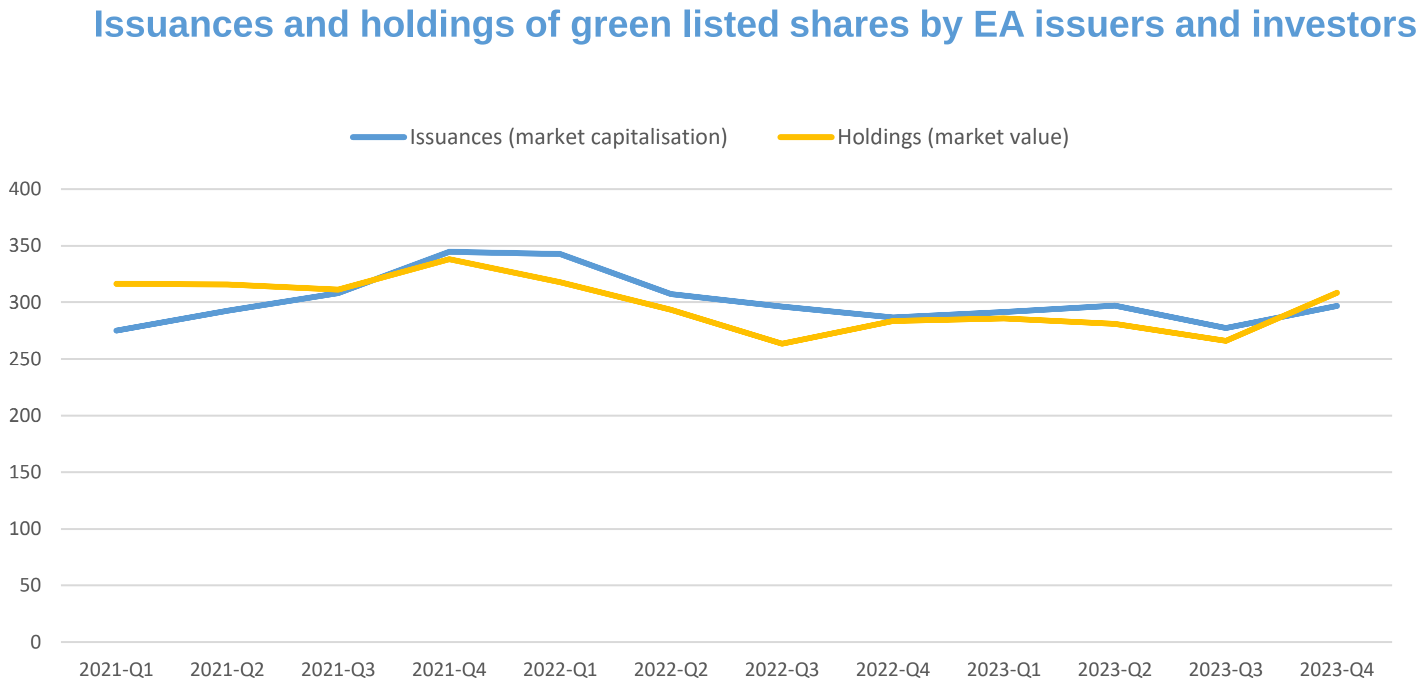
Left-hand scale: percentages.

Compiling climate finance statistics from s-b-s data: listed shares

Compiling climate finance statistics from s-b-s: listed shares

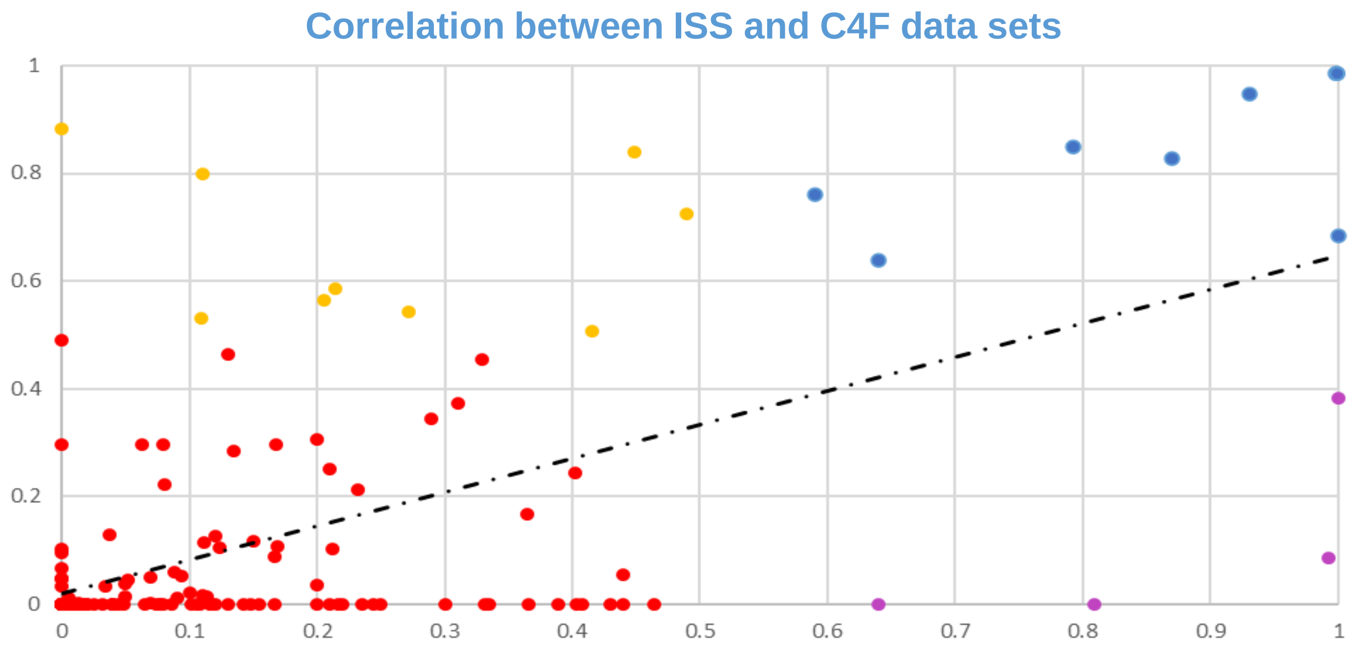
- Identifying green listed shares poses additional problem compared to debt securities (no “use of proceed” approach possible)
- World Federation of Exchanges (WFE) developed “green equity principles”:
  - as a minimum: 50% of annual revenues should be from activities that contribute to the green economy
- Some stock exchanges (London Stock Exchange, NASDAQ) developed their own “green designations”, largely based on WFE principles
- The “50% of green revenues” criterion is simple and easy to operationalise, while other approaches have their own shortcomings (best-in-class approach, comparisons against back data or future emission targets, qualitative assessments)
- Generic compilation approach described above can be also easily applied to green shares
- Applying this approach, we propose results based on ISS and C4F datasets and backpropagate “green flags” to build historical time series

Results for EA green listed shares market



Left-hand scale: EUR billions. For the holdings series, all green shares are considered, including those not issued in the euro area.

Results for EA green listed shares market



X axis: share of green revenues over total (ISS); Y axis: share of green revenues over total (C4F). The trendline is depicted in black.

The colours represent shares which are green according to both ISS and C4F (blue), ISS only (yellow), C4F only (pink), or neither (red). Only issuers which are present in both datasets are plotted. The Pearson correlation coefficient is 0.62.

Conclusions

Conclusion

Summary

1) Paper provides general framework for compiling harmonised statistics on issuances and holdings of climate finance debt securities and ...
2) ... explores a new approach for measuring the volume of issuances and holdings of green equity securities

► Direct contribution to DGI Rec. 4 work on developing harmonised framework for compiling climate finance statistics

- Directions for future work/research on compiling climate finance statistics:
  - ► Use of additional data sources on green revenues to benchmark data quality and assessment of underlying differences in methodologies and data collection approaches
  - ► Measuring new funds raised via IPOs and capital increases to quantify actual contribution of new green shares to overall climate finance
  - ► Future methodological work (e.g., in context of Rec. 4 and SNA/BPM updates) needed to provide concrete measurement compilation guidance for climate finance statistics

IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

Measuring foreign direct investment carbon footprint: an experiment with micro data[1]

V Genre, A Magniez, D Nefzi and F Robin,
Banque of France

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

Measuring FDI carbon footprint: an experiment with micro data

Véronique Genre, Alice Magniez, David Nefzi and François Robin[1]

Abstract

In response to the G20's Data Gaps Initiative (DGI-3), this paper develops a novel methodology for measuring the carbon footprint of Foreign Direct Investment (FDI) using firm-level data. While current approaches rely on macroeconomic data and input-output models, this study conducts a micro-level analysis, using granular emissions data from about 2,500 companies over the period 2016–2022. By focusing on FDI stocks rather than flows, the methodology offers an alternative assessment of greenhouse gas (GHG) emissions linked to both inward and outward FDI in France. Emissions data from listed companies is extrapolated to their foreign affiliates thanks to an allocation model based on firms' assets and sectoral environmental efficiency.

The findings reveal significant variations in the carbon footprint of French multinationals abroad and foreign-owned enterprises in France, with results strongly influenced by the environmental efficiency of different sectors and countries. The analysis also highlights substantial data gaps, particularly for unlisted firms and FDI in less-developed regions. The use of estimation models and proxies to address missing data illustrates both the potential and the limitations of micro-data approaches. Despite these challenges, the methodology provides a promising complement to existing macro-based methodology and opens new avenues for robustness checks. Future improvements in international data transparency, as well as regulatory initiatives like the European Corporate Sustainability Reporting Directive (CSRD), are expected to enhance the reliability and coverage of this approach.

Keywords: foreign assets, foreign direct investment, carbon emissions, environment, economic impact of globalization

JEL classification: C18, F21, F23, F64, Q51

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[1] The views expressed here are those of the authors and not necessarily that of Banque de France. The authors thank Rocco Incardona and Jorge Diz Dias (ECB); Nadia Accoto, Giacomo Oddo and Daniele Di Pietro (Bank of Italy) for their helpful discussions at the "climate" FDI Network working sub-group; and Timothée Gigout (Banque de France) for paving the way in estimating the French FDI carbon footprint.

1. Introduction

In the aftermath of the Global Financial Crisis, back in 2009, the G20 Finance Ministers and Central Banks Governors first launched the Data Gaps Initiative (DGI) to fill in policy-relevant data gaps, which had prevented the crisis from being foreseen. The successful conclusion of the first initiative led to the launch of two subsequent phases with the objective to ensure methodological development, collection and dissemination of reliable and timely statistics for policymakers. In autumn 2021, the G20 endorsed a new guideline for the third phase of the initiative. DGI-3 included, among others, recommendations in the area of climate change and in particular, on how to measure FDI carbon footprint.

Countries generally welcome and even go to great lengths to attract inward Foreign Direct Investment (FDI). FDI is defined as an investment involving a long-term relationship, which reflects a lasting interest, of a resident entity in one economy (the so called DI, direct investor) in an entity that is resident in another economy (IMF, 2008). The lasting interest is determined when the direct investor acquires a minimum of 10% voting power or capital share of the investee (the direct investment enterprise, DIE). Compared with other forms of capital flows, FDI is less volatile. It has been associated with rising wages (Gopinath and Chen, 2003) and improved productivity, with technological know-how and skills' spillovers to the domestic economy (Sugiharti *et al*., 2022), with introduction of new industries and exports diversification (Tadesse and Shukralla, 2013), and, eventually and under the right conditions, with increasing domestic growth.

By contrast, the environmental impact of FDI remains unclear. Countries with low income tend to have lower pollution standards and may attract pollution-intensive FDI and see their greenhouse gases (GHG) emissions deteriorate. This is known as the *pollution haven* hypothesis, by which FDI significantly increases carbon emission levels in host economies. At the same time, FDI may deploy new technologies that are cleaner than domestic production and thus, foster improvements in the host economy. This is known as the *pollution halo* hypothesis. Empirical research has also found evidence of FDI accelerating the development and production process of a lower carbon economy thanks to FDI (see Gill *et al.* (2018) for a critical review of available empirical research to date).

One way to avoid having to take a stance on these two hypotheses would be to directly measure the carbon footprint of FDI. Yet this has proven challenging. Borga *et al.* (2022) suggest a methodology that may well set the standard for the coming years. This methodology is mostly based on input-output modelling, a method that has been gaining traction in recent years (Tukker *et al.* 2018, 2020). International input-output tables map all flows of goods and services across industries in different regions of the world from production to final demand. Together with GHG emissions by country and sector, one may solve linear systems to measure footprints of sectors, countries or a combination of both. Because of data availability, the IMF approach can only be applied to inward FDI flows for now.

In this paper, we experiment a method based on granular data using both inward and outward FDI stocks. Our method may be closer to FDI compilers' methods as it focuses on individual firms' data.

Our approach aims to complement the conceptual framework adopted by the IMF (Borga et al., 2022). While the IMF suggests a method to estimate carbon emissions of the share of total domestic production that is due to foreign-owned enterprises, their method relies on a particularly strong assumption. The carbon intensity of production among companies owned by non-residents across different sectors must be perfectly homogenous. In other words, it assumes no variation in production processes within industries. In contrast, our methodology leverages microeconomic data, particularly corporate greenhouse gas (GHG) emissions, to relax this uniformity assumption. This allows us to better capture the diversity in environmental efficiency across production processes. Furthermore, our approach focuses on invested companies involving a French resident, regardless of whether the investment is inward or outward.

Our methodology also diverges from the IMF's approach in another key dimension. The IMF primarily examines the activities of foreign affiliates of multinational enterprises, focusing on resident firms with at least 50% foreign ownership. By contrast, our scope is broader; encompassing all foreign direct investment (FDI) relationships, i.e. cases where a non-resident firm holds 10% or more of a resident firm's equity.

In the medium term, this granular approach will enable us to test the robustness of the assumptions underpinning the IMF's framework. Ultimately, we share a common objective: to evaluate the extent to which multinationals are responsible for GHG emissions through their FDI. This involves attributing accountability to the entity at the top of the group structure for GHG emissions across the entire ownership chain, including its subsidiaries and their sub-subsidiaries.

1. An approach based on granular data

To work out a FDI carbon footprint, our basic idea is to use GHG emissions corporate reports and to consider that companies that do not publish GHG reports but are from the same country, same sector of activity and have the same characteristics in terms of size, net revenues and fixed capital will broadly get the same environmental impact.

The Greenhouse Gas Protocol (GHG Protocol) is an international protocol providing a framework for measuring, accounting and managing greenhouse gas emissions resulting from operations of both private and public sector. In 2004, was released the Corporate Accounting and Reporting Standard that has now become the world's most widely used GHG accounting standard. It defines the concepts of scope 1, 2 and 3 GHG emissions. The International Sustainability Standards Board (ISSB) by the International Financial Reporting Standards (IFRS) Foundation requires companies to measure their greenhouse gas emissions in accordance with GHG Protocol[2].

Scope 1 includes direct GHG emissions from fixed or mobile sources controlled by the organization (e.g., direct combustion of fossil fuels to power heat sources or stationary combustion engines and emissions from all vehicles running on fossil

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[2] https://ghgprotocol.org/blog/ghg-protocol-use-within-issbs-ifrs-s2-standard-enables-widespread-adoption-common-standard-ghg

fuels). Scope 2 covers GHG emissions arising from purchased energy — from a utility provider. That is, all GHG emissions released into the atmosphere, originating from the consumption of purchased electricity, steam, heat and cooling. Ultimately, Scope 3 includes indirect emissions not owned and not included in Scope 2. These emissions occur in the value chain of the company reporting the data and include both upstream and downstream emissions.

The GHG Protocol defines methods for setting boundaries for a GHG inventory: these determine which entities (e.g., subsidiaries, joint ventures, partnerships) and assets (e.g., facilities, vehicles) will be included in the scope 1 and scope 2 GHG emissions inventory. When an organization chooses an approach to consolidate GHG emissions, among three options, it has to apply it consistently to define entities and assets to include in their reporting[3]. This can yield some heterogeneity among international groups' GHG reports. Hereafter however, we assume that companies follow consolidation method through full integration accounting.

A first question arises as to which GHG emission perimeter to consider. Focusing on Scope 1 carbon footprint should prevent double counting, but it limits firms' accountability. Having in mind Scope 1 emissions for an energy-producing firm are the Scope 2 emissions of a firm in the manufacturing sector, Scopes 1 and 2 carbon footprint is the most common definition that encompasses GHG emissions resulting from firms' activities. Adding Scope 3 emission implies more over-counting (Charpentier *et al.*, 2023), but this is also a representation of what a firm is accountable for. We have experimented with all three scopes. Scope 3 results, however, are much less reliable. Indeed the corporate standard does not require Scope 3 emissions to be presented so that much fewer firms actually report these. As it requires collecting data at product-level from suppliers, many firms only report a few Scope 3 categories at their discretion, which leads to inaccurate estimations of their overall Scope 3 emissions.

In France, all companies with more than 500 employees have had to publish their GHG emissions on a yearly basis for the past 12 years, but only half of them actually comply. However, an increasing number of firms report GHG total emissions forced by either law, political pressure or financial incentives. Several private data providers, such as Institutional Shareholder Services (ISS), Carbon 4 Finance, the Carbon Disclosure Project, Refinitiv or Institutional Shareholder Services, now collect this data directly from companies' reports or estimate it. In total, Scopes 1 and 2 GHG emissions can be extracted for 28,000 companies worldwide, 20% of which being provided by the company itself and 80% being estimated by data providers, not always with a fully transparent methodology. This data always represents consolidated GHG emissions at the group level.

An iterative process, depending on data availability

Our aim is to measure the carbon footprint of outward and inward French FDI. To do so, we experiment with those DIEs being part of in an FDI framework involving a French resident, regardless of the investment direction.

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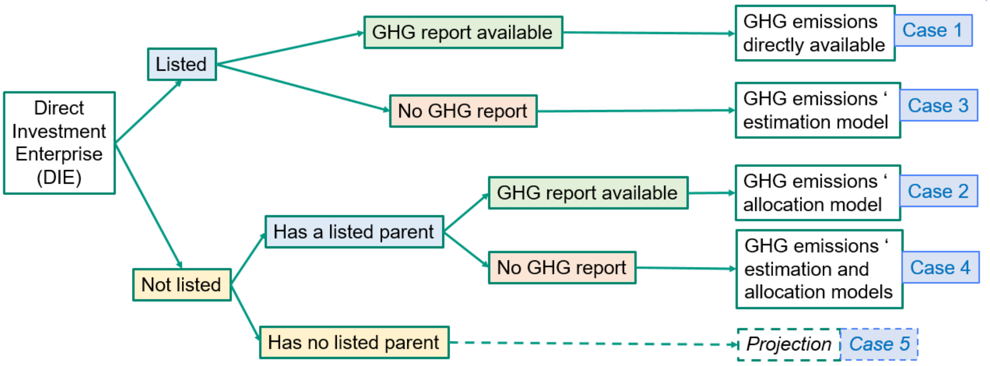
[3] https://www.epa.gov/climateleadership/determine-organizational-boundaries

Our challenge here is to allocate the whole group's GHG emissions to its different affiliated entities (DIEs). Overall, our approach can be summarised in two steps:

1) First, we gather GHG total emissions for the group from ISS;
2) Then, we allocate this total amount to its different DIEs according to the models depicted below.

These two steps largely depend on data availability. A decision tree can summarise the whole process (Figure 1). When a company is listed, data is more widely available, be it detailed financial statements, size, financial ratios, sector of activity, etc. For those companies, we generally have GHG emissions data that can be used directly (Case 1). However, for the rare listed DIEs where GHG data is not available (Case 3), we need to estimate it. All links with the DIE are determined by the direct investor's shareholding.

Figure 1 – Decision tree for choosing the GHG emissions estimation method



One important issue to bear in mind is that DIEs are often unlisted: in the case of France, only 10% of FDI assets and 20% of liabilities (in value) are listed on a stock exchange. Because GHG data is only available for listed companies, we look for listed parents of unlisted DIEs along the ownership chain, be it the direct investor or the ultimate parent. To do so, we rely on the LIFI database, maintained by the French statistical office, INSEE. This database maps ownership links between companies domestically, but also abroad since it can identify foreign parents and group heads. Hence, we get a list of possible information-rich parents for each of our DIEs[4].

We then look for the ISIN code of these parent companies using the European Centralised Securities DataBase (CSDB), either directly, thanks to the SIREN code (French company's unique national identifier) or indirectly, thanks to text mining techniques running through companies' names. This latter process requires a manual checking step. Eventually, we can match a fair share of the list of unlisted DIEs with a relevant listed parent higher up in the chain of ownership. GHG total emissions' data is available for more than 90% of the listed parents and because the parent is listed,

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[4] For inward FDI, DIEs are domestic and listed parent companies are generally located abroad. For outward FDI, DIEs are foreign and parent companies is usually domestic, but it may happen that the resident company is only a link in the whole ownership chain. Thankfully, the French economy does not shelter SPEs (Special Purpose Entities), which simplifies the view over the whole ownership chain.

we also have access to all kind of additional information that will helps us design a GHG allocation model for its DIEs (Case 2).

For those rare cases where no listed parent, - either direct investor or at the top of the chain of ownership -, reports any GHG emissions, we need an estimation model: first, we estimate GHG emissions at the group level for the listed parent identified with an ISIN code. Then, we allocate these consolidated GHG emissions to the relevant DIE (Case 4).

Cases 1 to 4 are can be applied to only 15% of known DIEs (either foreign-owned DIEs in France or French DIEs abroad), but those 15% actually account for 72% of French total FDI value, which appears as a more relevant share.

Case 5 arises when there is no listed entity in the entire chain of ownership. In this case, information is scarce, especially for those DIEs located abroad. In the absence of available microeconomic data, we experimented a mezzo-approach to estimate their GHG emissions. The idea behind was to approximate individual firm's GHG emissions (E_i) calculated as its value added multiplied by CO2 emission per unit of value added at country level, in those sectors of activity receiving the investment (1).

$$E_i = VA_i \times E_{s,c} \tag{1}$$

where i is the DIE unit, s, the sector f activity and c, the country

CO2 intensity figures being one of the UN Sustainable Development Goals' indicator, they are now quite widely available for many countries, including at a sectoral level. Estimating DIE's value added, however, required a leap of faith, albeit grounded on simple theory: production, hence value added, can roughly be considered as resulting from two main factors, capital and labour. Extensive academic work has focused on labour shares and there is data computed for many countries (see for example Guerriero, 2019). Based on the most basic production function, DIE's value added can be inferred from the DIE net results (the only available data) divided by the average capital share per sector/country (2).

$$VA_i = \frac{Net\ results_i}{1 - Labour\ Share_{s,c}} \Leftrightarrow \frac{Net\ results_i}{Capital\ Share_{s,c}} \tag{2}$$

This line of investigation proved to be a dead end. Labour shares at the sectoral level are only available for large industrialised countries, with a strong degree of heterogeneity in levels. This heterogeneity is driven by multiple factors: domestic labour market composition, policies, sectoral breakdown of the economy, etc. Eventually, our oversimplified model proved counterproductive and detrimental to our efforts as too much information needed to be assumed. Dealing with case 5 clearly illustrates a gaping business accounting data gap. Firms that fall into this category represent around 28% (in value) of FDI.

Conceptual framework and theoretical model to allocate GHG emissions within a multinational group

Disregarding Case 5, the following developments aim to establish a model applicable to cases 2 and 4 that allocates GHG emissions among the different entities within the same corporate group, whether subsidiaries or parent company. This allocation model is both simple and general, as it ensures the breakdown of the group's total GHG emissions across its various entities.

The working assumption of this model is as follows: we assume that GHG emissions — specifically for scopes 1 and 2 — are directly linked to the stock of tangible long-term assets. This assumption aligns with the definitions of scopes 1 and 2.

The model basically works in three steps: (i) group-level GHG emissions are distributed at the entity-level based on stocks of tangible assets; (ii) this initial estimation is adjusted to account for the average carbon intensity of the country/sector to which each entity belongs; (iii) second-round estimates are normalized so that final entity-level estimates are consistent with group-level carbon emissions.

Let us consider a corporate group composed of n units.

Let E represent the total emissions of the group, C_i the tangible long-term assets of unit i, and $\alpha_{c_i s_i y_i}$ the average carbon footprint of entities in sector of activity s, located in country c, during year y, where $i = 1, 2, \ldots, n$. To simplify the notation, since every variable is yearly, we do not index the equations by y.

The carbon footprint $\alpha_{c_i s_i}$, expressed in tCO2e/Million LCU per international dollar, is defined as the ratio between the total emissions of sector s in country c during year y, and the added value of sector s in country c during year y. The introduction of this variable allows for the allocation of the group's GHG emissions among each unit, accounting for the average environmental efficiency of sector/country/year.

We have the following equations:

- The initial allocation of emissions based on tangible long-term assets:

$$e_i = \frac{C_i}{\sum_{i=1}^{n} C_i} \times E \tag{3}$$

- The adjustment of emissions according to sector/country/year average environmental efficiency:

$$e_i^* = \alpha_{c_i s_i} \times e_i \tag{4}$$

- The normalization of values proportionally:

$$E_i = \frac{e_i^*}{\sum_{i=1}^{n} e_i^*} \times E \tag{5}$$

Thus, the sum of E_i is equal to the total emissions of the group, E. This model allows for the allocation of emissions among n units, taking into account their respective tangible long-term assets and sector/country/year average environmental efficiency, ensuring a complete breakdown of GHG emissions.

As previously mentioned, the literature addressing the relationship between FDI and carbon emissions offers ambiguous conclusions. The equivocal nature of the results can be attributed to two opposing effects: the 'pollution haven' effect and the 'pollution halo' effect.

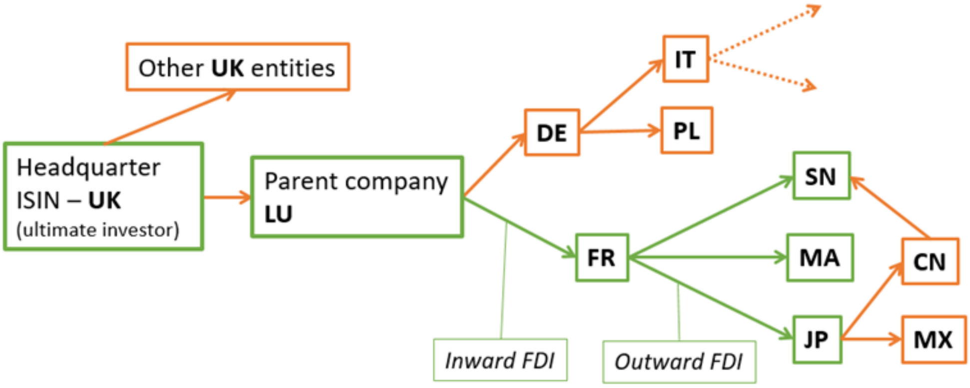
The initial allocation, in the first step, can be interpreted as assuming a pollution halo, as it presupposes identical production technology within the same productive structure. However, the second step, as it seeks to adjust the allocation to account for technological heterogeneity within the same productive structure, can be understood as assuming a pollution haven effect.

This model represents a first-best solution. In our case, data availability constraints are binding. Specifically, data on tangible long-term assets is largely available for listed groups, but much less for unlisted groups. Additionally, we do not have access to tangible long-term assets data for direct investment enterprises (DIEs). Employment data, that could be used as proxy, leads to the same setback.

Furthermore, the theoretical model assumes access to information on the entire productive structure of a group — meaning all affiliates must be accounted for. In our case, however, we only have FDI data on entities that are acquired or under the control or significant influence of French resident entities.

For inward FDI, we have information about French subsidiaries owned by a foreign parent company. That means we collect neither data about subsidiaries owned in other countries nor about entities in the investing country. For outward FDI, we only know about foreign subsidiaries owned by a French parent company (Figure 2).

Figure 2 – Example of the information French FDI data compilers have access to



Note: Domestic FDI compilation provides information in green, but data compilers remain unaware of all information in orange. In this fictive example, countries are written in ISO code. Dotted lines represent other possible FDI we do not know of.

Given the available information, the model outlined above needs to be adjusted to make it tractable.

A little detour via accounting is needed. In our case, at the DIE level, we have information on a portion of their equity, specifically the amount of the direct investor's shareholding, which represents the stock of direct investment in company i. By definition, equity includes tangible assets, as it helps finance long-term tangible assets such as the machinery of the invested companies. Therefore, in the process of full consolidation accounting, if we call A the parent company and B a subsidiary, the shares of B held by A are eliminated from A's balance sheet, and all assets and liabilities are added together line by line. In other words, the direct investor includes all the assets of the invested company in the assets side of its own balance sheet.

For listed groups for which we can retrieve carbon emissions data from the ISS database, we do have detailed balance sheet information, including long-term tangible assets and total assets, which we obtain from the Refinitiv database.

Therefore, by comparing the direct investor's shareholding in the DIE, i.e. the FDI, to the group's consolidated total of long-term tangible assets, we minimize (maximize) the contribution of the invested company to the group’s long-term tangible assets if the direct investor’s shareholding is lower (higher) than the invested company’s long-term tangible assets.

Note that this approach works well for capital-intensive industries (e.g. manufacturing). However, this much less the case for labour-intensive industries (e.g. services), where total of long-term tangible assets can be smaller than the direct investor's shareholding in the DIE.

Hence we propose a variation that consists of comparing the direct investor’s shareholding in the invested company to the group’s consolidated total assets. In this case, by definition, the contribution of the invested company to the group’s consolidated total assets will be lower than its actual contribution, as the invested company’s equity is less than or equal to its total assets.

As a result, the aforementioned model will tend to underestimate GHG emission of the subsidiaries compared to their true values.

When the complete structure of a corporate group is unknown due to missing affiliates, it is essential to adjust the emissions allocation model to account for these gaps. Our approach introduces a fictitious “missing” affiliate to represent the collective impact of the unknown DIEs. This ensures that the total group GHG emissions are fully allocated, and the known DIEs are not unfairly overburdened with GHG emissions that should be attributed to missing units.

We then have the following equations:

- The initial allocation of emissions based on FDI and tangible long-term (total) assets:

$$e_i = \frac{FDI_i}{C_{group}} \times E \tag{6}$$

$$e_i = \frac{FDI_i}{TA_{group}} \times E \tag{6'}$$

  Where C_{group} is the group’s tangible long-term assets and TA_{group}, the group’s total assets, and FDI_i is the direct investor's share of capital in a DIE.

- The adjustment of emissions according to sector/country/year average environmental efficiency:

$$e_i^* = \alpha_{ics} \times e_i \tag{7}$$

- Unique fictitious missing affiliate compensating for unavailable information on group structure:

$$e_M^* = \frac{\left(C_{group} - \sum_{i=1}^{n} FDI_i\right)}{C_{group}} \times \overline{\alpha_{cs}} \times E, \qquad \overline{\alpha_{cs}} = \frac{1}{n}\sum_{i=1}^{n} \alpha_{ics} \tag{8}$$

- $$e_M^* = \frac{\left(TA_{group} - \sum_{i=1}^{n} FDI_i\right)}{TA_{group}} \times \overline{\alpha_{cs}} \times E,\ \overline{\alpha_{cs}} = \frac{1}{n}\sum_{i=1}^{n} \alpha_{ics} \tag{8'}$$

  The normalization of values proportionally:

$$E_i = \frac{e_i^*}{\sum_{i=1}^{n} e_i^* + e_M^*} \times E \tag{9}$$

Albeit not a panacea, the adjustment through a unique fictitious missing affiliate boils down to bunching together the contribution of GHG emissions by the parent company and all its potential unknown affiliates, including resident ones.

An alternative way to model a fictitious missing affiliate could be to simulate the average behaviour of the entities we know (mean imputation):

$$e_M^* = \frac{E}{TA_{group}} \frac{1}{n} \sum\nolimits_{i=1}^{n} \alpha_{csi} \times FDI_i \tag{8''}$$

However, after computation, we noticed that the mean imputation for missing information (equation 8’’) often leads to inconsistent results. This is due to the very partial view domestic FDI data compilers have on the global group structure of multinationals. For instance, in Figure 2 (see above), all the unknown entities in orange would be averaged into the fictitious subsidiary (depending on green entities’ information). They would weigh as one single entity, while in reality they are six of them at least. As a result, this approach often leads to large overestimation of carbon footprint. Ideally, fostering more data sharing among FDI compilers could fix that issue. Hence we need to “compensate” by using equation (8) and consider the above model when we need to allocate GHG emissions within the group structure.

GHG emissions prediction model

For cases 1 and 2, GHG total emissions are available from listed companies – be it the DIE directly or the parent.

We use this piece of information to first build a simple GHG estimation model based on various variables, ranging from consolidated financial data to firms’ characteristics. The data comes from ISS and Refinitiv. We develop a general linearized model (GLM) as GHG emissions data presents a lognormal distribution (see Table 1). For the following charts and tables, total GHG emissions correspond to the sum of scope 1 and scope 2 GHG emissions.

Table 1

Distribution of total GHG emissions, in CO2 tons equivalent

Listed entities providing the data (2016-2022)

Statistics	Value
Minimum	4.4e-1
1st percentile	6.4e1
5th percentile	5.2e2
1st quartile	5.7e3
Median	3.7e4
3rd quartile	2.3e5

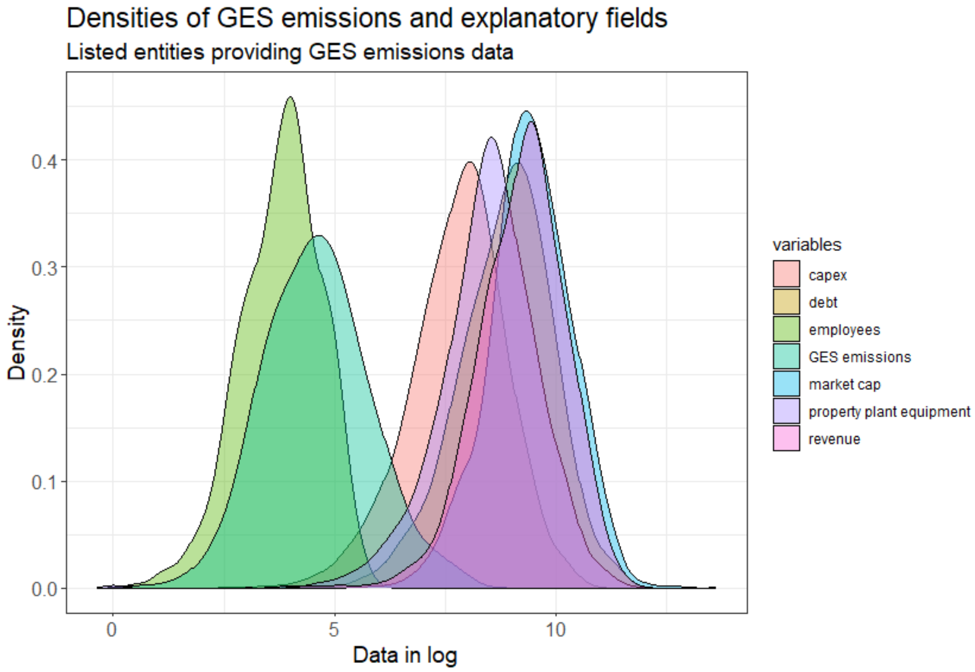
95th percentile	4.2e6
99th percentile	3.6e7
Maximum	5.2e8

Source: private data providers – Banque de France.

Note: median of total GHG emissions is 37,000 tons of CO2

Table 1 clearly shows the exponential shape of total GHG total emissions' distribution. A stepwise regression (using the Bayesian information criterion) helps us select the relevant numerical firm-specific determinants for GHG emissions reported in Figure 4.

Figure 4



Sources: data from private providers - Banque de France

Given the shape of their distribution, all these significant variables have been log-transformed. Their relation with GHG total emissions can be summarised into correlations (Table 2). Firms' financial situation is fairly closely correlated with GHG emissions with a higher debt and higher net revenues associated with higher GHG emissions. Even more striking, capital expenditure and physical equipment are highly correlated with GHG emissions, as well as firm size, proxied by the number of employees.

Table 2

Correlation of log-transformed numeric variables with total GHG emissions

Listed entities providing the data (2016-2022)

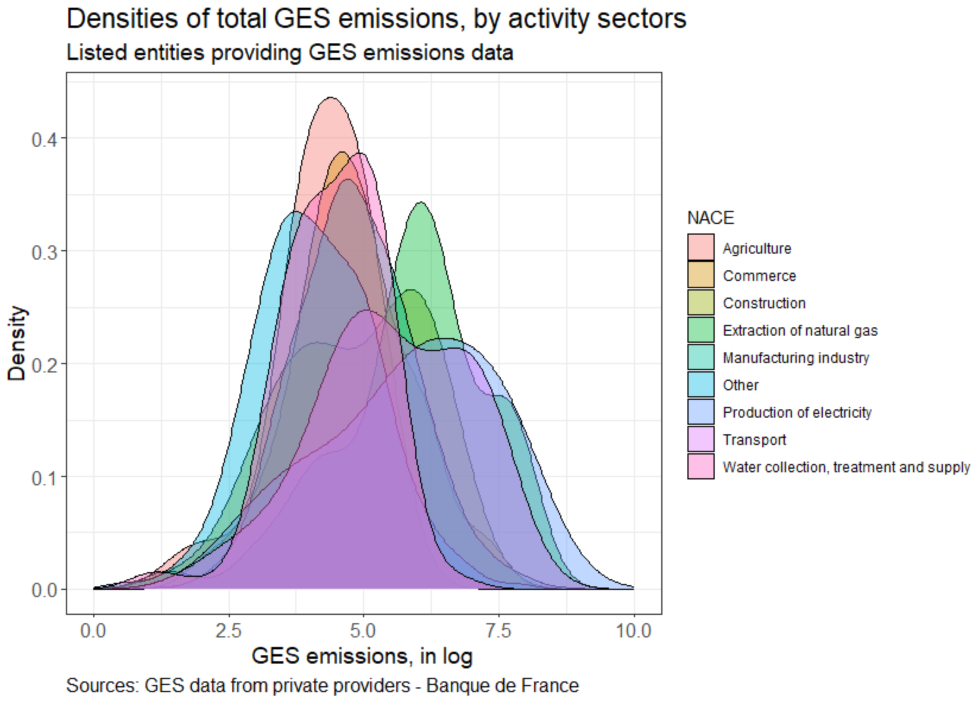
Variable	Correlation value
Revenue	0.73
Employees	0.69
Market cap	0.58
Debt	0.63
Property plant equipment	0.79
Capex	0.75
Asset	0.59

Source: private data providers – Banque de France.

Note: variables about physical investments are the more correlated

Data is yearly from 2016 to 2022 and broken down by geographical zones (ex. Western Europe for France) and 18 wide sectors of activity, as GHG total emission also very much depend on the latter (see Figure 5).

Figure 5



Densities of total GES emissions, by activity sectors

Listed entities providing GES emissions data

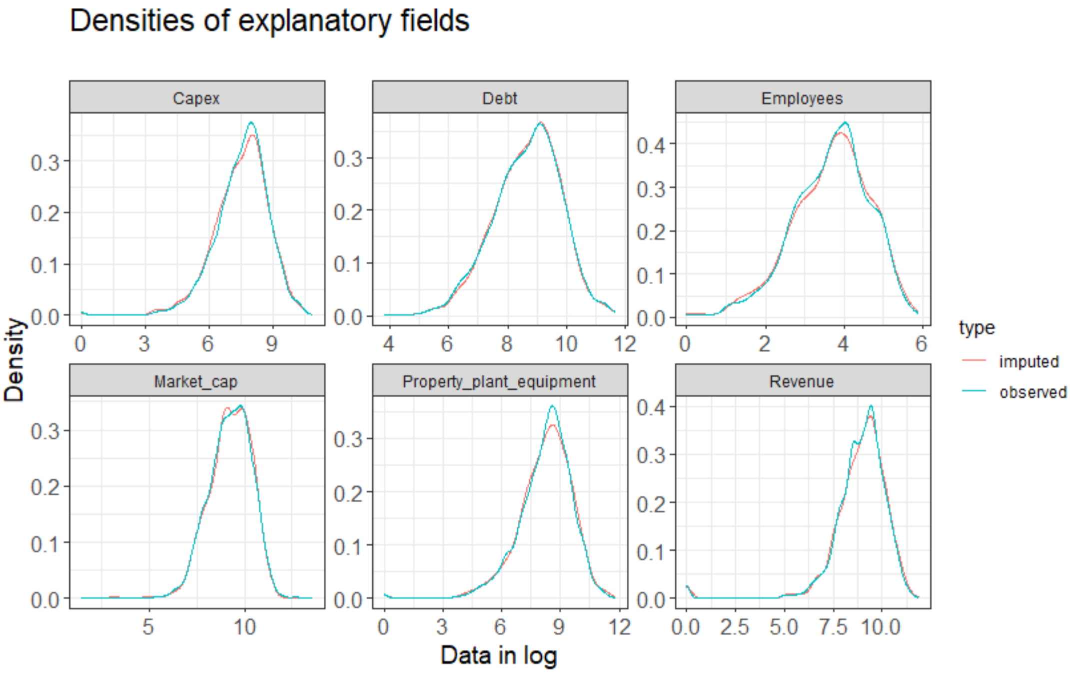
Sources: GES data from private providers - Banque de France

Based on this variable selection, the GLM equation may be written as follows, with X being the list of determinants selected above:

$$\log(GES_{total\_emissions}) = \beta X + \varepsilon$$

Numerical variables mostly come from Refinitiv and are very often properly completed for listed companies of our sample. However, we fill in missing observations using the Multivariate Imputation by Chained Equations (MICE) approach, similar to the nearest neighbours' based on available fields. Data imputation at this stage is believed to be benign as only 3 % of listed entities are missing one variable or more. Comparing variables' densities between imputed and observed data confirms the MICE imputation does not distort data too much (see Figure 6).

Figure 4



Sources: data from private providers - Banque de France

Our GLM fitting (based on 1000 listed companies every year) provides satisfactory results, with a R² of 0.66 for our Scope 1 model and 0.60 for scope 2 model. When applying a 10-fold cross-validation, the out-of-sample mean fitting error reaches 2.2, which is deemed acceptable given the standard deviation of the modelled variables is 2.95. Most numerical variables appear significant (see Table in appendix). Firm size (proxied by the number of employees) appears as a significant positive determinant of GHG emissions : the larger the firm, the higher GHG emissions. Fixed equipment also appear significant and of the expected sign. Categorical variables appear overall less significant. Yet, significant sectors of activity to predict higher levels of GHG emissions is B (mining and quarrying) and D (which includes gas and electricity-related activities). Inversely, services sector predicts lower levels of emissions, particularly in sector K (financial and insurances) and J (information and communication), which appear sensible. Eastern Asia and sub-Saharan Africa are the only two very significant geographical determinants of GHG emissions, but the geographical zone matches the entity at a consolidated level, that may not well be the actual production region. Finally, the 2020 year dummy stands out, probably reflecting the downward impact of Covid on global GHG emissions.

In order to challenge these results, we run a Recursive Partitioning And Regression Tree (RPART). The results confirm those of our GLM model (see Table 3).

Table 3

Variable importance according to the RPART tree

Listed entities providing the data (2016-2022)

Variable	Relative Importance	
	Scope 1	Scope 2
Property plant equipment	18%	18%
Capex	19%	16%
Revenue	16%	19%
Debt	10%	10%
Employees	14%	22%
Market cap	11%	11%
Sector of activity	3%	1.5%

Source: Refinitiv – Banque de France.

Note: the tree was pruned before geo zones came out

The main conclusion from Table 3 is that fixed capital and revenue flows are indeed the more important variables to explain scope 1 GHG emissions, even at a consolidated level. Interestingly, when trying to estimate Scope 2 GHG emissions, firm size become the variable with most predictive power.

We can now use this GHG emissions model to estimated GHG emissions of listed DIEs (case 3) and of listed parent companies (case 4) that do not provide GHG total emissions.

2. Results

This data-intensive exercise provides an estimated carbon footprint measured in tons of emitted CO2 for each DIE being part of the French FDI framework, outside the scope of Case 5 (i.e. for 28% of total French FDI in value). While this may seem a low coverage, our results look promising. By adding up DIEs' footprint depending on the FDI direction (outward or inward), we get two sets of data, reported in Figure 5 (for outward FDI) and 6 (for inward FDI).

Figure 5 pictures the carbon footprint of French FDI abroad in 2022. The darker the country, the higher GHG emissions due to French-owned DIEs. France has a higher density of resident multinational groups than other countries. In 2022, French FDI assets abroad stood at €1,414 billion, far above inward FDI, at only €746 billion. About half of French FDI abroad is located in other European countries, and clearly, the French carbon footprint is significant in neighbouring countries. Beyond Europe, the United States attract about 16% of French FDI and, in our sample, the French DIEs in the US emitted 674 900 tCO2e in 2022. Comparatively, China is only 2% of French outward FDI but the carbon footprint appears a lot worse, with more than 964 700 tCO2e emitted in 2022. This figure is likely to be largely underestimated since since China is one of the country that counts a lot of totally unlisted chains of ownership (Case 5).

Figure 6 shows the carbon footprint of foreign direct investors in France. Because investing countries are fewer, and mainly developed countries, there are fewer counterparties. FDI frameworks can be notoriously complicated to trace as multinationals have designed very complex corporate structure spanning over several countries and tax havens. Yet we note that the highest foreign carbon footprint in France is that of the United States, which is also the largest ultimate investor in France. Other European countries such as Germany, Spain or Italy are also top investors and their carbon footprint in France is significant.

Overall, the average carbon footprint of inward FDI is lower than that of outward FDI, which may be related to the CO2 emission efficiency of France, where energy production largely relies on low-carbon emitting nuclear power.

It is hard to benchmark our results, given we have only estimated a share of the French FDI carbon footprint. Based on a methodology close to that suggested by the IMF using input-ouput tables, a first estimate of the French carbon footprint of FDI stocks abroad had reached about 131 million tons of CO2 in 2014, about 0,5% of global emissions (Gigout, 2024) and amid a downward global trend in emission intensity. Our partial estimates are indeed below this benchmark.

Figure 5

Scopes 1 and 2 Carbon footprint of French direct investment abroad (tons of CO2; in logarithmic scale; 2022)

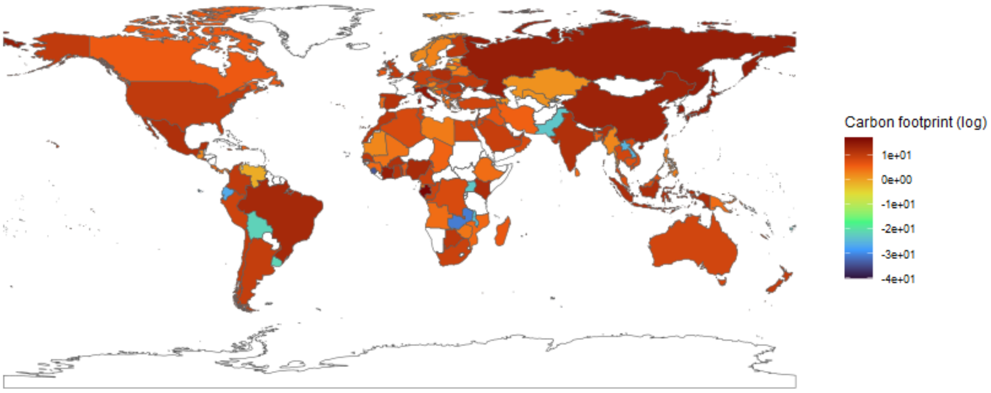
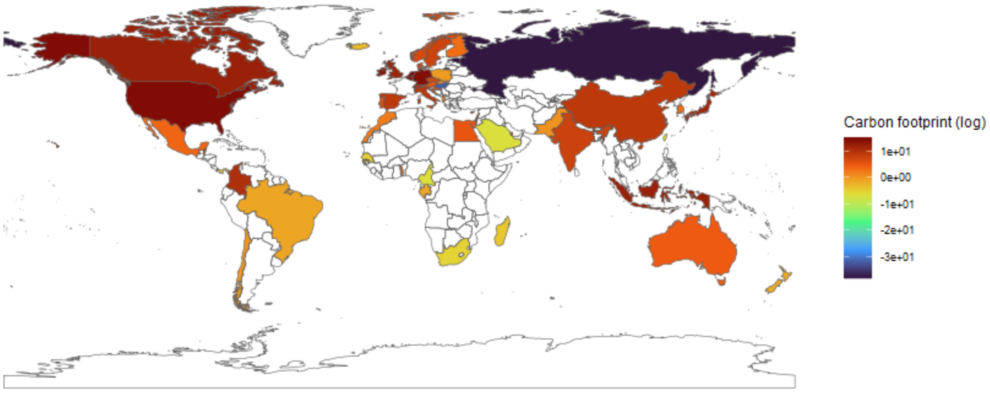


Figure 6

Scopes 1 and 2 Carbon footprint of foreign direct investment in France (tons of CO2; in logarithmic scale; 2022)



Source: Banque de France.

An interesting way to look at our results is to derive a CO2 intensity of FDI, by simply measuring GHG emissions divided by total FDI. Hence we can compare countries by looking at the environmental cost of one unit of FDI, whether outward or inward. Once again, our view is still partial since it is based on a fraction of total FDI.

Figure 7

Scopes 1 and 2 Carbon intensity of French direct investment abroad (in tons of CO2/FDI value; 2022)

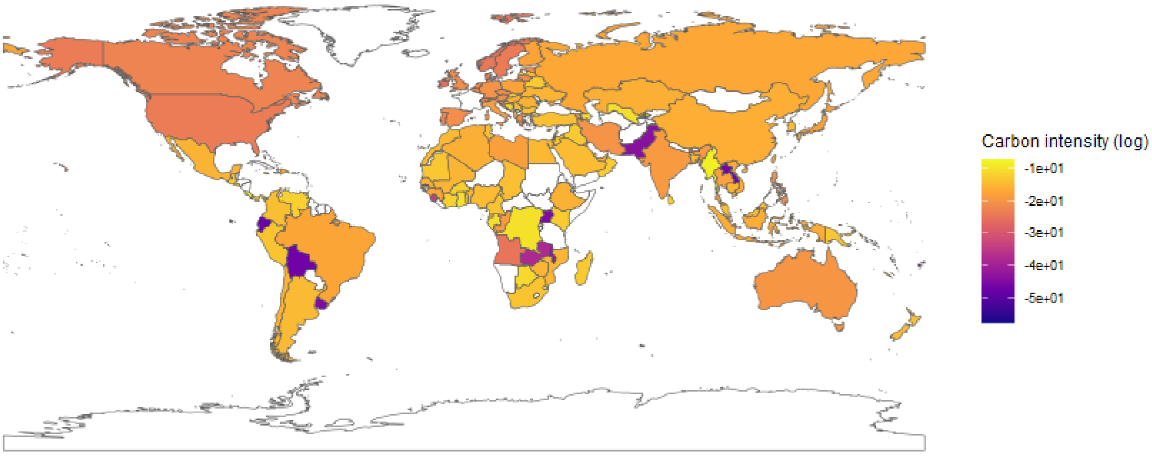
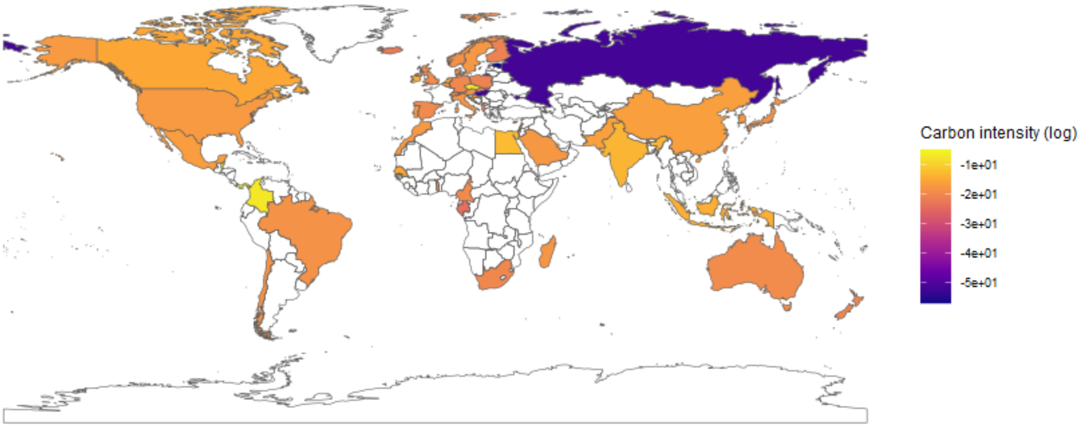


Figure 8

Scopes 1 and 2 Carbon intensity of foreign direct investment in France (in tons of CO2/FDI value; 2022)



Source: Banque de France.

3. Current limits and hopes

This paper presents a novel, data-driven approach to measuring the FDI carbon footprint using granular, firm-level data. This approach is close to FDI compilers' methods as they who often have to delve into companies' individual financial statements or investigate multinational group structures. By focusing on accumulated stocks rather than monetary flows, we also wanted to offer a more accurate reflection of how multinational enterprises contribute to GHG emissions through their global operations. While current approaches rely on macroeconomic methods and input-output tables, our micro-level approach provides a closer examination of emissions tied to individual firms, enhancing the precision and relevance of FDI carbon footprint assessments.

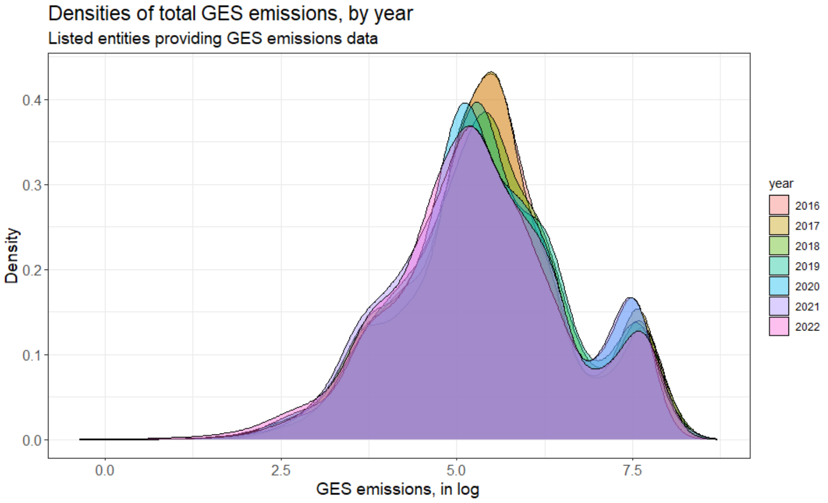
However, the results remain partial due to limitation in data availability. As our work progressed, a numerous amount of unforeseen questions and obstacles arose. First, we questioned the consistency and reliability of GHG emissions available both in corporate reports and estimated by private date providers. We starved for carbon efficiency data for less developed countries and for some information about the DIE's sector of activity, especially for outward FDI. Frustration peaked when trying to circumvent the lack of business accounting data for unlisted firms. Dealing with Case 5 unlisted firms was especially disappointing, although our mezzo-economic shortcut initially sounded promising. Yet, implausible results, in the absence of any "true" benchmark, become a quality measure. Despite a huge amount of work on data cleaning, consolidation and imputation, a considerable data gap still exists for almost a third of FDI assets. The GHG emissions allocation model is a step forward, but it is not without challenges either. While our use of a fictitious "missing affiliate" to address unknown entities in corporate groups is a promising technique, the way it is designed is not innocuous. For example, we tested an alternative model by which the fictitious DIE was granted the average emissions of known DIEs, which failed to provide credible results.

Despite these challenges, we are optimistic about useful developments in the short to medium term. Last year, several hundred non-financial entities have been testing a prototype climate indicator developed by Banque de France. The idea is to eventually add a new dimension to the Bank’s activity of rating French firms’ financial health. Business accounting data gap remains a clear sore spot. To run such a granular exercise, one needs more precise business accounting details about foreign DIEs. The new European Corporate Sustainability Reporting Directive (CSRD), applicable since January 2024, sets new standards and extra-financial reporting requirements for large companies and listed SMEs. Such regulatory advancements, together with the increasing availability of climate data, offer hope for more comprehensive and reliable assessments of FDI-related emissions. Over the past 15 years, a number of countries have established voluntary or mandatory GHG emissions measurement and reporting schemes with the aim to reduce global emissions. We are reaching the exciting stage where available data enables us to test different approaches suggested by international recommendations.

Looking forward, further research should focus on refining the micro-based methodology and comparing it with macro-level approaches to verify robustness. Improved business accounting practices that provides a more transparent view over global business structures of multinationals and more detailed emissions reporting will be crucial to fully understanding the carbon footprint of FDI.

Appendix

Yearly total GHG emissions (in log)



Densities of total GES emissions, by year

Listed entities providing GES emissions data

Sources: GES data from private providers - Banque de France

GLM fitting

GLM fitting for scope 1 GHG emissions

Coefficients

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-2.244	0.246	-9.135	<2e-16	***
Year : 2017	0.030	0.036	0.844	0.399	
Year ; 2018	-0.009	0.036	-0.243	0.808	
Year : 2019	-0.022	0.035	-0.628	0.530	
Year : 2020	-0.120	0.035	-3.408	6.58e-4	***
Year : 2021	-0.063	0.036	-1.745	0.081	
Year : 2022	-0.013	0.039	-0.340	0.734	
Geo : Central Asia	0.187	0.396	0.471	0.637	
Geo : Eastern Asia	-0.018	0.171	-0.105	0.917	
Geo : Eastern Europe	0.026	0.197	0.131	0.895	
Geo : Latin America and the Caribbean	0.433	0.187	2.311	0.021	*
Geo : Northern Africa	0.059	0.191	0.311	0.756	
Geo : Northern America	0.048	0.1684	0.287	0.774	
Geo : Northern Europe	0.179	0.172	1.044	0.297	
Geo : South-eastern Asia	1.227	0.251	4.905	9.54e-07	***
Geo : Southern Asia	0.179	0.196	0.913	0.364	

Geo : Sub-Saharan Africa	0.731	0.203	3.605	3.14e-4	***
Geo : Western Asia	0.219	0.197	1.114	0.265	
Geo : Western Europe	0.123	0.168	0.735	0.462	
NAICS Sector : B	1.165	0.155	7.516	6.34e-14	***
NAICS Sector : C	0.087	0.135	0.644	0.519	
NAICS Sector : D	1.19	0.151	7.882	3.72e-15	***
NAICS Sector : E	-0.228	0.146	-1.554	0.120	
NAICS Sector : F	0.144	0.160	0.899	0.369	
NAICS Sector : G	-0.021	0.140	-0.150	0.880	
NAICS Sector : H	0.563	0.149	3.774	1.6e-4	***
NAICS Sector : I	-0.163	0.162	-1.005	0.315	
NAICS Sector : J	-0.788	0.138	-5.704	1.22e-08	***
NAICS Sector : K	-0.936	0.140	-6.687	2.46e-11	***
NAICS Sector : L	0.019	0.145	0.135	0.893	
NAICS Sector : M	-0.598	0.138	-4.332	1.50e-5	***
NAICS Sector : P	-0.117	0.423	-0.278	0.781	
NAICS Sector : Q	-0.145	0.202	-0.719	0.472	
NAICS Sector : R	-0.157	0.187	-0.840	0.401	
NAICS Sector : S	-0.586	0.232	-2.529	0.011	*
log(employees)	0.609	0.017	35.903	<2e-16	***
log(market cap)	-0.052	0.017	-3.111	1.08e-3	**
log(debt)	0.112	0.015	7.285	3.56e-13	***
log(property plan equipment)	0.334	0.018	18.287	<2e-16	***
log(capex)	0.098	0.019	5.075	3.98e-7	***

AIC : 16756
Number of Fischer Scoring Iterations : 2
R^2 : 0.66

GLM fitting for scope 2 GHG emissions

Coefficients					
	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-1.191	0.231	-5.160	2.54e-7	***
Year : 2017	-0.062	0.033	-1.866	0.062	
Year ; 2018	-0.113	0.033	-3.405	0.001	***
Year : 2019	-0.172	0.033	-5.297	1.21e-7	***
Year : 2020	-0.278	0.033	-8.471	<2e-16	***
Year : 2021	-0.261	0.034	-7.760	9.71e-15	***
Year : 2022	-0.304	0.036	-8.429	<2e-16	***
Geo : Central Asia	0.195	0.369	0.529	0.597	
Geo : Eastern Asia	0.170	0.159	1.069	0.285	
Geo : Eastern Europe	0.108	0.183	0.590	0.555	
Geo : Latin America and the Caribbean	0.311	0.175	1.782	0.074	
Geo : Northern Africa	-0.087	0.178	-0.489	0.625	
Geo : Northern America	0.171	0.158	1.088	0.277	
Geo : Northern Europe	-0.011	0.160	-0.069	0.945	
Geo : South-eastern Asia	0.997	0.233	4.268	2.00e-5	***
Geo : Southern Asia	0.452	0.183	2.475	0.013	*
Geo : Sub-Saharan Africa	0.285	0.189	1.508	0.132	
Geo : Western Asia	0.151	0.183	0.823	0.411	
Geo : Western Europe	0.021	0.157	0.133	0.894	
NAICS Sector : B	0.794	0.144	5.492	4.1e-8	***
NAICS Sector : C	0.366	0.126	2.910	0.004	**
NAICS Sector : D	0.411	0.141	2.916	0.004	**
NAICS Sector : E	-0.207	0.137	-1.513	0.130	
NAICS Sector : F	-0.141	0.149	-0.946	0.344	
NAICS Sector : G	0.219	0.130	1.679	0.093	
NAICS Sector : H	-0.122	0.139	-0.873	0.383	
NAICS Sector : I	0.234	0.151	1.552	0.121	
NAICS Sector : J	-0.083	0.129	-0.643	0.520	
NAICS Sector : K	-0.365	0.130	-2.799	0.005	**
NAICS Sector : L	0.389	0.135	2.881	0.004	**
NAICS Sector : M	-0.152	0.129	-1.183	0.237	

NAICS Sector : P	-0.083	0.394	-0.210	0.834	
NAICS Sector : Q	0.332	0.188	1.762	0.078	
NAICS Sector : R	0.173	0.174	0.997	0.32	
NAICS Sector : S	-0.514	0.216	-2.381	0.012	*
log(employees)	0.578	0.016	34.961	<2e-16	***
log(revenue)	0.044	0.015	2.818	0.005	**
log(market cap)	-0.038	0.016	-2.366	0.019	*
log(debt)	0.068	0.014	4.788	1.72e-6	***
log(property plan equipment)	0.209	0.018	11.613	<2e-16	***
log(capex)	0.099	0.018	5.492	4.12e-8	***

AIC : 15777
Number of Fischer Scoring Iterations : 2
R^2 : 0.60

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FDI CARBON FOOTPRINT: AN EXPERIMENT WITH GRANULAR DATA

VERONIQUE GENRE, ALICE MAGNIEZ, DAVID NEFZI & **FRANÇOIS ROBIN**

DEPUTY HEAD OF INTERNATIONAL TRADE AND FOREIGN DIRECT INVESTMENT DIVISION

BALANCE OF PAYMENTS DIRECTION

IFC, IZMIR – 07/05/2024

BANQUE DE FRANCE
EUROSYSTÈME

CONTEXT

Environmental impact of FDI unclear

Data Gaps Initiative 3 – Rec 3 = Carbon footprints of FDI

- IMF lead, with OECD

Methodology based on macro data (gross fixed capital formation) and input-output tables (cf. Borga et al., 2022)

- Could we do it the other round?

Combine firms’ GHG reports with data compilers’ FDI granular data

Comparison

Robustness checks
Data consistency
Reconcile top-down and bottom-up approaches

A GROWING AMOUNT OF GRANULAR GHG EMISSIONS' DATA

- **Private data providers for companies' GHG emissions**
  - Carbon 4 finance
  - Carbon Disclosure Project
  - Refinitiv
  - Institutional Shareholder Services
  - *Institut Louis Bachelier*

- Collect the data from annual reports or estimate it
- ~28,000 listed companies / year for Scopes 1 & 2

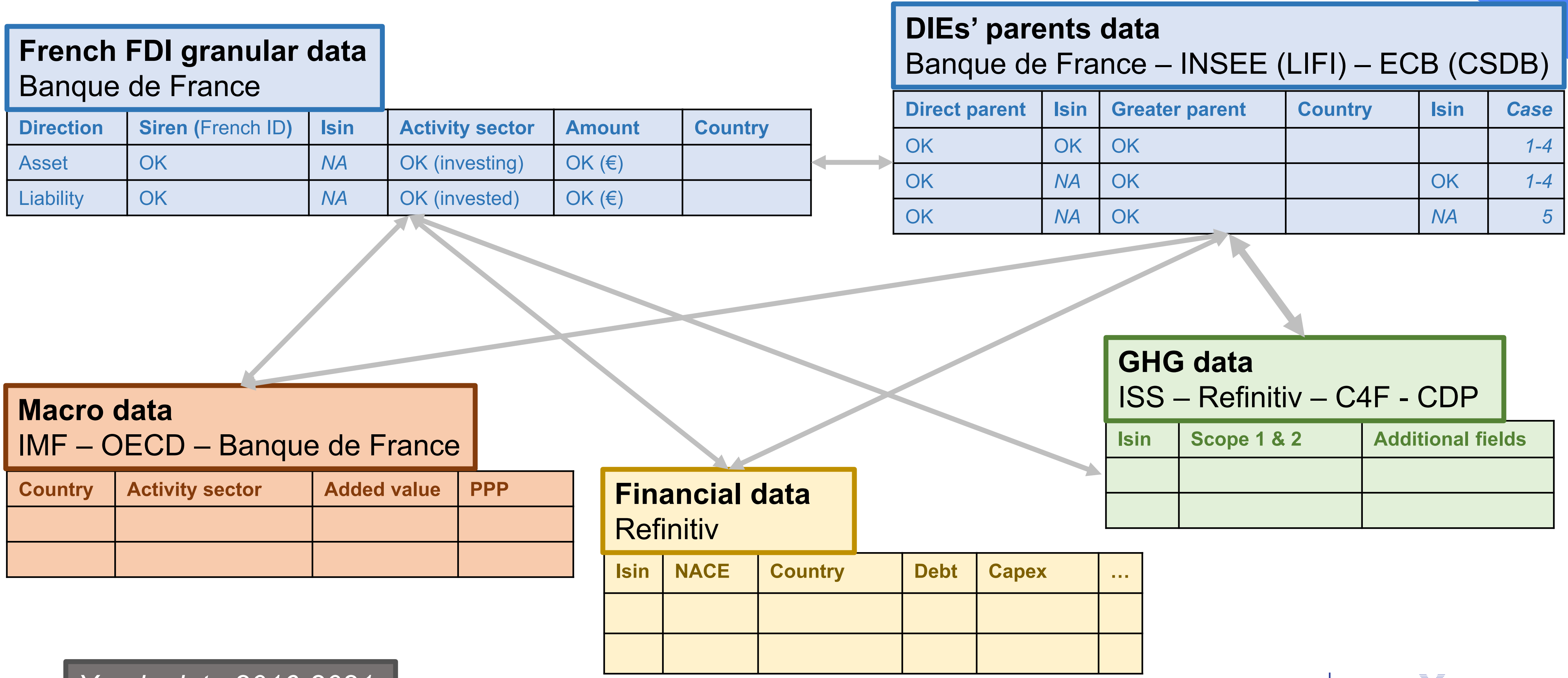
20%

80%

❗ **Robustness**

- **Issue: <u>listed</u> companies only**
  - Listed French FDI in value:
    - **10% of assets**
    - **20% of liabilities**

OTHER AVAILABLE DATA



French FDI granular data
Banque de France

Direction	Siren (French ID)	Isin	Activity sector	Amount	Country
Asset	OK	*NA*	OK (investing)	OK (€)	
Liability	OK	*NA*	OK (invested)	OK (€)	

DIEs' parents data
Banque de France – INSEE (LIFI) – ECB (CSDB)

Direct parent	Isin	Greater parent	Country	Isin	*Case*
OK	OK	OK			*1-4*
OK	*NA*	OK		OK	*1-4*
OK	*NA*	OK		*NA*	*5*

GHG data
ISS – Refinitiv – C4F - CDP

Isin	Scope 1 & 2	Additional fields

Macro data
IMF – OECD – Banque de France

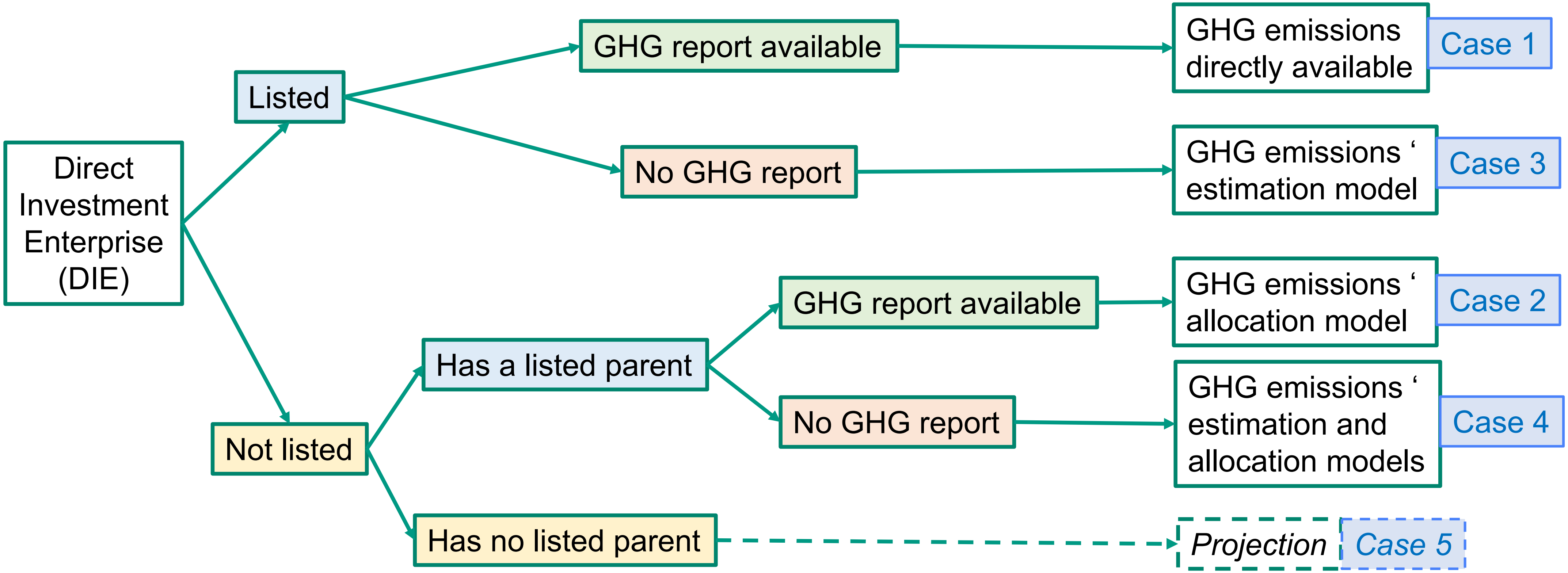
Country	Activity sector	Added value	PPP

Financial data
Refinitiv

Isin	NACE	Country	Debt	Capex	…

Yearly data 2016-2021

GHG EMISSIONS' ESTIMATION FOR DIES



Direct Investment Enterprise (DIE)

Listed

GHG report available

GHG emissions directly available

Case 1

No GHG report

GHG emissions ' estimation model

Case 3

Not listed

Has a listed parent

GHG report available

GHG emissions ' allocation model

Case 2

No GHG report

GHG emissions ' estimation and allocation models

Case 4

Has no listed parent

Projection

Case 5

CASES IN MORE DETAILS

- **Cases 1 to 4**
  - **Estimation model**
    - Built from Cases 1 & 2 data

$$GHG\ emissions \sim financial\ data$$

    - To be applied to Cases 3 & 4
  - **Allocation model for Cases 2 & 4**
    - What part of the DIE in the group total GHG emissions?

6,000 ISIN

~49% in value

~1% in value

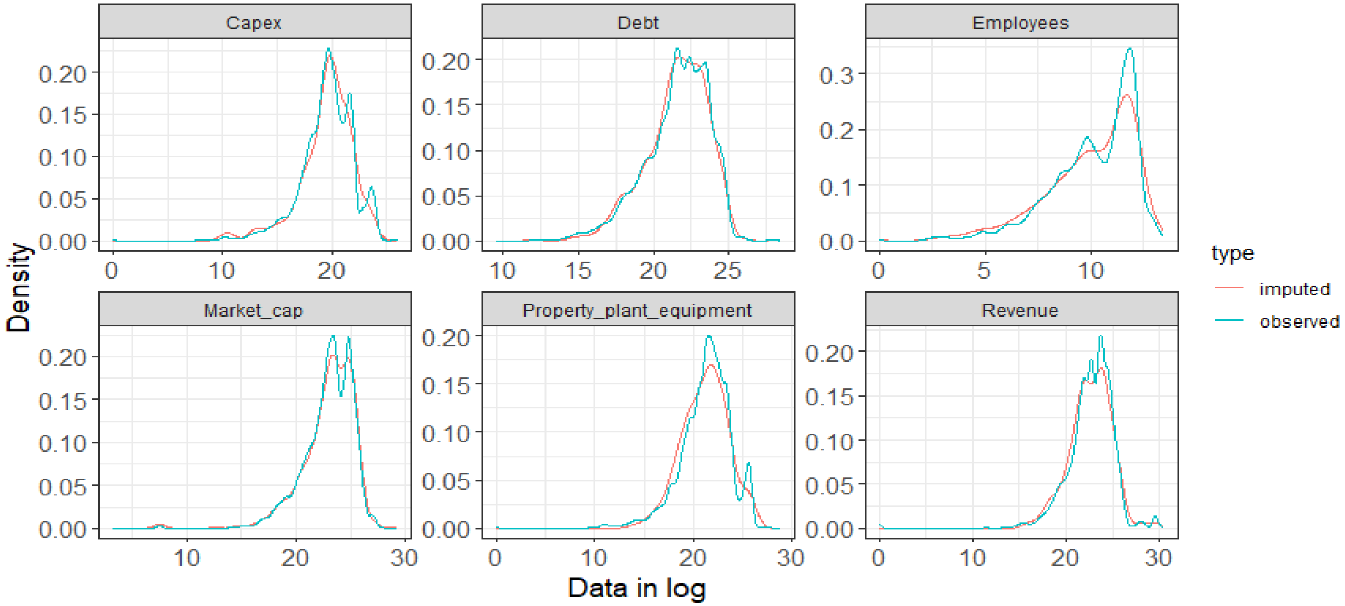
- **Case 5**
  - **Not dealt so far** (*it will in the next version of the paper*)
    - Idea: projection from Cases 1 to 4
    - Main challenge: data availability

~50% in value

GRANULAR DATA IMPUTATION

- **Some missing financial variables**
  - Multivariate Imputation by Chained Equations (MICE)

Densities of explanatory fields

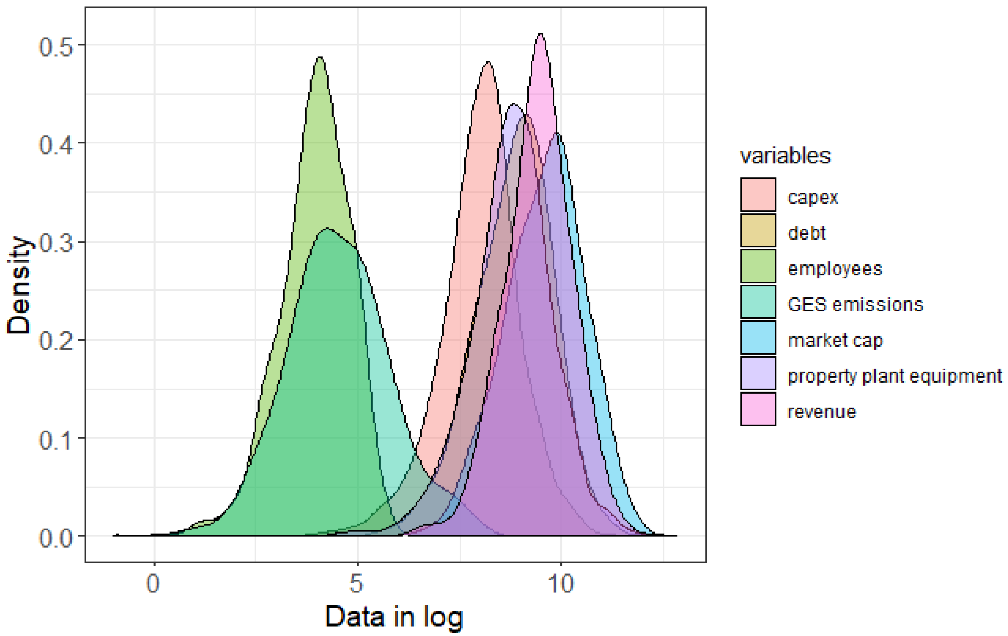


Sources: data from private providers - Banque de France

ESTIMATION MODEL

- **Consolidated data for both financial and GHG emissions**
  - General Linearized Model (*might be improved later with boosting methods*)
  - Numeric variables and factors: activity sector and geography information

R²=0,7
Imputed data ~1% in value



Densities of GES emissions and explanatory fields

Listed entities providing GES emissions data

Sources: data from private providers - Banque de France

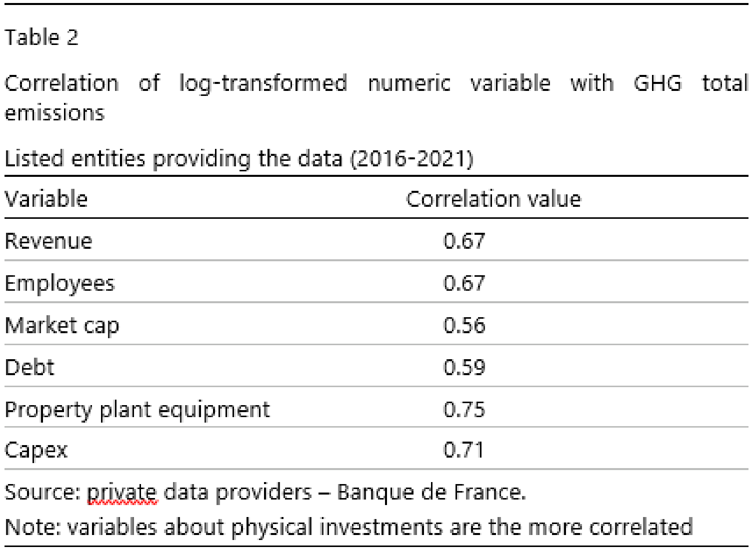


Table 2

Correlation of log-transformed numeric variable with GHG total emissions

Listed entities providing the data (2016-2021)

Variable	Correlation value
Revenue	0.67
Employees	0.67
Market cap	0.56
Debt	0.59
Property plant equipment	0.75
Capex	0.71

Source: private data providers – Banque de France.

Note: variables about physical investments are the more correlated

ALLOCATION MODEL *(NB: we don't collect VA for DIEs)*

1) Holding ratio

$$GHG_{DIE}^{gross} = \frac{DIE_{\boxed{book\ value}}}{Parent_{long\ term\ investments}} GHG_{total\ emissions}$$

3rd best choice:

- Property plant equipment
- Employees (could be done for liabilities)

2) Correction step: from environmental efficiency

$$GHG_{DIE}^{corrected} = \boxed{\frac{GHG\ emissions_{country,sector}}{VA_{country,sector}}} GHG_{DIE}^{gross}$$

Energy efficiency

Missing data imputation:

1) Neighbour
2) Worst case

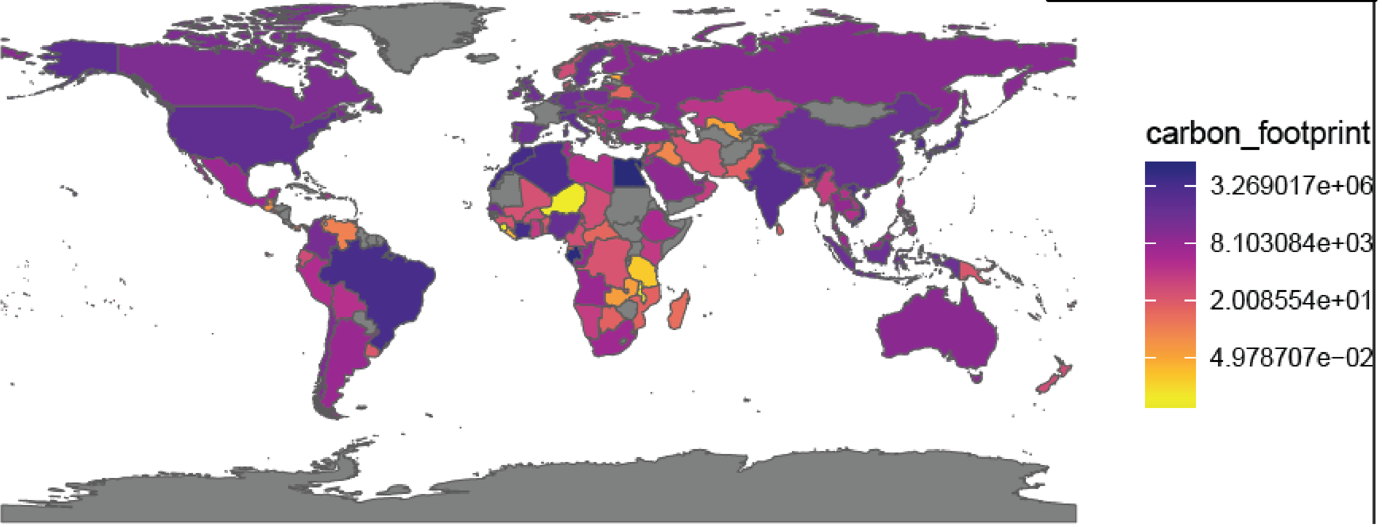
3) Normalization step (at a group level)

$$GHG_{Fictive\ DIE} = \overline{GHG_{Known\ DIEs}^{corrected}}$$

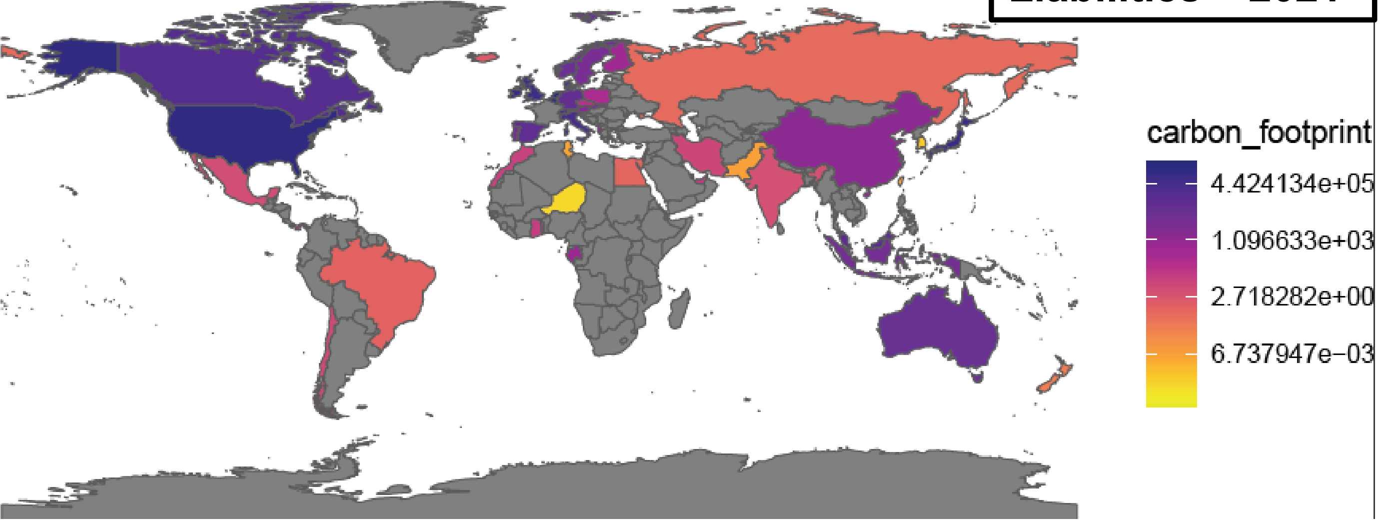
$$GHG_{DIE} = \frac{GHG_{DIE}^{corrected} GHG_{total\ emissions}}{GHG_{Fictive\ DIE} + GHG_{Known\ DIEs}^{corrected}}$$

RESULTS

Assets – 2021



Liabilities – 2021



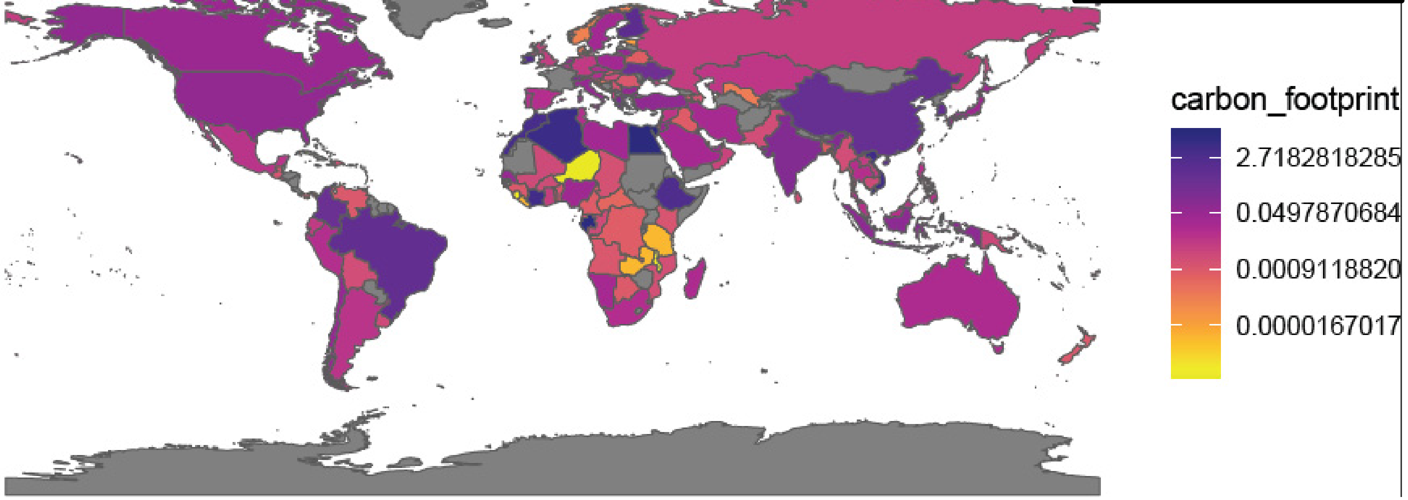
Log scale (tons of CO2)
~50% of FDI (in value)

Scope 1

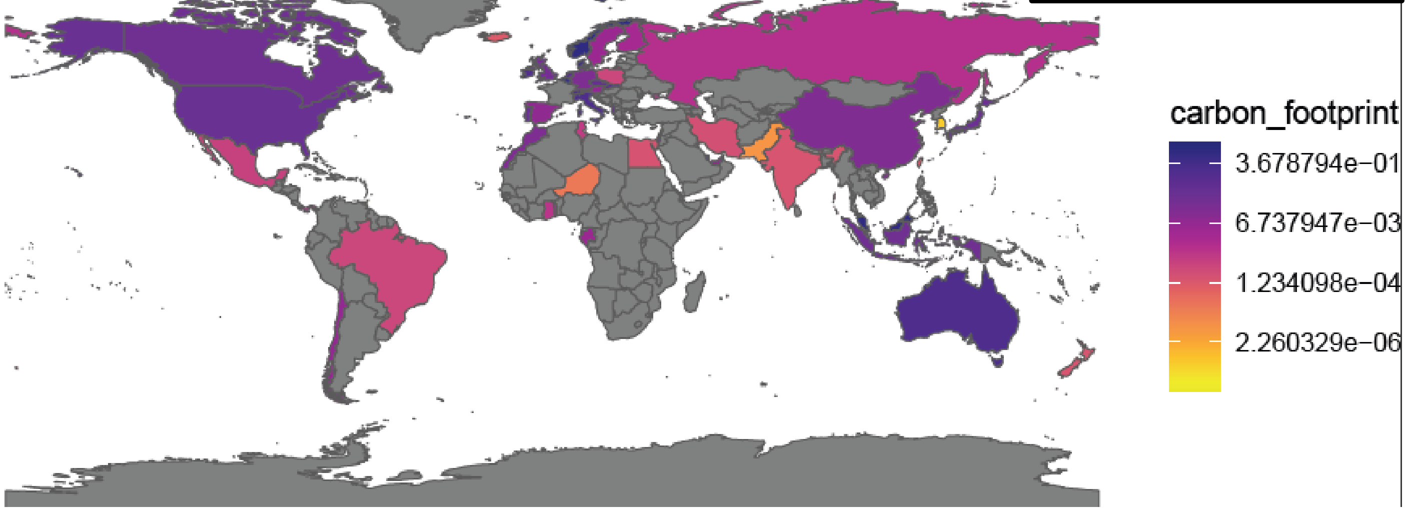
- Direct emissions

RESULTS – INTENSITY

Assets – 2021



Liabilities – 2021



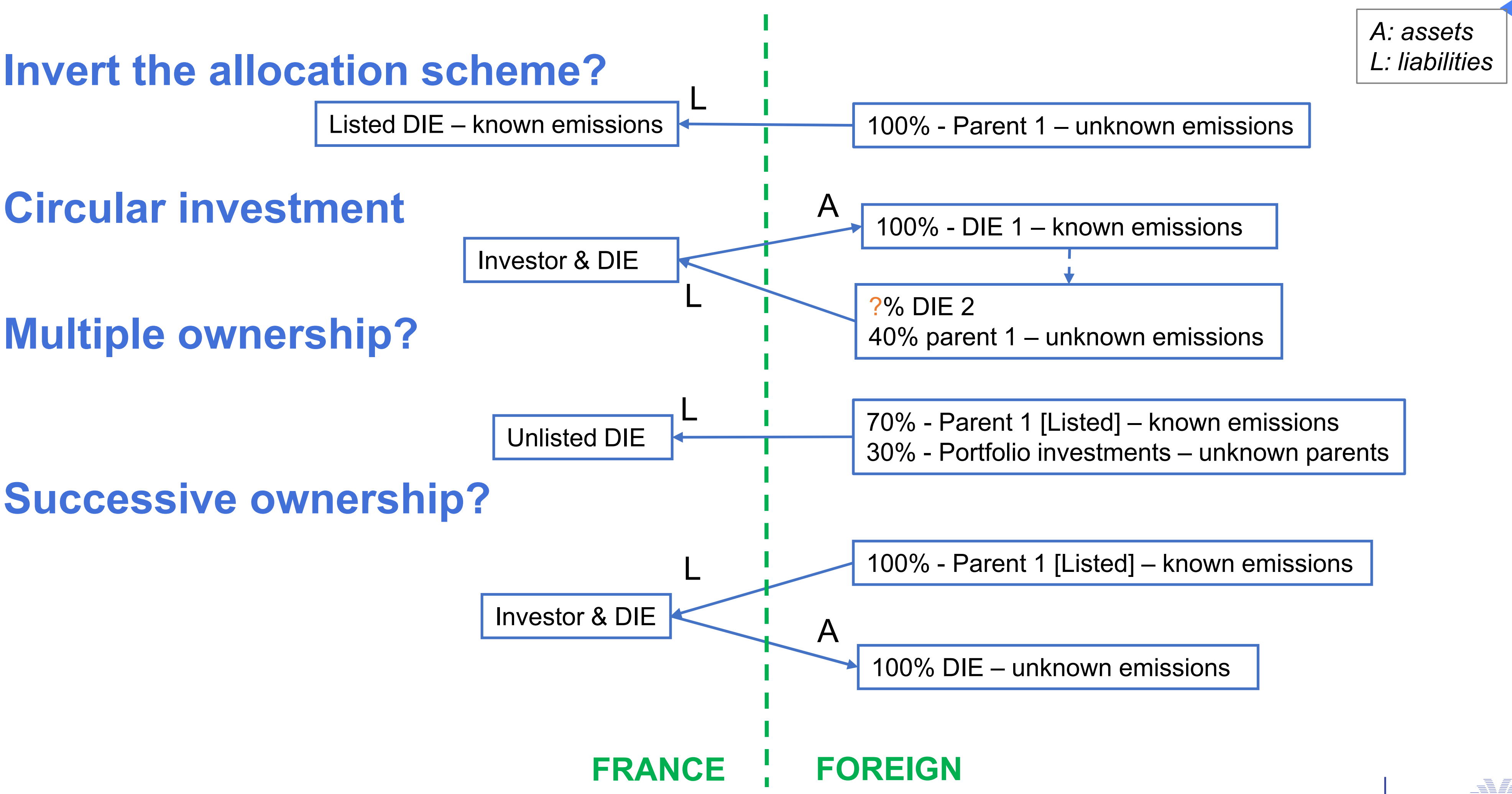
Log scale (tons of CO2 / FDI value)

~50% of FDI (in value)

Scope 1 & 2

- Use the ratio of energy sector in the allocation model
- Some DIEs might own their provider
- Scope 1 of energy sector might duplicate with other sectors' Scope 2
- Better represents what GHG emissions DIEs are responsible of

CURRENT ISSUES DUE TO FDI COMPLEXITY



A: assets
L: liabilities

Invert the allocation scheme?

Listed DIE – known emissions ← L ← 100% - Parent 1 – unknown emissions

Circular investment

Investor & DIE → A → 100% - DIE 1 – known emissions

Investor & DIE ← L ← ?% DIE 2
40% parent 1 – unknown emissions

Multiple ownership?

Unlisted DIE ← L ← 70% - Parent 1 [Listed] – known emissions
30% - Portfolio investments – unknown parents

Successive ownership?

Investor & DIE ← L ← 100% - Parent 1 [Listed] – known emissions

Investor & DIE → A → 100% DIE – unknown emissions

FRANCE

FOREIGN

LIMITS AND FUTURE WORK

- **Underestimates**
  - 50% FDI

- **Further improvements**
  - Explore other data for the imputation of energy efficiencies’ ratios
  - Most of granular GHG emission data is estimated

- **Complementary approach**
  - Estimate value added (VA) at affiliates’ level
  - Use VA to allocate emissions across DIE

$$GHG_{DIE} = VA_{DIE} \times \frac{GHG_{Country,Sector}}{VA_{Country,Sector}}$$

Some caveats will remain (VA estimation, successive ownership, missing data…)

BANQUE DE FRANCE

EUROSYSTÈME

IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

ESG work at the Central Bank of Angola[1]

S Monteiro,
Central Bank of Angola

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

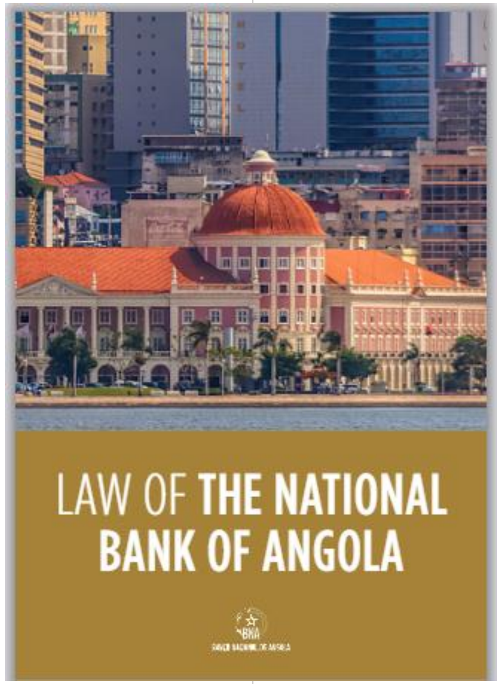
ENVIRONMENT, SOCIAL AND GOVERNANCE (ESG) AT BANCO NACIONAL DE ANGOLA – CENTRAL BANK

BANK OF TURKEY - Workshop "Addressing climate change data needs: the global debate and central banks' contribution

Suzana Monteiro, *Senior Advisor to the Governor*
April, 2024

CONTENT

01 Introduction



LAW OF THE NATIONAL BANK OF ANGOLA

Base

- The BNA is the authority for monetary supervision and resolution, both macroprudential and microprudential, and its main mission is price stability and financial stability, becoming a participant in the sustainable development process of the Angolan economy;
- The BNA has started to **consider the topic of ESG as one of its priorities**, just like most central banks and financial supervisors;
- The **environmental pillar** has gained greater prominence because environmental risks, particularly associated with the phenomenon of climate change, constitute an important source of risk for financial institutions;
- Therefore, the sustainability strategy of the BNA is fundamentally based on three priority pillars aimed at promoting a culture of sustainability within its mandate, namely: **regulatory and supervisory policy, monetary policy and financial and corporate or institutional Stability**

02 ESG concepts: purpose and principles

ESG principles in the financial sector

- ESG practices, whose primary objective is to prevent “environmental and climate” damage, have been expanding in the face of the need to reconcile development and sustainability, a concern that is not new and that began to gain strength as early as 1972, with the holding of the United Nations Conference on Human Development and the Environment, better known as the “Stockholm Conference;

- ESG refers to **environmental, social and governance** factors that affect both people and the planet. Environmental risks refer to financial risks arising from environmental degradation and the loss of ecosystem services. Social factors include sub-factors such as equality, inclusion, data protection and privacy, labor standards, investment in human resources, poverty eradication and social well-being of society, customer satisfaction, etc. Governance factors include sub-factors such as organizational structure, senior management remuneration policies, audit committee structure, employee relations, diversity and equality, and so on.

- The main objective of adopting ESG in the functions of Central Banks is to improve the contribution of the allocation of financial resources to the promotion of sustainable and inclusive growth in order to guarantee financial stability in the face of risks arising from related risks, in particular climate and ESG in general.

02 ESG concepts: purpose and principles

ESG vs Sustainable Development Goals

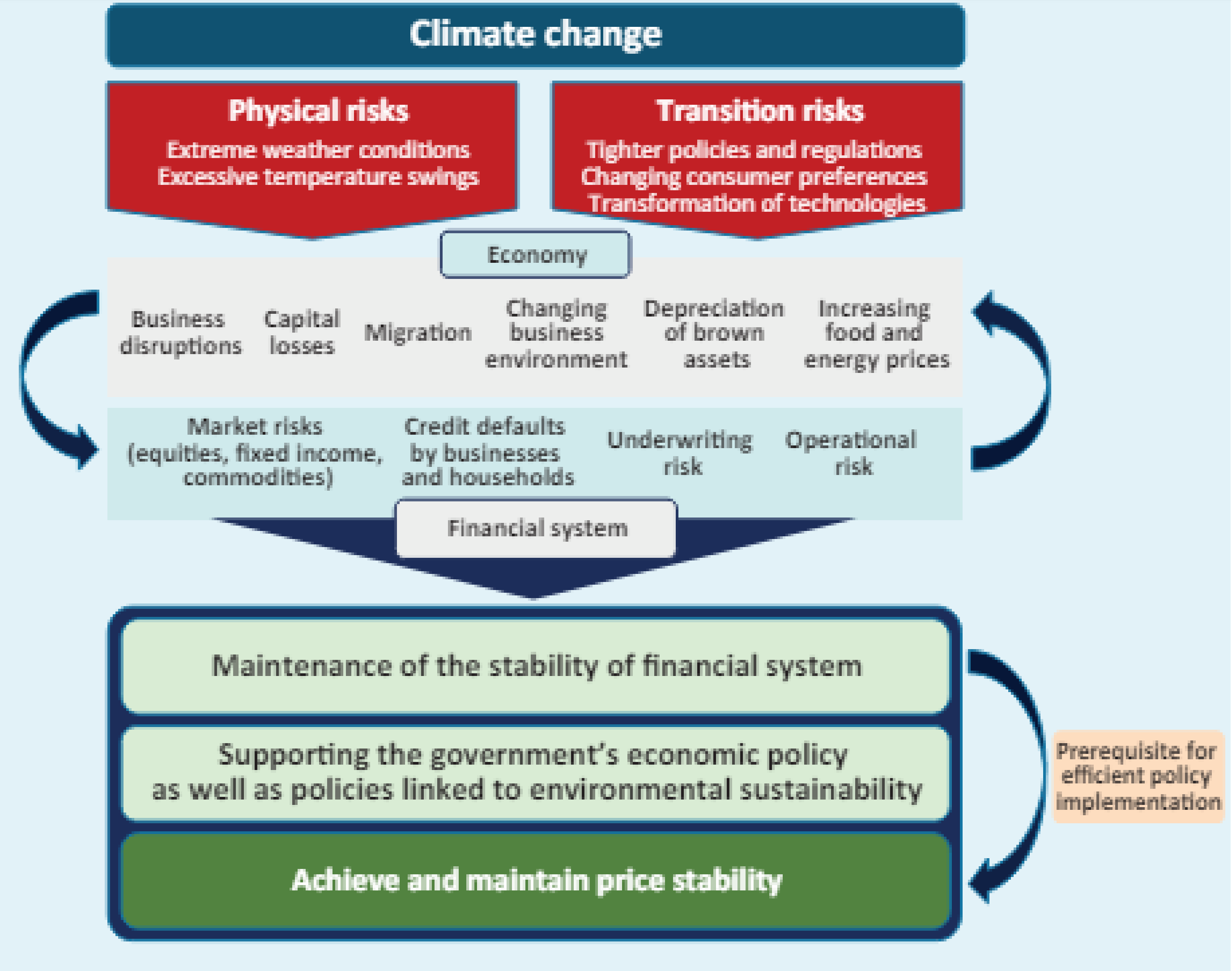
❑ This type of financial approach, **aims to provide capital to businesses** that are able to demonstrate a commitment and efective practices, towards lowering:

- carbon emissions
- ecossystems degradation
- water stress
- polution and
- waste disposal
- together with promoting social inclusion, transparency and accountability.

❑ By doing so, **financial institutions and investors are aligning their investment decisions with global sustainability policies, such as:**

02 ESG concepts: purpose and principles

Impacts of climate change on the primary and secondary objectives of the CB.



Source: MAGYAR NEMZETI BANK (MMB) https://www.mnb.hu/letoltes/sustainability-and-central-bank-policy-green-aspects-of-the-magyar-nemzeti-bank-s-monetary-policy-toolkit.pdf.

- ❑ On the other hand, climate-related financial risks, whether originating from physical or transition risks, have a significant impact on financial systems and prices;

- ❑ For this reason, several central banks have increasingly expanded their functions and tools for managing for international reserves, monetary and financial policy, as well as microprudential and macroprudential tools, in order to better manage and incorporate climate and environmental aspects into their activities.

02 ESG concepts: purpose and principles

Climate-related risks, Opportunities, and Financial Impact..

Source: Task Force on Climate-related Financial Disclosures (TCFD), report June 2017.

❑ Risks to financial stability from climate change are typically divided into:

Physical risks include the economic costs and financial losses resulting from the increased severity and frequency of extreme climate change-related weather events as well as longer term progressive shifts of the climate.

Transition risks are related to the process of adjustment towards a low-carbon economy. Emissions must eventually reach “net zero” to prevent further climate change, which will likely have a significant impact on all sectors of the economy affecting financial assets values.

03 Benchmark: Central Banks Engaged in "Green" Activities and Their Core Objectives.

N.º	Central Bank of	"Green" central banking activities	Mandates Objectives
1	Austria (ESCB)	2018: Oesterreichische nationalbank becomes NGFS member	Price stability, "need of the national economy with regard to economic growth and employment trends shall be taken into account and the general economic policies in the European Union shall be supported"
2	Australia	2018: reserve bank of Australia becomes NGFS member	a) The stability currency of Australia; b) the maintenance of full employment in Australia; c) and the economic prosperity and welfre of the people of Australia.
3	Bangladesh	2009: Bangladesh Bank introduces green refinancing lines 2012: Bangladesh Bank becomes a SNB member 2016: Bangladesh Bank issues "integrated Risk Management Guidelines for Financial Institutions", green portfolio ceiling, Green Transformation Fund; 2017; Bangladesh Bank issues Guidelines on Environment & Social Risk Management for Banks and Financial Institutions.	Price stability, "towards fostering growth and development of country´s productive resources in the best national interest
4	Belgium	2017: Nationale Bank van Belgie becomes TCFD supporter 2018: Nationale Bank van Belgie becomes NGFS member	Price stability, financial stability

03 Benchmark: Central Banks Engaged in “Green” Activities and Their Core Objectives.

	Central Bank of	“Green” central banking activities	Mandates Objectives
5	Germany	2017: Deutsche Bundesbank becomes a founding member of NGFS	Price Stability
6	India	2015: reserve Bank of India introduces Priority Sector Lending – targets and Classification	“maintain price stability while keeping in mind the objective of growth”
7	Jordan	2016: Central Bank of Jordan becomes SBN member	The objective of the central bank shall be to maintain monetary stability …
8	Luxembourg	2018: Banque Centrale du Luxembourg becomes NGFS member	Price stability
9	Mexico	2017: Banco de Mexico becomes founding member of NGFS.	Price stability, “thereby strengthening the State´s guidance of national development”.
10	Mongolia	2012: Bank of Mongolia becomes SBN member 2014: Bank of Mongolia issues Mongolia sustainable Finance Principles and Sector Guidelines (with Mongolia Bankinf Association).	Price stability, maintaing the stability of financial market and banking system to support balanced development of national economy”
11	Nigeria	2012: Central Bank of Nigeria becomes SBN member	“Monetary and price stability, financial stability, economic and financial advice to government
12	Spain	2018: Banco de Espanha becomes NGFS member	Price stability, “the public authorities shall promote favarable conditions for social and economic progresso and for a more equitable distribuiton of regional and personal incoe within the framework of a policy of economic stability. They shall in particular carry out a policy aimed at full employment.”

03 Benchmark: Climate Change policy landscape banchmark.

- ❑ In order to guide its transition to a low-carbon economy, we found that regardless of whether there is an explicit mandate, the majority of Central Banks covered have already adopted green financing policies or guidelines, whether in the management of their own portfolios or in the form of a more integrated approach, driving the banking sector towards sustainability.

	CB mandate includes sustainability or sustainable	CB recognises climate risk as financial risk	CB committed to moving financial sector towards sustainability	CB incorporates sustainable finance in its portfolio	CB embraces CSR
Angola		x	x	x	x
Egypt		x	x	x	x
Kenya		x	x	x	x
Mauritius		x	x	x	x
Marrocco		x	x	x	x
Nigeria			x	x	x
South Africa	x	x	x	x	x
Tanzania	x		Not clear	Not clear	x
BCEAO	x	x	x	x	x

Source: Author´s summary, page 100. https://www.iai.it/sites/default/files/iairs_8.pdf. CB- central bank. CSR - Corporate Social Responsibility.

04 ESG: what are we doing

Angola is subdivided into two seasons throughout the year: summer and warm winter. In 2023, Cacimbo's dry weather lasted until September, instead of ending in August as expected. In November, we experienced rains similar to those in April. These are just two examples of the climate changes experienced in Angola that we have experienced firsthand. What does this mean for our financial system?...it's time to act! For sure that´s a wake up call!

BNA.

04 ESG: what are we doing

Promoting sustainable finance

NGFS Glasgow Declaration
Committed to Action

1. **Subscrição dos Acordos de Paris**; Inclusion of the SDGs in the National development plan; Inclusion of sustainable financing in the National climate change strategy;

2. In January 2022, **CSSF set ESG in its Strategic Plan 2022 -2023**;

In **December 2022**, the CSSF carried out a **diagnosis to assess the level of maturity of ESG** (First financial market survey);

3. **Established a cooperation** agreement:
Bank of France and French Development Agency (ADF);
ESG taxonomy for the Central Bank (in course).

4. First **generic recommendations for the SFA**; Market awareness: **international conference**, together with the different SFA regulators.

5. In March 2024, **the Bank approved its sustainability policy: 3 (three) strategic areas.**;
Task force multi-sectorial.

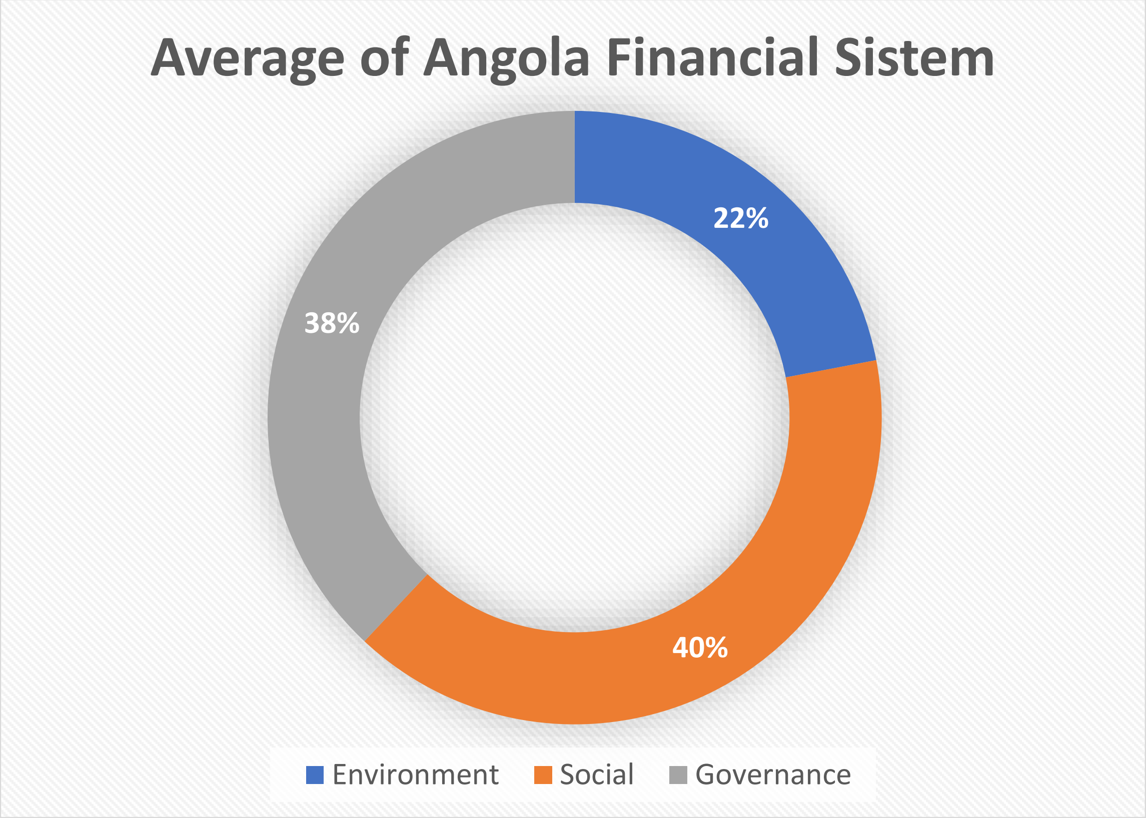

ESTRATÉGIA NACIONAL PARA AS ALTERAÇÕES CLIMÁTICAS 2018-2030
República de Angola

Ensure the resilience/stability of the financial system in the face of ESG risks

04 ESG: what are we doing

- ☐ In December 2022, the CSSF carried out a survey to assess the level of maturity regarding the adherence to environmental, social and governance principles and criteria by financial institutions operating in the Angolan market, in a context in which there was no specific legislation about the matter;

- ☐ The **result of the survey** carried out demonstrated that the Angolan financial system is still in an early stage, with the environmental axis demonstrated the lowest level of engagement.



Result of the 1st First Survey of the Angolan Financial System (SFA).

04 ESG: what are we doing

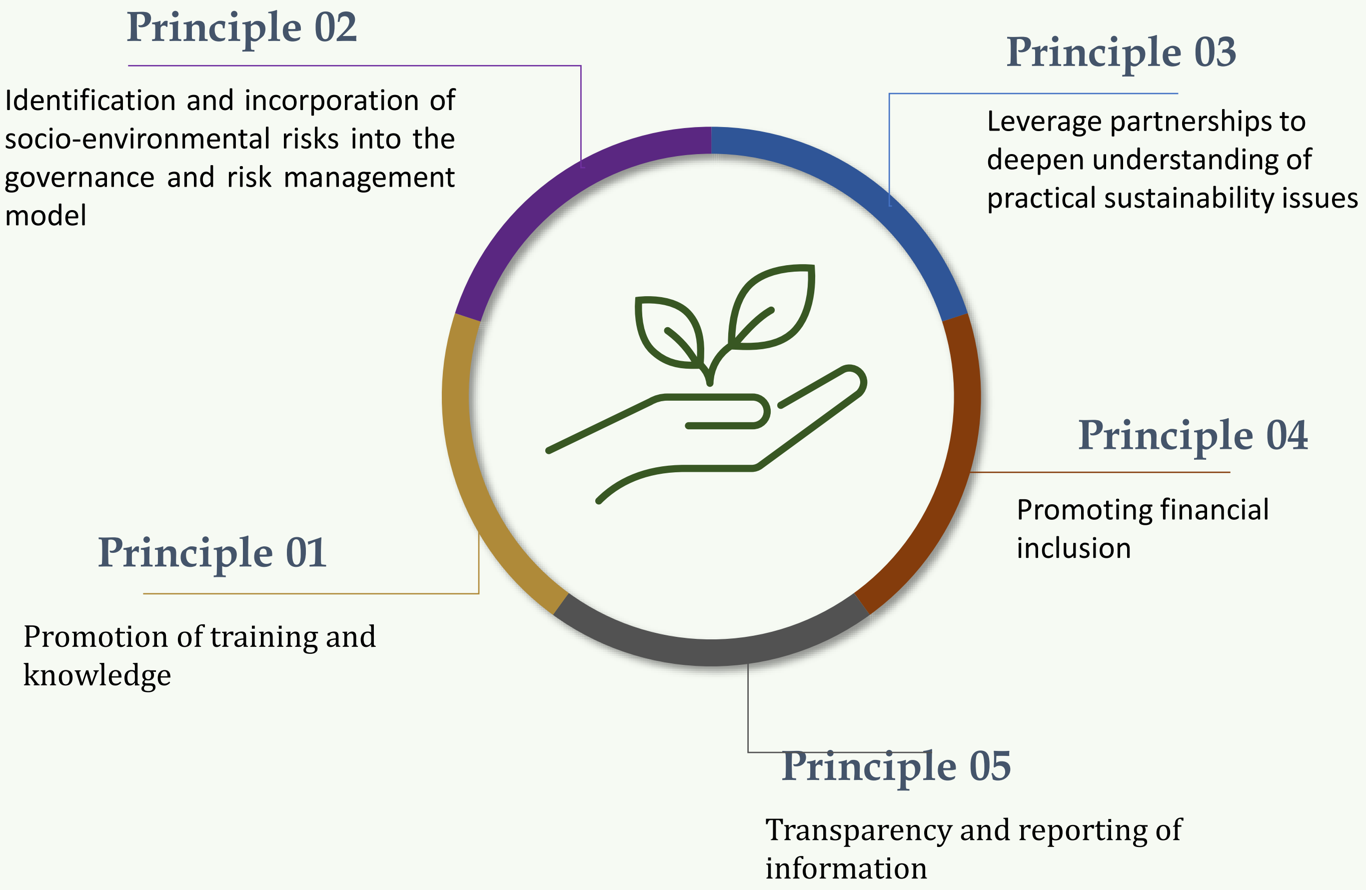
CSSF CONSELHO DE SUPERVISORES DO SISTEMA FINANCEIRO

PRINCÍPIOS DE SUSTENTABILIDADE DO SISTEMA FINANCEIRO ANGOLANO

Versão I – Recomendações Genéricas

18 DE AGOSTO DE 2023

SFA SUSTAINABILITY PRINCIPLES



Principle 02

Identification and incorporation of socio-environmental risks into the governance and risk management model

Principle 03

Leverage partnerships to deepen understanding of practical sustainability issues

Principle 04

Promoting financial inclusion

Principle 01

Promotion of training and knowledge

Principle 05

Transparency and reporting of information

04 ESG: what are we doing

3 (three) strategic Pillars

Corporate

- In January 2023, a comprehensive diagnosis was carried out to identify ESG practices at BNA;
- Improvement at BNA governance: for the first time, has executive and non-executive member of the board;
- Created committees and subcommittees to support the Board of Directors;
- Mapping its carbon footprint,
- preparing a waste and water management system;
- Updating its purchasing policies and regulations to include sustainable parameters in contracts;
- On going social taxonomy;
- On going decarbonization Program to achieve carbon neutrality.
- social responsibility policy,

Monetary Policy and Financial Stability

- Integrate climate-related considerations into its monetary policy analyses;
- Study on the impact of socio-environmental risks on the Angolan economy;
- Study on the definition of sustainability criteria for reserve management;
- Improve the monetary policy transmission mechanism.

Regulation and Supervision

- **Reforms in terms of regulation and supervisory processes**: law, regulation and supervision process;
- Five-year period 2023 – 2028, the BNA defined as one of its strategic plan: ensure the modernization and sustainability of the financial system;
- First survey on banking revealed a low level of maturity: Environment: 26%; Social: 50%; Governance: 53%;
- Incorporate ESG criteria and standards into their risks management model: ICAAP and Market discipline;
- Revisar a regulamentação para incorporação dos padrões ESG;
- Update Stress tests to incorporate climate risks, on going.
- Update its corporate governance regulation.

05 Final Consideration, Challenge and Perpective

- ❑ The incorporation of ESG pillars into the Angolan financial system, mainly in the banking sector, is at its early stage, therefore commercial banks should seek to increase their maturity in “environmental” and social terms by improving their internal sustainability practices and while at the same time developing products that help industries in emissions reduction/decarbonization;

- ❑ The published principles played a crucial role in pressuring financial institutions in general, and banks in particular, to adopt ESG principles in defining their strategies;

- ❑ Therefore, it is clear that there must be a joint effort between regulators and supervisors of the financial system as well as the market to increase the level of awareness and, consequently, maturity from the point of view of environmental protection;

- ❑ the BNA is at the forefront of initiatives that have included the financial system in general, and in particular with the calculation of its carbon footprint, with its social responsibility policy and with its ongoing decarbonization plan;

05 Final Consideration, Challenge and Perpectives

Challenges

- Insufficiency and training of human resources;
- Lack of expertise;
- High costs for IFB in implementing new requirements and ESG criteria;
- Outsourcing;

Perpectives

- Develop a sustainability framework for the SFA;
- Integration of ESG practices in the implementation of the institutions' strategic;
- Create database and define statistical indicators;
- Climate stress testing exercises;
- Carry out a second round of the survey on ESG;
- Define rules for reporting and disseminating information regarding ESG to the market.

BNA

Thank you!

04 ESG: what are we doing

Mar. 2022

Definition of Sustainability as the fourth pillar of the CSSF Strategy

Dez. 2022

Diagnosis on the maturity level of Financial System

Jan. 2023

The working group for the creation of the BNA Sustainability Policy has been approved and work has begun

NGFS Glasgow Declaration
Committed to Action

Dez. 2023

- BNA's accession to NGFS;
- Disclosure of diagnostic results;
- Promotion the creation of a multi-sectoral working group;
- Publication of sustainable banking principles.

2024

- 2nd round of the survey for diagnosis;
- Promotion of the creation of green/social taxonomy;
- Discussion around stress tests

LOADING...

IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

The role of governments in emission cuts: evidence from emerging and advanced economies[1]

C Özkan and Z Çavuşoğlu Adıgüzel,
The Central Bank of the Republic of Türkiye

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

The Role of Governments in Emission Cuts: Evidence from Emerging and Advanced Economies

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Abstract

Government policies such as subsidies, environmentally-related research and development expenditures and technological incentives play crucial role in mitigating the implications of climate change. Our study investigates the role of governments in scaling up climate transition in advanced and emerging countries. We employ Panel Augmented Mean Group Estimator to find the long-term relationship between carbon intensity and various government policies. Covering 2010-2021 period, the data of 18 countries were included in the estimations. Carbon intensity, as a measure of climate change, is proxied by carbondioxide (CO2) emissions per GDP while government policy is represented with 3 indicators: i. Total fossil fuel support as a % of tax revenue, ii. Environmentally-related government research and development (R&D) budget as a % of total government R&D budget and iii. Development of environment-related technologies as a % of all technologies. The results of the estimation covering all countries in the dataset indicate that development of environment-related technologies is positively interrelated with CO2 emissions per GDP, contrary to our ex-ante expectations. It is inferred that the development of technologies does not necessarily reflect their level of usage. As for emerging countries, there is a mixed pattern in the interrelation between climate change and explanatory variables related to government policies. This is partly because the environmental policies and regulations in emerging countries are not sufficiently entrenched to achieve intended results and there appears to be a lack of effective data reporting. On the other hand, the results indicate that in advanced countries, fossil fuel subsidies are positively interrelated with CO2 emissions per GDP in the long-term, compatible with our ex-ante expectations on the deteriorating impact of fossil fuel subsidies on climate change. Checking country-based estimation results, it is striking that in advanced countries with higher income levels, development of environment-related technologies does not contribute to limit climate change. This finding confirms difference between exporters and end-users of environmental technologies. We draw attention to the export factor where the exporter bears the environmental damages of production process while not thoroughly benefitting from the environmental advantages of the technology. US, UK, Canada, Japan and Germany, where environment-related technologies are not interrelated with carbon intensity, might be considered as predominant technology-exporters. Finally, we propose additional policy implications regarding the role of governments in emission cuts. Government support might range from grants, subsidies, feed-in-tariffs, tax exemptions, direct tax credits, credit guarantees and other kind of incentive schemes for decarbonization technology investments. Along with financial support, governments might also support decarbonization via creating an enabling regulatory landscape for the development of climate and environment-related technologies as well as removing information asymmetries pertaining to climate investments.

Keywords: Carbon Intensity, Government Policy, Environmentally-related R&D Budget, Fossil Fuel Subsidies, Environment-related technologies

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1. INTRODUCTION

Climate change has recently been more pronounced around the globe. On this ground, Paris Agreement serves as a significant landmark to mobilize a global response to the threat of climate change. Although the Agreement is not legally binding under international law, all stakeholders including governments are considered as part of global climate effort. It is hopeful that there has been some progress in cutting global emissions, since the Paris Agreement was signed in 2015. Still, the world is heading for a temperature rise far above the Paris Agreement goals, unless countries deliver more than they have promised. UN's 2023 Emissions Gap Report finds that fully implementing unconditional Nationally Determined Contributions (NDCs) made under the Paris Agreement would put the world on track for limiting temperature rise to 2.9°C above pre-industrial levels this century. (UN, 2023). Furthermore data shows that significant amount of renewable power additions are required to meet government targets with deadlines between 2020 and 2030. (FS-UNEP Centre, 2020) Thus, all sectors of the global economy will have to go a massive transformation to drive the emission reductions so as to live up to the Paris Agreement targets.

In an attempt to promote sustainable economic development, a supportive environment is needed to scale up domestic manufacturing capacities for the climate and environment-related technologies[3]. Technologies that are used to address climate change are known as climate technologies. Climate technologies that help reduce greenhouse gas emissions include renewable energies such as wind energy, solar power and hydropower. As for environment-related technologies, they include the means of production and services that contribute to the efficient use of available resources, as well as the protection and conservation of natural resources. Climate and environment-related technologies both have positive environmental impact and contribute to sustainability. The most common feature of all these technologies is that they all require high level of upfront investment, which pays itself back gradually.

Here comes the crucial role of government. Albeit being in varying levels, the role of governments in achieving climate targets and tackling climate change is undoubtful. Governments and related authorities might play a critical role in creating an enabling landscape for the development of both climate and environment-related technologies.

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[3] In this study, climate technologies and environment-related technologies are used interchangeably, due to the lack of data on climate technologies.

Along these lines, it has recently been witnessed that some governments announced plans to green their industries and scale up climate transition in their respective jurisdictions. First and foremost is the European Union's (EU) Green Deal Industrial Plan. While the European Commission is looking to "secure the EU's industrial lead in the fast-growing net-zero technology sector", the plan is primarily to level the climate finance playing field following the passing of the Inflation Reduction Act (IRA) in the US and new subsidies to boost domestic clean-technology manufacturing in China (EU Commission, 2023). The current juncture has also witnessed the rise of green protectionism efforts by many jurisdictions, to secure the delivery of critical minerals. Furthermore, recent data indicates an upward trend in government measures to combat climate change; such as collecting environmental taxes and allocating government spending on environmental protection (IMF, 2023). All these recent actions and policies in the global or domestic landscapes reveal that governments are also in the game to address the implications of climate change.

Recently, government-provided fossil fuel subsidies that aim to support certain industries or households, have been loudly criticized due to their potential effect on increasing CO2 emissions, and subsequently elevating climate change. In this context, Black et al. (2023) puts forward the current use of fossil fuel subsidies by country and region and at the global level. According to data, global fossil fuel subsidies reached to $7 trillion by the end of 2022, representing 7.1% of global GDP. It defines total fossil fuel subsidy as a multiplication of consumption with the gap between efficient prices (total of supply, environmental and other costs) and retailed prices. This price gap is so pronounced that increased use of fossil fuels is leading to climate-related damages and exposure to air pollution, which is responsible for 4.5 million premature deaths worldwide. In addition, underpricing of fossil fuels reduces government revenues and disrupts the achievement of income distribution targets, as underpricing tends to benefit the wealthy rather than the low-income segment. The same study argues that fossil fuel price reform to remove subsidies could cushion global CO2 emissions by 43% below baseline levels by 2030, increase revenues by 3.6% of global GDP and restrain 1.6 million deaths a year from air pollution.

Another intriguing question is whether or not government policy is needed to redirect technical change from dirty to clean technologies. The response to the question has been widely discussed in the literature. Our study, as an attempt to comtemplate on the issue, builds its discussion on the stated earlier literature, while mainly targeting to capture the role of governments in scaling up climate transition in several jurisdictions.

We try to explore the interrelation between carbon intensity and government policy. Carbon intensity is proxied by CO2 emissions per GDP in each jurisdiction, on a yearly basis. Basically, carbon intensity is a measure of carbon dioxide per unit of activity, like generating a product. We believe that this indicator is a better proxy, depicting the level of dirtiness of the production. We proxy the government policy by 3 indicators; i. Environmentally-related government R&D budget as a % of total government R&D budget, ii. Total fossil fuel support as a % of tax revenue and iii. Development of environment-related technologies as a % of all technologies. The study is a cross-country analysis, aiming to differentiate between emerging and advanced economies. OECD Green Growth Indicators are utilized in annual frequency, with the most available time horizon. The study employs Panel Augmented Mean Group Estimator, based on cross-sectional dependence and slope homogeneity test results.

Our paper acknowledges the role of government in mitigating climate change, not only by the monetary support but also non-monetary support. Thus, we also focus on governments' and related public institutions' supporting role in increasing private climate investments, via closing climate-related data gaps and removing information asymmetries. Indeed, international institutions are also helping to remove such information barriers. IMF Climate Change Indicators Dashboard, World Bank Climate Change Knowledge Portal, OECD Climate Action Monitor, BIS Irving Fisher Committee on Central Bank Statistics and G20 Sustainable Finance Progress Tracking Dashboard are leading initiatives to effectively address climate-related data gaps.

The study, while including an analytical approach, also discusses the issues stated above. The remainder of the study is organized as follows: Section 2 reviews the literature. The data are presented in Section 3, while model and methodology are discussed in Section 4. Section 5 discusses panel estimation results. Finally, Section 6 concludes.

2. LITERATURE REVIEW

The interrelation of the climate change with various other indicators has been widely investigated in the earlier liteature. Examination of this line of literature reveals that most of the literature use CO2 emissions as a proxy for climate change.

Examining the empirical research, we find that Moosavian et al. (2022) try to constitute a government policy in respect to subsidy rate on research&development (R&D) investment and tax rates on fossil fuels in order to achieve the highest benefits in economic, welfare and environmental terms. They use a computable general equilibrium model to find the optimum subsidy rate for both R&D investment in GDP and the tax rate imposed on fossil fuels. In the context of the model, the optimal level of subsidy and tax rate is calculated based on two scenarios. Based on the results of the scenarios, they conclude that both of the fossil fuel tax policy and the environment-related R&D subsidy policy contribute to the reduction of energy consumption, air pollution and welfare, excluding the social benefits achieved by environmental government policies.

Petrovic and Lobanov (2019) examine the effect of R&D expenditure on CO2 emissions in 16 OECD countries. The results of the long-run regression indicate an expected average negative effect of R&D expenditure on CO2 emissions, while the country-specific analysis shows that R&D expenditure can have both negative and positive effects on emissions in the long-run. Thus, they emphasize that it is important for decision-makers to focus on reducing CO2 emissions when setting R&D policies, as R&D investments cannot be labeled beforehand as an emission-reducing factor.

Using a computable general equilibrium model, Yusoff and Bekhet (2016) examine the impact of removal of fuel subsidies in Malaysian economy. The study mentions that energy subsidies can lead to inefficient energy consumption and environmental pollution and have a negative impact on the government budget. The results of the general equilibrium model show that the removal of the subsidy policy significantly reduces fuel consumption and leads to an increase in the use of alternative energy. On the other hand, the removal of fuel tax subsidies also has a positive impact on macroeconomic variables, increasing real GDP, reducing government expenditure and increasing government revenue.

Garrone and Grilli (2010) explore the role of public energy R&D (PERD) spending on energy innovation process, by establishing a connection with carbon emissions per GDP. Their study examines two channels through which PERD influences greenhouse gas emissions: the carbon factor and the carbon intensity, where the carbon factor describes carbon emissions per unit of energy use. These two factors are important as their reduction leads to emission reductions without adverse effects on economic growth. In the analysis, 13 advanced economies are examined using a dynamic panel model, utilizing data for 1980-2004 period. The results show that, while PERD enhances energy efficiency, it does not have a significant contribution to explain the carbon factor and carbon intensity. They emphasise that government expenditures on R&D are necessary but not adequate to achieve the desired innovation in energy.

Halkos and Paizanos (2013) analyse the effect of government spending on the environmental pollution in 77 countries, using panel data spanning from 1980 to 2000. The study considers both direct and indirect effects of government spending on pollution, where its indirect effect comes from increasing per capita income. The study finds that government spending has a clear negative effect on CO2 emissions at all income levels, while it has a variable effect on sulphur dioxide emissions at different income levels.

In another interesting research, Acemoglu et al. (2012) argue that government policy is needed to steer technical change from dirty to clean technologies. They introduce an endogeneous growth model with endogenous and directed technical change and focus on the structure of the equilibrium with dynamic tax and subsidy policies that will ensure sustainable growth and maximize intergenerational welfare. Their endogenous growth model, which is in line with guided technological change, takes environmental constraints and limited resources into consideration. In their analysis, they divided inputs into clean and dirty (using non-renewable resources) to state that long-term sustainable growth can be possible with temporary policy measures when inputs are sufficiently substitutable. They also articulate that the optimal policies to prevent the intensive use of carbon taxes will consist of both carbon taxes and research subsidies. Additionally, they claim that the cost will increase in case of any delay in intervention and the economy will face environmental disaster when there is no intervention. As as a result, with timely interventions, environmental goals can be achieved without the need for continuous intervention and without compromising long-term growth. Otherwise, they stated that the laissez-faire paradigm would lead to environmental disasters.

Mongo et al. (2021) investigate the impact of environmental innovations, i.e. green technologies, on CO2 emissions. Their analysis employs an autoregressive distributed lag model (ARDL) model, utilizing data from 15 EU countries in the period between 1991 and 2014. In the model, they use environmental innovations, renewable energy consumption, GDP per capita and the degree of economic openness to explain CO2 emissions. According to the results, they interpret that environmental innovations would reduce CO2 emissions in the long run, while the effect of environmental innovations is reversed in the short run, indicating a possible rebound effect.

Du et al. (2019) examine the effect of green technology innovation on CO2 emissions with a panel data including 71 countries from 1996 to 2012, taking income level of the countries into account. The results show that green technology innovation does not contribute to mitigating CO2 emissions when the income level of the country is below a threshold which is close to USD 35,000. When the income level rises above this threshold, green technology innovation becomes a significant factor in reducing CO2 emissions.

Zhang (2021) investigates the impact of technological innovation and economic growth on carbon emissions employing Granger causality test and a regression model. The study utilizes panel data of five BRICS countries (Brazil, Russia, India, China and South Africa) from 1990 to 2019. According to causality test results, there is a one-way causality from both technology patents and economic growth to carbon emissions. On the other hand, regression results show that technology patents help reducing carbon emissions, as economic growth significantly uplifts carbon emissions.

To sum up, examination of the literature reveals varying results on the interrelation of environmental R&D expenditure as well as innovations with the level of CO2 emissions.

3. DATA

Our study utilizes data from various open international sources, mainly the data of international institutions. The data were used in annual frequency from 2010 to 2021, based on the availability of data span. The data of 18 countries have been included in the panel regressions, based on the availability of the country-based variables sourced from OECD Green Growth Indicators dataset. Thus; Chile, Colombia, Korea, Mexico, Türkiye, Czechia and Hungary were included in emerging countries, while Australia, Canada, France, Germany, Italy, Japan, Netherlands, Spain, Sweden, UK and US were included in advanced countries.

Table 1 summarizes the description of the data.

Table 1. Data Description

Abbreviation	Indicator	Measurement Scale	Source
CO2_Emission_per_GDP	CO2 Emission Per GDP (as a measure of carbon intensity)	t CO2/kUSD/yr	IEA-EDGAR CO2 Dataset (Crippa et al, 2022)
FFS_percentage_of_TR	Total Fossil Fuel Support	% of Tax Revenue	OECD Green Growth Indicators (OECD, 2024)
EnvR&D_percentage_of_GovR&D	Environmentally Related Government R&D Budget	% of Total Government R&D	OECD Green Growth Indicators (OECD, 2024)
EnvTech_percentage_of_AT	Development of Environment-related Technologies	% of All Technologies)	OECD Green Growth Indicators (OECD, 2024)

Descriptive statistics of the data are presented in Table 2. The descriptive statistics reveal that Environmentally Related Government R&D Budget, % of Total Government R&D variable has the highest standart deviation. It is also recognized that all series are positively skewed. The last but not least is that after checking residual variances, we transform all variables into logarithmic form to control heteroscedasticity, before employing our estimations.

Table 2. Descriptive Stats (Individual Samples)

Statistics	CO2 Emission Per GDP	Total Fossil Fuel Support, % of Tax Revenue	Environmentally Related Government R&D Budget, % of Total Government R&D	Development of Environment-related Technologies % of All Technologies)
Mean	0.20	1.27	3.04	12.28
Median	0.18	0.71	2.36	12.32
Maximum	0.41	12.19	21.56	26.42
Minimum	0.07	0.05	0.05	5.62
Std. Dev	0.07	1.69	3.53	2.72
Skewness	0.59	3.86	3.49	1.00
Kurtosis	2.41	21.57	15.21	7.52
Jarque-Bera	15.87	3544.55	1,692.29	183.69
Probability	0.00	0.00	0.00	0.00
Sum	44.38	266.74	624.67	2,210.79
Sum Sq. Dev.	1.36	599.38	2,550.87	1,324.58
Observations	216	210	205	180

4. MODEL AND METHODOLOGY

To explore the relationship between CO2 emissions per GDP and all other green growth indicators, we constructed the following model.

$$CO2\_Emission\_perGDP_{it} = \alpha + \beta_1\, FFS\_percentage\_of\_TR_{it} + \beta_2\, EnvR\&D\_percentage\_of\_GovR\&D_{it} + \beta_3 EnvTech\_percentage\_of\_AT_{it}$$

Based on our assumption checks, we find that there is cross-sectional dependence and slope heterogeneity in the dataset. Thus, we decided to use Augmented Mean Group (AMG) Estimator to estimate the model. AMG is one of the 2nd generation Panel ARDL estimators that deals with cross-sectional dependence and heterogeneity of slope parameters. The estimator was proposed by Eberhardt and Bond (2009) and developed by Eberhardt & Teal

(2010). It is possible to get long-run group-specific (emerging countries or advanced countries) coefficients. Due to the fact that AMG estimator is applicable even in the case of non-stationary data, it is not necessary to check unit-root and co-integration before employing AMG estimator.

Our assumption checks are employed at 3 stages. First, we inquired cross-sectional dependence in our data with 3 tests, Breusch-Pagan LM, Peseran Scaled LM and Peseran CD. Since the probability value shows 5% level of significance in all individual variables, confirmed by at least 2 tests, the null hypothesis is rejected. Thus, we report that there is cross-sectional dependence in each series. Furthermore, after estimating a simple ordinary panel regression, we checked the cross-sectional dependence of residuals as well and concluded that residuals are also cross-sectionally correlated.

Table 3. Cross-sectional Dependence Test

	Breusch-Pagan LM	**Peseran Scaled LM**	**Peseran CD**
Variable			
CO2_Emission_per_GDP	(1480.42) [0.00]*	(75.88) [0.00]*	(38.18) [0.00]*
FFS_percentage_of_TR	(472.66) [0.00]*	(18.27) [0.00]*	(-0.42) [0.67]
EnvR&D_percentage_of_GovR&D	(334.81) [0.00]*	(10.39) [0.00]*	(-0.025) [0.97]
EnvTech_percentage_of_AT	(360.78) [0.00]*	(11.87) [0.00]*	(11.70) [0.00]*
Residuals	(831.93) [0.00]*	(38.81) [0.00]*	(24.57) [0.00]*

Note: H_0: No cross-sectional dependence (correlation) (.) and [.] indicate test static and probability values respectively. * represents level of significance at 5%.

Second, we employed slope homogenity test of Pesaran, Yamagata (2008), named as Delta Test and its adjusted version. Based on the results of Delta test, we report that slope coefficients are heterogeneous except for the EnvR&D_percentage_of_GovR&D and the EnvTech_percentage_of_AT series, individually. However, since all 3 independent variables are jointly heterogeneous based on the Delta Test of the overall model, we infer that slope coefficients are heterogeneous.

Table 4. Slope Homogeneity Test

Delta	Overall Model	FFS_percentage_of_TR	EnvR&D_percentage_of_GovR&D	EnvTech_percentage_of_AT
$\hat{\Delta}$	(4.64) [0.00]*	(5.46) [0.00]*	(0.33) [0.74]	(-0.53) [0.60]
$\hat{\Delta}_{\text{adj.}}$	(6.64) [0.00]*	(6.97) [0.00]*	(0.43) [0.67]	(-0.76) [0.45]

Note: H_0: Slope coefficients are homogenous. (.) and [.] indicate test static and probability values respectively. * indicates level of significance at 5%.

At the last stage, we tested cointegration with Westerlund Cointegration Test. Based on the test results, we are able to reject the null hypothesis of no cointegration, confirming that variables are cointegrated in some panels as well as in all panels. Thus, we might infer that there is long-term relationship between investigated variables.

Table 5. Westerlund Cointegration Test

	H0: No cointegration Ha: Some panels are cointegrated	H0: No cointegration Ha: All panels are cointegrated
Variance Ratio	(4.90) [0.0000]*	(3.40) [0.0003]*

Note: (.) and [.] indicate test static and probability values respectively. * indicates level of significance at 5%.

5. ESTIMATION RESULTS

We use Panel Augmented Mean Group Estimator, the estimation results of which are summarised in Table 6, based on all countries, advanced and emerging country groups.

Table 6. Main Estimation Results

	All Countries	**Emerging Countries**	**Advanced Countries**
log_CO2_emission_perGDP			
log_FFS_percentage_of_TR	(0.029) [0.249]	(-0.023) [0.527]	(0.062) [0.021]*
log_EnvRD_percentage_of_Gov_RD	(0.014) [0.574]	(-0.003) [0.911]	(0.008) [0.749]
log_EnvTech_percentage_of_AT	(0.102) [0.018]*	(0.061) [0.186]	(0.086) [0.209]
__00000R_c	(0.954) [0.00]	(1.298) [0.00]	(0.852) [0.00]
_cons	(-1.758) [0.00]	(-1.658) [0.00]	(-1.710) [0.00]

Note: H0: Coefficient is equal to 0, (.) and [.] indicate coefficient and probability values respectively. * represents level of significance at 5%.

When **all countries** are included in the panel regressions, only variable that has significant contribution in explaining carbon intensity is the development of environmental technologies as a % of all technologies. However, the sign of the coefficient reflects a positive long-term relationship between the percentage share of environmental technology innovation and CO2 emissions per GDP, contrary to our ex-ante expectation. Based on this finding, we infer that development of technologies within a country does not necessarily reflect their level of use, as many countries export technologies. Thus, while countries may suffer from the side effects of technology development during production process, they may not be able to reap the long-term benefits of environment-related technologies in terms of reduction of CO2 emissions. Additionally, our dataset includes 13 years, which could be relatively short to see the long-term relation between environmental technologies and CO2 emissions. There is also some supporting evidence in the literature that the short-term implications of environmental technologies on climate change might be different from their long-term implications. On the other hand, there appears no significant relationship between CO2 emissions per GDP and other two variables in the model: Environmentally-related government R&D budget as a % of government R&D budget (research and development budget) and Total fossil fuel support as a % of tax revenue (fossil fuel support) (Table 6).

As for **emerging economies**, none of three explanatory variables shows significance to indicate a relationship with CO2 emissions per GDP in the long run. The results suggest a lack of efficient and sufficient data reporting on environmental policies in emerging economies. Furthermore, environmental policies in some emerging economies are not associated with a long history. Even if they are, the effective enforcement and results of these policies are somewhat questionable (Table 6).

Examining the estimation results for **advanced economies**, the significance level and the sign of the coefficient of fossil fuel support variable indicate that increased fossil fuel subsidies lead to deteriorating climate change problem, which is in line with the literature and with our ex-ante assumptions. The results draw attention to the negative implications of government policies in the form of subsidies on climate change. Such policies encourage the production and the consumption of fossil fuels. They directly guide consumer/producer behaviour to prefer fossil fuels and to make full use of government support, taking advantage of reduced production costs or reduced expenditure in energy. In addition, fossil fuel subsidies keep older technologies in place, leading to a more carbon-intensive production process. They therefore tend to inhibit the development of and the transition to clean technologies. Finally, aggregate results on advanced economies indicate that environmental technologies and environmental R&D budget do not contribute to limit climate change (Table 6).

Based on **country-level estimations of emerging countries**, the green technology variable is significant in 4 out of 7 emerging economies (Chile, Korea, Türkiye, Hungary). In Chile, Korea, Hungary, it has a positive long-term relationship with CO2 emissions per GDP. This might be resulting from the fact that the industrial production processes are relatively dirtier in these countries due to insufficiency or lack of climate policies or regulations. Besides, Türkiye is the only emerging country, where environmental technologies are contributing to the expected ex-ante reduction in CO2 emissions. This might indicate that Türkiye is domestically using its environment-related technologies, rather than exporting them. In addition, the industrial production processes might be relatively cleaner. Lastly, fossil fuel support variable is not significant in any of the emerging markets (Table 6.1).

Based on **country-level estimations for advanced economies**, in high-income countries such as Australia, Canada, France, Germany, Japan, the United States of America, the United Kingdom, green technologies are found to be unrelated with CO2 emissions per GDP, implying that development of environmental technologies does not contribute to limit climate change. This leads us to the argument that the development of technologies does not necessarily reflect their level of usage. These countries might be considered as predominant technology-exporters. However, in 3 out of 11 developed countries (the Netherlands, Spain, Sweden), the estimation results indicate a significant positive relationship between green technologies and CO2 emissions, implying adverse affects of technology development process on the environment. In the context of this study, the Netherlands stands out, as all explanatory variables are significant in the case of this country. Perhaps it is because the Netherlands has been an advanced practitioner of environmental policy for many years and it provides efficient data reporting for analysis (Table 6.2).

Table 6.1. Country-Based Estimation Results - Emerging Economies (EMEs)

	CHL	**COL**	**KOR**	**MEX**	**TUR**	**CZE**	**HUN**
log_FFS_percentage_of_TR	(0.056) [0.317]	(-0.074) [0.162]	(0.031) [0.397]	(0.008) [0.258]	(0.059) [0.165]	(-0.058) [0.059]	(-0.250) [0.12]
log_EnvRD_percentage_of_Gov_RD	(-0.166) [0.161]	(0.058) [0.487]	(0.151) [0.005]*	(0.005) [0.926]	(0.015) [0.784]	(-0.033) [0.339]	(0.028) [0.668]
log_EnvTech_percentage_of_AT	(0.180) [0.057]*	(0.041) [0.512]	(0.171) 0.001]*	(-0.006) [0.85]	(-0.162) [0.043]*	(0.040) [0.104]	(0.232) [0.019]*
__00000R_c	(1.084) [0.104]	(0.502) [0.001]	(0.749) [0.000]	(0.956) [0.000]	(1.080) [0.011]	(1.567) [0.000]	(1.280) [0.000]
_cons	(-1.921) [0.000]	(-2.251) [0.000]	(-1.595) [0.000]	(-1.429) [0.000]	(-1.209) [0.000]	(-1.208) [0.000]	(-2.200) [0.000]

Note: H_0: Coefficient is equal to 0, (.) and [.] indicate coefficient and probability values respectively. * represents level of significance at 5%.

Table 6.2. Country-Based Estimation Results - Advanced Countries

	AU	**CA**	**FR**	**DE**	**IT**	**JP**	**NL**	**ES**	**SE**	**UK**	**US**
log_FFS_percentage_of_TR	(0.048) [0.136]	(0.009) [0.721]	(0.097) [0.135]	(0.043) [0.860]	(-0.048) [0.213]	(0.131) [0.031]*	(-0.041) [0.000]*	(0.264) [0.107]	(0.130) [0.000]*	(0.049) [0.114]	(0.065) [0.438]
log_EnvRD_percentage_of_Gov_RD	(-0.012) [0.784]	(0.043) [0.595]	(0.016) [0.548]	(0.219) [0.498]	(0.075) [0.207]	(-0.029) [0.415]	(-0.022) [0.000]*	(-0.046) [0.698]	(-0.042) [0.14]	(-0.203) [0.279]	(0.197) [0.241]
log_EnvTech_percentage_of_AT	(0.106) [0.172]	(0.050) [0.674]	(-0.140) [0.366]	(-0.214) [0.474]	(0.030) [0.345]	(0.147) [0.455]	(0.438) [0.000]*	(0.436) [0.003]*	(0.187) [0.004]*	(0.308) [0.36]	(-0.010) [0.983]
__00000R_c	(0.944) [0.000]	(0.422) [0.003]	(1.494) [0.000]	(1.123) [0.069]	(0.884) [0.000]	(0.485) [0.082]	(0.473) [0.000]	(-0.559) [0.466]	(1.508) [0.000]	(2.555) [0.000]	(0.624) [0.477]
_cons	(-1.164) [0.000]	(-1.179) [0.000]	(-1.531) [0.001]	(-1.183) [0.236]	(-1.947) [0.000]	(-1.474) [0.01]	(-2.771) [0.000]	(-2.838) [0.000]	(-2.602) [0.000]	(-2.223) [0.019]	(-0.912) [0.408]

Note: H0: Coefficient is equal to 0, (.) and [.] indicate coefficient and probability values respectively. * represents level of significance at 5%.

6. CONCLUSION

It is undoubted that innovation and technology will play a critical role in green transition. Although energy transition holds the key to reach climate targets, development of other environment-related technologies or any kind of breakthrough in the form of environmental R&D and innovation will definitely affect the pace and scale of global transition. Not just the development of low-carbon technologies but also policies that establish free flow of these from advanced economies to EMEs would help achieving climate targets. Furthermore, the pace of transition, particularly in emerging countries, is heavily reliant on the level of climate finance, both for mitigation and adaptation efforts. Thus, fulfillment of developed countries' commitment to jointly mobilize $100 billion in climate finance per year through 2025 to developing countries is central to achieving the targets. In addition, there is an urgent need for coordinated action by international organizations, private investors and country authorities to mobilize climate finance to EMEs.

Since technology investments require high level of upfront investments, risks and uncertainties born by private capital providers are inevitably high. Thus, the role that governments might play in supporting these investments will be crucial. Government support might range from grants, subsidies, feed-in-tariffs, tax exemptions, direct tax credits, credit guarantees and other kind of incentive schemes for decarbonization technology investments.

Along with monetary support, governments might also support innovations via creating an enabling regulatory landscape for the development of both climate and environment-related technologies. Governments might also support the technology innovation, by removing information asymmetries pertaining to climate investments. This would be possible with comprehensive and globally comparable data sources, that could help monitor the effectiveness of policies, leading to remedial action when needed. Thereby, policymakers would use sophisticated and eloborative statistics in the complex process of reducing emissions to make the necessary interventions. In addition, filling the data gaps is essential to assess the impact of climate change and green transition on the overall economy and the financial system.

On the other hand, considering the fact that jurisdictions around the globe have just began to devise their climate policies, fiscal incentives to shift to clean energy sources are not adequate. In fact, fossil fuel subsidies are still prevalent both globally and regionally. This is mostly attributable to the fact that fossil fuels are the main source of energy for many countries and energy security is a major concern. However, policies to reduce fossil fuel subsidies would definitely complement other mitigation instruments.

The purpose of our study is to investigate the role of governments in scaling up climate transition in advanced and emerging countries. Carbon intensity is proxied by CO2 emissions per GDP while government policy is represented with 3 indicators: i. Total fossil fuel support as a % of tax revenue, ii. Environmentally-related government research and development (R&D) budget as a % of Government R&D budget and iii. Development of environment-related technologies as a % of all technologies.

In order to determine the long-run relationships, we employ Augmented Mean Group (AMG) estimator. Our estimation results are presented for emerging and advanced economies, along with a presentation of country-based results.

The results of the estimation indicate that the relationship between government policy indicators and CO2 emissions per GDP varies among different country groups. When all countries are included in estimations, a positive relationship between environment-related technologies and carbon intensity stands out, which is inconsistent with our ex-ante expectations. This means that an increase in the development of environment-related technologies may aggravate climate change, highlighting the environmental effects of technology production process. On this front, we draw attention to the export factor where the exporter bears the environmental damages of production process while not benefitting from the environmental advantages of the technology. Examining the country-based results, it is revealed that in advanced countries with higher incomes, development of environment-related technologies does not contribute to limit climate change in their respective jurisdictions. This finding confirms our inference on the difference between exporters and end-users of environmental technologies. In fact, US, UK, Canada, Japan and Germany, where environment-related technologies are not interrelated with carbon intensity, might be considered as predominant technology-exporters.

Another government policy indicator, fossil fuel subsidies are significantly and positively interrelated with carbon intensity in advanced countries, suggesting that an increase in fossil fuel subsidies worsens climate change in the long-run. This is consistent with our ex-ante expectation on deteriorating impact of fossil fuel subsidies on climate change.

As a last word, our study has some limitations. Due to the unavailability of technology-related OECD Green Growth Indicators for many countries as well as limited time span of the data, our sample size is small. Sample size problem is more pronounced for emerging countries. On the contrary, we are not subject to omitted variables bias, since our research tries to find the long-term relationships between the selected variables, rather than aiming to determine the drivers of climate change. Further research opportunities in this area might include use of other technology-related indicators such as patents. In addition, sample size might be expanded, via including more countries in the estimations.

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MERKEZ BANKASI

The Role of Governments in Emission Cuts: Evidence from Emerging and Advanced Economies

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The Central Bank of the Republic of Türkiye

Workshop on “Addressing Climate Change Data Needs: The Global Debate and Central Banks' Contribution” İzmir

May 7th , 2024

Presentation Plan

- Research Question
- Literature
- Data
- Methodology
- Estimation Results
- Conclusion
- Further Research Areas
- Policy Recommendations

Research Question

Paris Agreement, although not binding, considers governments as being part of global climate effort.

- Recent actions and policies at the global or national level;
  - Reveals that governments are key players in addressing the impacts of climate change:
    - Via clean energy or technology subsidies, tax exemptions or climate-related regulations
- **Research Question:**
  - What is the role of governments in scaling up climate transition in advanced and emerging countries?
    - Is government policy needed to redirect technical change from dirty to clean technologies?
- We explore the interrelation between carbon intensity and government policy indicators.
  - Where;
    - Carbon intensity, a good measure of the level of dirtiness of the production, is proxied by CO2 emissions per GDP
    - Government policy is represented with environmental R&D budget, fossil fuel subsidies and development of environmental technologies.

Literature

The evidence is mixed on the interrelation of environmentally-related government R&D expenditure as well as innovative technologies with CO2 emissions.

- Acemoglu at al. (2012) argue that government policy is needed to steer technical change from dirty to clean technologies. They state that with timely interventions, environmental goals can be achieved without the need for continuous intervention and without compromising long-term growth.
- Yusoff and Bekhet (2016) and Moosavian et al. (2022) find a relationship between fossil fuel subsidies/fossil fuel tax rates and the level of carbon emissions, showing the deteriorating effect of fossil fuels on the environment. Moosavian et al. (2022) also investigate the contribution of environment-related R&D subsidy policy to environmental protection.
- Petrovic and Lobanov (2019), Garrone and Grilli (2010) conclude that research&development expenditures are necessary but not sufficient to reduce carbon emissions.
- Halkos and Paizanos (2013) analyse the effect of government spending on environmental pollution, showing a clear negative effect of government spending on CO2 emissions in all income levels. The same result is found by Mongo et al. (2021), however the effect of environmental technologies is reversed in the short run.
- According to Due et al. (2019), green technology innovation contributes to mitigating CO2 emissions when the income level of the country is above a threshold (USD 35,000).
- Zhang (2021) investigates the impact of technological innovation and economic growth on CO2 emissions. Results show that technology patents help reducing carbon emissions, as economic growth significantly uplifts carbon emissions.

Data

Our sample includes the data of **18** countries in annual frequency from **2010** to **2021**.

The variables are used in logarithmic form to control for heteroscedasticity.

Indicator	Measurement Scale	Source
CO2 Emission Per GDP (as a measure of carbon intensity)	t CO2/kUSD/yr	IEA-EDGAR CO2 Dataset (Crippa et al, 2022)
Total Fossil Fuel Support	% of Tax Revenue	OECD Green Growth Indicators (OECD, 2024)
Environmentally Related Government R&D Budget	% of Total Government R&D	OECD Green Growth Indicators (OECD, 2024)
Development of Environment-related Technologies	% of All Technologies	OECD Green Growth Indicators (OECD, 2024)

- **Emerging countries**: Chile, Colombia, Korea, Mexico, Türkiye, Czechia and Hungary.
- **Advanced countries:** Australia, Canada, France, Germany, Italy, Japan, Netherlands, Spain, Sweden, UK and US.

Descriptive Statistics

Environmentally-Related Government R&D Budget, % of Total Government R&D variable has the highest standart deviation.

All series are positively skewed

Statistics	CO2 Emission Per GDP	Total Fossil Fuel Support, % of Tax Revenue	Environmentally Related Government R&D Budget, % of Total Government R&D	Development of Environment-related Technologies % of All Technologies)
Mean	0.20	1.27	3.04	12.28
Median	0.18	0.71	2.36	12.32
Maximum	0.41	12.19	21.56	26.42
Minimum	0.07	0.05	0.05	5.62
Std. Dev	0.07	1.69	3.53	2.72
Skewness	0.59	3.86	3.49	1.00
Kurtosis	2.41	21.57	15.21	7.52
Jarque-Bera	15.87	3544.55	1,692.29	183.69
Probability	0.00	0.00	0.00	0.00
Sum	44.38	266.74	624.67	2,210.79
Sum Sq. Dev.	1.36	599.38	2,550.87	1,324.58
Observations	216	210	205	180

Methodology

Panel Augmented Mean Group (AMG) Estimator by Eberhardt and Bond (2009), Eberhardt and Teal (2010) is employed.

- **Model**

$$CO2\_Emission\_perGDP_{it} = \alpha + \beta_1\, FFS\_percentage\_of\_TR_{it} + \beta_2\, EnvR\&D\_percentage\_of\_GovR\&D_{it} + \beta_3 EnvTech\_percentage\_of\_AT_{it}$$

- **Assumption Checks to Use Augmented Mean Group (AMG) Estimator**

1) Breusch-Pagan LM, Peseran Scaled LM and Peseran CD tests revealed that the series are cross-sectionally dependent. *(Residuals are also cross-sectionally correlated)*

2) Slope homogeneity test of Pesaran, named as Delta Test and its adjusted version revealed that slope coefficients are heterogeneous.

3) Westerlund Cointegration Test revealed that there is long-term relationship between investigated variables. *(We reject the null hypothesis of no cointegration)*

Estimation Results

The estimation results differentiate between emerging and advanced economies.

	All Countries	Emerging Economies	Advanced Economies
CO2 Emission Per GDP			
Total Fossil Fuel Support % of Tax Revenue	(0.029) [0.249]	(-0.023) [0.527]	(0.062) [0.021]*
Environmentally Related Government R&D Budget % of Total Government R&D	(0.014) [0.574]	(-0.003) [0.911]	(0.008) [0.749]
Development of Environment-related Technologies % of All Technologies	(0.102) [0.018]*	(0.061) [0.186]	(0.086) [0.209]

Note: H0: Coefficient is equal to 0, (.) and [.] indicate coefficient and probability values respectively. * represents level of significance at 5%.

- In **all countries**, the development of environmental technologies as a % of all technologies is the only significant variable to explain carbon intensity.
  - Its sign reflects a positive long-term relationship between the percentage share of environmental technology innovation and CO2 emissions per GDP, contrary to our ex-ante expectation, due to high level of heterogeneity among countries.
- In **emerging economies**, none of three explanatory variables shows significance to indicate a relationship with CO2 emissions per GDP in the long run.
- For **advanced economies**, fossil fuel support variable is significant and it indicates that increased fossil fuel subsidies lead to deteriorating climate change problem, which is in line with the literature as well as our ex-ante expectations.

Conclusion

- A positive relationship between environment-related technologies and carbon intensity stands out, which means that an increase in the development of environment-related technologies may aggravate climate change, highlighting the environmental effects of technology production process.
    - We draw attention to the export factor where the exporter bears the environmental damages of production process while not benefitting from the environmental advantages of the technology.
    - This finding confirms our inference on the difference between exporters and end-users of environmental technologies.
    - US, UK, Canada, Japan and Germany, where environment-related technologies are not interrelated with carbon intensity, might be considered as predominant technology-exporters.
- Fossil fuel subsidies are significantly and positively interrelated with carbon intensity in advanced countries, suggesting that an increase in fossil fuel subsidies worsens climate change in the long-run.
- **To conclude**, governments might support decarbonization via creating an enabling regulatory landscape as well as financial support, for the development of climate and environment-related technologies.

Further Research Areas

- **Including other technology-related indicators** such as ***patents***

- **Extending *the time span*** of the sample, specifically for EMEs
  - Long-term patterns and interrelations could become more apparent.

- **Increasing cross-sections** in the sample, specifically related to EMEs
  - The analysis could give better results, that help differentiate among emerging and advanced countries.

Policy Recommendations

- Although energy transition holds the key to reach climate targets, **development of other environment-related technologies** or any kind of breakthrough in the form of environmental R&D and innovation will definitely **affect the pace and scale of global transition.**
- Not just the development of low-carbon technologies but also policies **that establish free flow of these from advanced economies to EMEs** would help achieving climate targets.
- Furthermore, the pace of transition, particularly in emerging countries, is heavily reliant on **the level of climate finance**, both for mitigation and adaptation efforts.
- Climate finance is provided based on **proper and transparent reporting** on climate-related risks and opportunities.
- Here comes the role of reliable and **comprehensive data and availability of indicators** that helps standardization of reporting.
  - **National taxonomies and interoperability of those** is definitely needed for standardized data.
  - Central banks **with their soft power as well as their qualified work force** would help address climate-related data gaps via;
    - Publishing valuable **sustainable finance d**ata, to address the concerns of private investors.
    - Improving coordination with international institutions, that will serve for **exchange of knowledge and best practices** in the area.

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The Role of Governments in Emission Cuts: Evidence from Emerging and Advanced Economies

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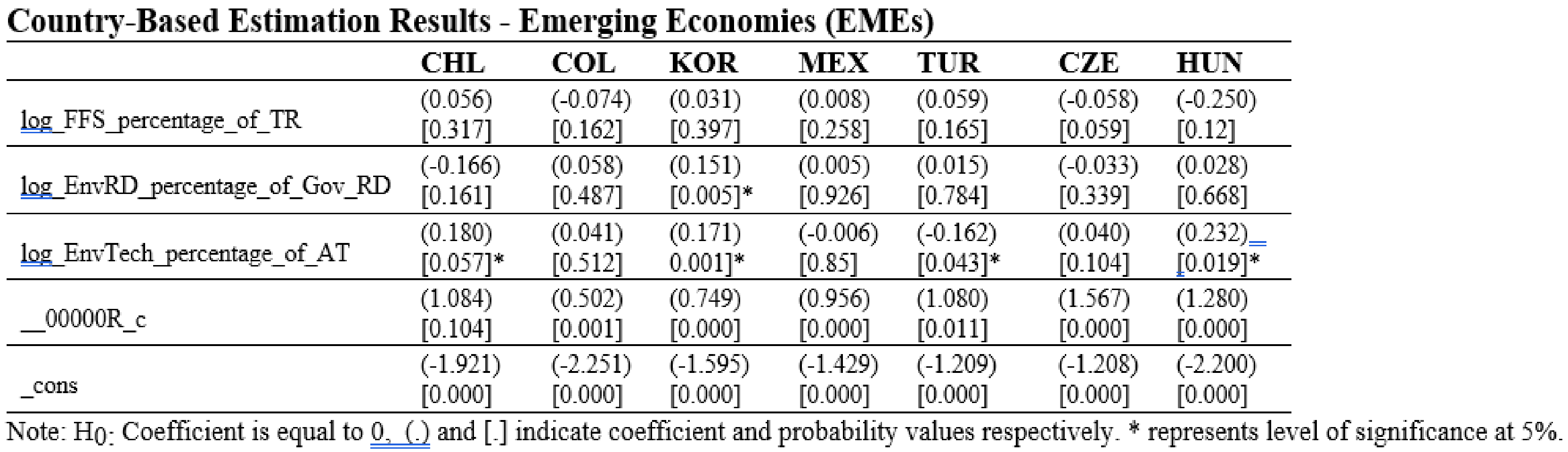
Annexes

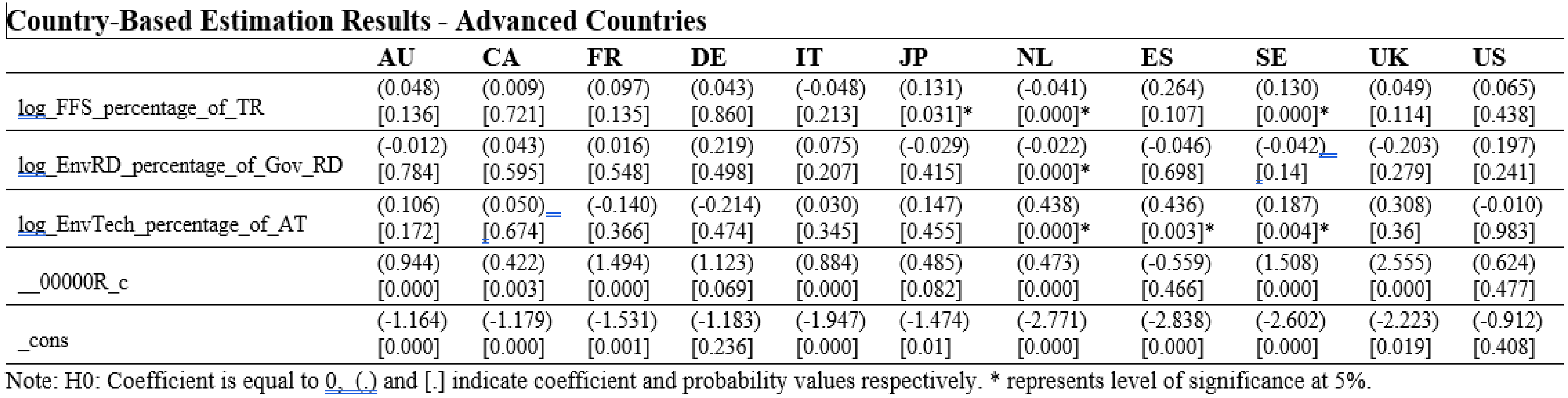
Country-Based Estimation Results



Country-Based Estimation Results - Emerging Economies (EMEs)

	CHL	COL	KOR	MEX	TUR	CZE	HUN
log_FFS_percentage_of_TR	(0.056) [0.317]	(-0.074) [0.162]	(0.031) [0.397]	(0.008) [0.258]	(0.059) [0.165]	(-0.058) [0.059]	(-0.250) [0.12]
log_EnvRD_percentage_of_Gov_RD	(-0.166) [0.161]	(0.058) [0.487]	(0.151) [0.005]*	(0.005) [0.926]	(0.015) [0.784]	(-0.033) [0.339]	(0.028) [0.668]
log_EnvTech_percentage_of_AT	(0.180) [0.057]*	(0.041) [0.512]	(0.171) 0.001]*	(-0.006) [0.85]	(-0.162) [0.043]*	(0.040) [0.104]	(0.232) [0.019]*
__00000R_c	(1.084) [0.104]	(0.502) [0.001]	(0.749) [0.000]	(0.956) [0.000]	(1.080) [0.011]	(1.567) [0.000]	(1.280) [0.000]
_cons	(-1.921) [0.000]	(-2.251) [0.000]	(-1.595) [0.000]	(-1.429) [0.000]	(-1.209) [0.000]	(-1.208) [0.000]	(-2.200) [0.000]

Note: H_0: Coefficient is equal to 0, (.) and [.] indicate coefficient and probability values respectively. * represents level of significance at 5%.



Country-Based Estimation Results - Advanced Countries

	AU	CA	FR	DE	IT	JP	NL	ES	SE	UK	US
log_FFS_percentage_of_TR	(0.048) [0.136]	(0.009) [0.721]	(0.097) [0.135]	(0.043) [0.860]	(-0.048) [0.213]	(0.131) [0.031]*	(-0.041) [0.000]*	(0.264) [0.107]	(0.130) [0.000]*	(0.049) [0.114]	(0.065) [0.438]
log_EnvRD_percentage_of_Gov_RD	(-0.012) [0.784]	(0.043) [0.595]	(0.016) [0.548]	(0.219) [0.498]	(0.075) [0.207]	(-0.029) [0.415]	(-0.022) [0.000]*	(-0.046) [0.698]	(-0.042) [0.14]	(-0.203) [0.279]	(0.197) [0.241]
log_EnvTech_percentage_of_AT	(0.106) [0.172]	(0.050) [0.674]	(-0.140) [0.366]	(-0.214) [0.474]	(0.030) [0.345]	(0.147) [0.455]	(0.438) [0.000]*	(0.436) [0.003]*	(0.187) [0.004]*	(0.308) [0.36]	(-0.010) [0.983]
__00000R_c	(0.944) [0.000]	(0.422) [0.003]	(1.494) [0.000]	(1.123) [0.069]	(0.884) [0.000]	(0.485) [0.082]	(0.473) [0.000]	(-0.559) [0.466]	(1.508) [0.000]	(2.555) [0.000]	(0.624) [0.477]
_cons	(-1.164) [0.000]	(-1.179) [0.000]	(-1.531) [0.001]	(-1.183) [0.236]	(-1.947) [0.000]	(-1.474) [0.01]	(-2.771) [0.000]	(-2.838) [0.000]	(-2.602) [0.000]	(-2.223) [0.019]	(-0.912) [0.408]

Note: H0: Coefficient is equal to 0, (.) and [.] indicate coefficient and probability values respectively. * represents level of significance at 5%.

Cross-sectional Dependence Tests (Peseran, 2004)

	Breusch-Pagan LM	Peseran Scaled LM	Peseran CD
Variable			
CO2_Emission_per_GDP	(1480.42) [0.00]*	(75.88) [0.00]*	(38.18) [0.00]*
FFS_percentage_of_TR	(472.66) [0.00]*	(18.27) [0.00]*	(-0.42) [0.67]
EnvR&D_percentage_of_GovR&D	(334.81) [0.00]*	(10.39) [0.00]*	(-0.025) [0.97]
EnvTech_percentage_of_AT	(360.78) [0.00]*	(11.87) [0.00]*	(11.70) [0.00]*
Residuals	(831.93) [0.00]*	(38.81) [0.00]*	(24.57) [0.00]*

Note: H0: No cross-sectional dependence (correlation) (.) and [.] indicate test static and probability values respectively. * represents level of significance at 5%.

Slope Homogeneity Test (Peseran & Yamagata, 2008)

Delta	Overall Model	FFS_percentage_of_TR	EnvR&D_percentage_of_GovR&D	EnvTech_percentage_of_AT
Δˆ	(4.64) [0.00]*	(5.46) [0.00]*	(0.33) [0.74]	(-0.53) [0.60]
Δˆ adj.	(6.64) [0.00]*	(6.97) [0.00]*	(0.43) [0.67]	(-0.76) [0.45]

Note: H0: Slope coefficients are homogeneous. (.) and [.] indicate test static and probability values respectively.
* indicates level of significance at 5%.

Cointegration Test of (Westerlund, 2007)

	H0: No cointegration Ha: Some panels are cointegrated	H0: No cointegration Ha: All panels are cointegrated
Variance Ratio	(4.90) [0.0000]*	(3.40) [0.0003]*

Note: (.) and [.] indicate test static and probability values respectively. * indicates level of significance at 5%.

IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

Houston, we have a problem: can satellite data bridge the climate-related data gap?[1]

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Bank of Spain,

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

Houston, we have a problem: Can satellite information bridge the climate-related data gap?

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ABSTRACT
Central banks and international supervisors have identified the difficulty of obtaining climate information as one of the key obstacles impeding the development of green financial products and markets. To bridge this data gap, the utilization of satellite information from Earth Observation (EO) systems may be necessary. To better understand this process, we analyze the potential of applying satellite data to green finance. First, we summarize the policy debate from a central banking perspective. We then briefly describe the main challenges for economists in dealing with the EO data format and quantitative methodologies for measuring its economic materiality. Finally, using topic modeling, we perform a systematic literature review of recent academic studies to uncover in which research areas satellite data is currently being used in green finance. We find the following topics: physical risk materialization (including both acute and chronic risk), deforestation, energy and emissions, agricultural risk and land use and land cover. We conclude providing a comprehensive analysis on the financial materiality of this alternative source of data, mapping these application domains with new green financial instruments and markets under development, such as thematic bonds or carbon credits, as well as some key considerations for policy discussion.

KEYWORDS
satellite data; sensors; green finance; central banking.

1. Introduction

Since the publication of the initial report from the Network for Greening the Financial System (NGFS 2019), there is consensus among central banks and international supervisors that closing existing data gaps and obtaining reliable data is crucial to analyze climate-related risks and opportunities. Although much effort has been made in this direction, as evidenced by, for example, the improvement in climate-related corporate disclosures (Diwan and Amarayil Sreeraman 2023; van Bommel, Rasche, and Spicer 2023; Singhania and Saini 2023), the need for better climate-related data remains true today. This is illustrated, for instance, by the recent publication by the European Central Bank (ECB) of a new set of experimental climate-related statistical indicators to narrow the climate data gap (ECB 2023), or the recent effort from the International Monetary Fund (IMF) to strengthen its climate information architecture (Ferreira et al. 2021).

In the financial system, it is noteworthy that the challenge of collecting and maintaining high-quality, granular climate data involves not only financial institutions, but also central banks, which are consequently increasing efforts to integrate sustainability and climate-related considerations into their operations (Dikau and Volz 2021; Durrani, Rosmin, and Volz 2020; Delgado 2023; Volz 2017). This includes investment decisions (NGFS 2019; ECB 2021b; BdE 2023; Bundesbank 2023), monetary policy tools (ECB 2021a), financial stability assessments through climate stress tests (Battiston et al. 2017; Acharya et al. 2023; European Central Bank 2022; Alogoskoufis et al. 2021), and the supervision of financial institutions (Kedward, Ryan-Collins, and Chenet 2023; Heynen 2022; ECB 2022).

As pointed out by NGFS (2022), however, gaps in climate-related data encompass three dimensions: availability (e.g., coverage, granularity, and accessibility), reliability (e.g., quality, auditability, and transparency) and comparability (as there is not yet a unique official reporting standard).[1] In some instances, relevant ground-based datasets are not available.[2] In other cases, the data exists but lacks the appropriate granularity, cannot be verified, or is of poor quality. Finally, in some cases, the available data sources are incomparable or inconsistent. Beyond data needs and gaps, climate-related data sources that do exist are underexploited by finance professionals. This can occur for a number of reasons: The specific data formats might not be immediately tractable for economic modeling, as it might require expert domain of its parametrization, complex pre-preprocessing pipelines to generate interpretable information, or it might simply not be widely known enough.

Satellite data is a potential candidate to help alleviate these challenges. Satellite data sources, also referred to as Earth Observation (EO) systems, could significantly narrow existing data gaps: This data source, collected by satellites orbiting Earth, is highly granular and has an important spatial component. As some satellites are able to capture high-resolution images with resolutions as little as 30 by 30 meters, they can provide consistent, objective, and close to real-time information – all while covering virtually the entire world. These unique characteristics of satellite data address common issues of using official (administrative) statistics for climate finance, such as publication time lags, data quality issues (especially in Global South economies), and the spatial heterogeneity of the real effects of climate change.[3]

The information contained in satellite data can be used to measure different features of the Earth's surface or atmosphere, such as temperature, terrain, or pollutants, which in turn could be helpful to build indicators for environmental health, land use, deforestation rates, and more. The recent and widespread availability of this (largely free) data source opens unique pathways for researchers and practitioners to track economically relevant activity.[4]

In the context of economic modeling for developing economies, remotely sensed

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[1] Though, notably international organizations like the International Financial Reporting Standards (IFRS) and the European Financial Reporting Advisory (EFRAG) are working on it thoroughly, e.g.: IFRS (2024); EFRAG (2024).

[2] Ground-based data refers to data not collected remotely, e.g., by sensors or satellites.

[3] We will discuss spatial heterogeneity in more detail later on. At this point, we are referring to the fact that the effects of catastrophic climate events are not spatially or geographically homogeneous. The Global South suffers much stronger adverse effects than the North, and even within continents, countries, or counties, transition and physical risks as well as repercussions are different. Depending on the level of granularity of the official statistic in question, these heterogeneities cannot be captured by administrative datasets and the associated common modeling techniques, such as spatially invariant regressions.

[4] See for instance private sector initiatives like Planet Labs, DrivenData Labs, or GMV

data has been used for quite some time.[5] In the context green finance, however, its use began in the insurance market, where it has been suggested and, in some instances, successfully implemented as a productive tool for claims settlement or risk estimation (e.g., Stigler and Lobell 2020; Nagendra et al. 2022; Nagendra, Narayanamurthy, and Moser 2022).

In new domains of sustainability and green finance, the application of satellite data and remote sensing expands far beyond traditional use cases like catastrophes' insurance. Simultaneously, however, satellite data has its limitations, all of which pose significant barriers to entry for newcomers to the field. For instance, the databases with the highest-resolution images tend to be private, the matching to external data sources is complicated, it might be difficult to track long periods of time.

Blindly using more data – even if it has high quality and/or granularity – is not in itself sufficient to conduct robust climate risk analyses (WWF 2023). Notably, this requires an investment with a considerable upfront cost, including the acquisition of new information technology resources and training employees with multidisciplinary skillsets, in order to be able to shift international capital flows towards more environmental friendly objectives (Elderson 2023). All in all, a sound understanding of how to integrate climate-related information with financial asset-level data is imperative. This general notion is acknowledged by the principle of double materiality, which describes the two reciprocal facets of climate change (Gourdel et al. 2022): the materiality, or impact, of economic activity on the environment on the one hand, and how the materialization of climate change affects businesses' financial well-being on the other hand. [6]

The establishment of the Innovation Hub of the Bank of International Settlements in 2019 (BISIH) showcases how important data quality and availability – as well as the technology required to analyze it – are for green finance in central banking. While not being the sole priority area, since the inception of this joint initiative led by the international community of central banks, green finance has been at its core. The goal of this collaborative platform is to exchange knowledge between its members and experiment using different technologies, such as Natural Language Processing (NLP) or blockchain, to help solve current issues in (sustainable) finance.[7] In this respect, the BISIN working group on green finance[8] identifies satellite data as one the main technologies which could assist both scaling up the availability of climate-related data and assessing its environmental materiality, which in turn could enable the creation of

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[5] See, e.g., Rangel-Gonzalez and Llamosas-Rosas (2019) or Beyer, Hu, and Yao (2022)

[6] To comprehend the financial materiality of a climate event, it is crucial to convert an environmental measure (e.g., droughts, forest area coverage, greenhouse gas emissions) into an economic indicator (e.g., employment rates, inflation rates, industrial production growth, Gratcheva et al. 2021), and consequently its impact on corporates and financial institutions performance. This requires appropriate data modeling techniques which are capable of illustrating complex environmental-financial relationships. Examples include causal machine learning techniques (Giannarakis et al. 2022; Iglesias-Suarez et al. 2024), which enable the identification and analysis of cause-effect relationships between climate variables and economic outcomes, and other econometric approaches which facilitate understanding the immediate response of economic variables to climate shocks (such as the Local Projections Method, see Jordà 2005).

[7] For instance, the Eurosystem Center of the BISIH is exploring the use of Large Language Models (LLMs) to automate the collection and management of climate-related information from corporates at scale (Project Gaia), while the Hong Kong Center has finalized Project Genesis 1.0 and 2.0, which aim to help gauge how distributed ledger technologies (DLT) could aid the development of digital green bonds. Meanwhile, the Singapore Center has conducted Project Viridis, a digital dashboard which tracks the exposure of banks to extreme weather events.

[8] The BIS created the Innovation Network in 2021 (BISIN) to track technological trends and developments with relevance to the thematic areas of the BISIH.

digital measurement, reporting and verification (MRV) systems, for instance (BISIN 2023).

Therefore, we aim to investigate the potential of satellite data for green finance. To this end, Section 2 provides background information on financial innovation and bridging sustainability data gaps at the policy level. In Section 3, we introduce the main characteristics of satellite data formats and the limitations of satellite data, and we discuss the main econometric modeling challenges. We devote Section 4 to a survey of the academic literature on satellite data for different applications in economics and finance, such as development economics or quantitative trading strategoes. Herein, we identify a gap in the prior literature on green finance. Based on this finding, our main contribution will be presented in Section 5, where we use NLP techniques to uncover new domains of satellite data application for sustainable finance. We do so in collecting and sorting a large set of over 17,000 scientific sources in a semi-automated fashion. Based on a final sample of over 200 *relevant* sources, we use topic modeling analysis to uncover the specific domains of (sustainable) finance and economics where satellite data has been explored to date. Finally, we provide concluding remarks including our assessment of why this time (i.e., the case of green finance) might be different for the successful and productive use of the potential offered by satellite data in Section 6. .

2. The role of technology to bridge climate data gaps

Central banks and international financial authorities are faced with the question of the role they can play in improving the availability, reliability and comparability of climate-related data. A survey conducted by the Irving Fisher Committee (IFC) on Central Bank Statistics found that central banks are increasingly focusing on climate-related data in particular, but also sustainable finance data issues as a whole, pointing to the following main recommendations for central banks (IFC 2021):

(1) One prerequisite for sustainable finance is to identify the data needed by central banks to support their policy objectives in order to fulfill their mandates at both the micro- and macro-prudential levels.
(2) Given the novelty of the subject, central banks should cooperate with traditional and new stakeholders to close data gaps, dealing with new environmental information providers; and working on acquiring new skillsets at working staff level, either through dedicated training or inter-disciplinary hiring.
(3) In addition, central banks should lead by example in that they improve the usage of the new data being collected.

As pointed out by the IFC Bulletin "*Post-pandemic landscape for central bank statistics*", the statistical sources and tools have to be continuously refined to match the landscape of ever-evolving challenges (IFC 2023). Furthermore, the IFC stresses that the quantity and quality of sustainable finance data need to be increased to assess climate-related risks in the financial sector and monitor the green transition.

To narrow the existing climate data gap and fulfill the commitments of its climate action plan, the European Central Bank (ECB) has published a first set of climate-related statistical indicators (ECB 2023).

However, these indicators are experimental. As such, they comply with many, but not all of the quality requirements of official ECB statistics. The three main areas covered are: an overview of green debt products, analytical indicators of carbon emissions financed by financial institutions, and indicators on the impact of physical risk events, such as the impact of natural hazards (e.g., floods, wildfires, or storms) on investment portfolios. Nevertheless, this factual information is not sufficient to enable forward-looking analysis of climate-related risks. Also, to ensure that these indicators are accessible and replicable, the authors use existing data from the European System of Central Banks (ESCB) or other publicly available data where possible. Another example in the field of natural capital and ecosystems is the work of Giglio et al. (2023), who aim to measure biodiversity risk exposure using a novel set of information. However, all of the proposed metrics are collected from company disclosures or opinions elicited from professionals. Both of these examples demonstrate how the inherent challenges of using novel data sources can be exacerbated by regulatory requirements which impede the speedy adoption of new environmental data types and sources for the green transition.

More recent work postulates that the path towards more and better climate-related information underpins technological innovation (Ofodile et al. 2024). Going forward, it is likely that central bank statistics need to rely heavily on the use of data science techniques to perform their traditional tasks and adhere to their missions. Therein, they would have to acknowledge that – while largely unparalleled in terms of quality – ground-based (administrative) datasets might not be suitable, or enough, to gain scalability in many types of sustainable finance applications. Consider this example: One company may have hundreds of assets connected to tens of thousands of sites through global supply chain processes. Therefore, in the absence of prohibitively costly ground-based data collection methods, actors might decide to turn to geospatial or remotely sensed alternatives for insights at scale (WWF 2023).

Among geospatial data sources, we particularly focus on the use of Earth Observation (EO) systems, leaving out of this study uses of satellite information for astronomical purposes, navigation or communications. Indeed, we define EO systems as data collected by satellites which orbit the Earth, including both land imagery and sensor data, such as greenhouse gas (GHG) emissions or heat loss. This type of data adds a new layer of valuable information for economists and financial analysts by including geolocated observations at a neutral stance. Therefore, the data is also reliable and objective. Importantly, the use of satellite data for official statistics is subject to some limitations which need to be considered. E.g.: we discuss the format of satellite data and its limitations in more detail in Section 3.

3. What is satellite data

The data collected by satellites from outer space varies depending on its orbital altitude, which influences both coverage area and travel speed. Typically, satellites are classified into four main types according to their function: Communication, Earth Observation, Navigation, and Astronomical. In this paper, our focus is primarily on Earth Observation satellites. These can be further divided into categories such as Weather satellites, which are crucial for monitoring and forecasting weather patterns, and providing up-to-date meteorological data. Another category, known as Remote Sensing satellites, is vital for environmental monitoring and geographic mapping. Notably, three outstanding primary sources for medium resolution imagery, which are available for public use, are Landsat data from the USGS Earth Explorer, Sentinel data from the Copernicus Open Access Hub, and MODIS data from the NASA Earth Data website.

Furthermore, a single satellite can have multiple instruments, and each instrument can have multiple sensors. Each sensor can detect light in one or more spectral bands, i.e., specific ranges of wavelengths of light, at one or more levels of spatial resolution. This means that one pixel corresponds to some geographic area at units such as "meters per pixel". Complete images have a total size which is often referred to as a frame.

Finally, satellite instruments can be passive, meaning that they simply collect the photons radiating from the Earth or bouncing off it from the Sun; or active, meaning that they send some form of signal down to the Earth's surface or atmosphere and measure how it is reflected back. Active sensors help overcome certain limitations of passive sensors because they can penetrate clouds and capture images at night.

The information thus captured by satellites can be used to measure different features of the Earth's surface or atmosphere, such as temperature, terrain, or pollutants. Signals from sensors can be combined to form a wide variety of images, from (i) "natural color" images, resembling what we humans might see if we were in orbit, to (ii) false-color images, which either show light we cannot perceive or enhance certain types of features, to (iii) videos, even. In Box 1, we explain how meaningful metrics can be obtained from this information. In the example cases shown in Box 1, the parameters can be used to measure the impact of economic activity on the ecosystem with the Normalized Difference Vegetation Index (NDVI), inspect wildfires using the Normalized Burn Ratio (NBR), or assess water scarcity with the Normalized Difference Water Index (NDWI).

The recent and widespread availability of this data source opens unique pathways for researchers and practitioners to track economically relevant activity. As seen in Box 1, metrics derived from satellite data allow us to estimate indicators on environmental health, land use, and deforestation rates in a consistent and objective fashion, in real-time, and with coverage of virtually the entire world. These unique traits hold enormous potential for economics and finance, as we show in the large-scale literature review (Sections 4 and 5).

Notably, these unique opportunities are mirrored by unique challenges not only in terms of data access, cleaning, and pre-processing, but also econometric modeling. When acquired by satellite sensors and downloaded to ground stations, data is in raw format. Most use cases will, however, require different treatments of this raw EO data to ensure its interpretability. To evaluate the potential of EO data for sustainable finance, we identify and discuss data formats and (econometric) modeling as the two major challenges to its economic materiality.

Understanding Satellite Color Bands and building metrics

Landsat collects 8 color bands:

- **B1 captures deep blue and violet light.**
  Useful for identifying aerosol particles which scatter short wavelengths like deep blue and violet.
- **B2 Captures blue light.**
  Helps differentiate between water bodies, as water reflects blue light more effectively.
- **B3 Captures green light.**
  Green light is strongly reflected by healthy vegetation, aiding in its assessment.
- **B4 Captures red light.**
  Essential for identifying plant types and assessing their health.
- **B5 Captures near-infrared light.**
  Biomass content: Indicates the health and density of plants.
- **B6 Captures shortwave infrared light (SWIR 1).**
  Useful for differentiating moisture levels in soil and vegetation.
- **B7 Captures shortwave infrared light (SWIR 2).**
  Maps geological features and vegetation through vapor penetration for clearer images.
- **B8 Captures panchromatic light.**
  Offers a broad wavelength range for detailed landscape imagery.

Each pixel of the image holds a value for each band. These values can be combined to create detailed layers depicting various features such as vegetated areas, burned areas, water extents, and urban zones. Some examples of metrics we can build are:

NDVI (Normalized Difference Vegetation Index) $= \frac{Band5-Band4}{Band5+Band4}$

Primarily measures vegetation health by contrasting near-infrared and red light. NDVI is useful for monitoring vegetation over time, including pre- and post-fire conditions to assess recovery. Healthy vegetation typically shows NDVI values from 0.3 to 0.8, with values greater than 0.3 indicating vegetated areas.

NBR (Normalized Burn Ratio) $= \frac{Band5-Band7}{Band5+Band7}$

Specially designed for identifying burned areas and estimating burn severity, utilizing near-infrared and shortwave infrared bands. Lower NBR values indicate higher burn severity, making it ideal for analyzing fire impacts and severity. Threshold adjustment should be based on specific burn severity levels and regional ecosystem characteristics.

NDWI (Normalized Difference Water Index) $= \frac{Band3-Band5}{Band3+Band5}$

Optimized for water body detection by highlighting liquid water absorption and reflectance. NDWI is used to monitor changes in water content of leaves and is also particularly effective in delineating open water features. This index helps differentiate between water bodies and other types of land cover.

Each pixel will have a value for these metrics. Using these indices, we can create detailed maps and areas from satellite images, enabling the assessment of vegetation health, water body extents, or burned area extents, among others.

3.1. *Data format and parametrization*

EO systems have a set of technical parameters that can be tuned to extract relevant information, and defines the quality of the data obtained. In general, some key parameters of EO data are resolution, size, and frequency (or refresh time, ESA 2020).

The spatial resolution of an image relates to the level of detail that can be retrieved from a scene. Image resolution can be measured in several ways; one of the most common, the Ground Sample Distance (GSD), is the distance between adjacent pixel centers measured on the ground. The lower this number is, the finer the detail that can be interpreted from the image. High resolution images will be required, for instance, to collect data for high precision agriculture, while lower resolutions are enough for applications such as weather forecasting.

The size of the scene to be observed is another important parameter. EO sensors on board satellites are characterized by their swath. The swath of an instrument is the width of the path or the strip on the ground it can image when the satellite orbits around the Earth. The swath depends on the features of the instrument and on the orbit of the satellite. Generally, the higher the spatial resolution, the lower the swath of the instrument.

Finally, the revisit time of a satellite system is a decisive factor of choice. It is defined as the length of time to wait for the satellite system to be able to observe the same point on Earth. This parameter is closely linked to the type of orbit of the satellites.

There is an inherent trade-off between spatial resolution and refresh rate. To have a high refresh rate, the satellite needs to orbit the Earth quickly. But to capture a high-spatial-resolution photo, the satellite needs to collect data from each tiny area which takes longer. Though, it shall be noted that more technical parameters might further govern the usefulness and quality of an EO image, such as bit depth, off-nadir angle, and cloud cover. This required parametrization of the data might be seen, therefore, as a challenge in itself for official statistical offices which require climate-related data to be fully transparent, and comparable (NGFS 2022).

3.2. *Econometric Modeling*

Recent advances in the rapidly growing literature on remote sensing and EO systems offer a plethora of solutions for spatial analysis. However, it is crucial to recognize that for quantitatve analysis, we must first translate the spectral band data collected by satellites into meaningful metrics. This process involves several steps, as outlined in the boxes ”Understanding Satellite Color Bands and Building Metrics” and ”From Parametrization to Environmental Metrics and Economic Materiality.”
Quantitative modeling has been significantly aided by the widespread availability and use of machine learning (ML) and artificial intelligence (AI) algorithms, such as neural networks, which are uniquely equipped to handle prevalent issues in (climate) finance, such as non-linearity, heterogeneity, and clustering issues (Alonso, Carbó, José Manuel, and Marqués, J Manuel 2023).[9] The Local Projections Method constitutes an alternative econometric approach to obtain the impulse response to shocks (Jordà 2005). This method can enable a solid policy discussion of climate change, as it utilizes the same language as applied economics in the context of estimating the dynamic causal effects of policy interventions (Jordà 2023). Such interventions would traditionally refer to new fiscal policies (Jordà, Schularick, and Taylor 2020), but can now also be adapated to climate events such as natural disasters or temperature anomalies (Dieppe, Kilic Celik, and Okou 2020; Nie, Regelink, and Wang 2023).

Notably, two satellite data-specific characteristics tend to cause econometric model-

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[9] Such as, e.g., in the development of the geographical random forest (Hengl et al. 2018; Santos, Graw, and Bonilla 2019; Georganos et al. 2021; Georganos and Kalogirou 2022)

ing challanges which need to be addressed: spatially interdependent data and spatially heterogeneous estimators. A multidisciplinary, growing stream of the scientific literature deals with addressing these issues in order to obtain consistent and unbiased spatial estimates (Hengl et al. 2018; Georganos and Kalogirou 2022; Kopczewska and Ćwiakowski 2021). In the following, we briefly outline these two issues of spatial data:

(1) **Spatial dependency and autocorrelation:** Violating the basic assumption of independence (which tends to be required by the usual econometric models), geolocations in close proximity to one another are unlikely to be independent from one another. For instance, two neighboring areas of a forest are likely to be exposed to similar, if not the same, environmental stressors captured by satellite images. Therefore, models which fail to correct for spatial dependence and (auto-)correlation can produce biased estimates.
(2) **Spatial heterogeneity or spatial non-stationarity:** the relation between predictor and outcome variables in spatial settings tend to vary spatially, i.e., different estimates are required for different areas or locations (Georganos et al. 2021). For instance, the relationship between precipitation and flood risks differs for adjacent urban neighborhoods depending on their distance from bodies of water, building quality, or their proximity to disaster relief services.

Spatial weights matrices help address both of these major issues by incorporating the geographical structure of the data into the econometric model (Anselin 2022). However, deriving appropriate weights can be challenging, as the choice of weighting scheme relies on assumptions and increases model complexity. Though, approaches that address both spatial autocorrelation and spatial heterogeneity simultaneously, however, tend to increase computational complexity and cost beyond the computational capacities of regular machines (Ahn, Ryu, and Lee 2020).

Beyond these two major concerns specific to geospatial data, analyses leveraging satellite data can additionally suffer from statistical issues analogous to those of non-spatial models. For instance, endogeneity is common in spatial analyses, and including spatially endogenous variables further complicates the modeling process (Brady and Irwin 2011). Additionally, satellite data is also prone to suffering from sparsity and missingness. Importantly, these gaps tend to be non-random, i.e., systematically informative, and thereby impact results (see, e.g., Khan et al. 2017).

3.3. *Limitations for bridging the climate data gap*

As pointed out by the NGFS "*Final Report on Bridging Data Gaps*" (NGFS 2022), gaps in climate-related data encompass three dimensions: availability (e.g., coverage, granularity, and accessibility), reliability (e.g., quality, auditability, and transparency) and comparability. Despite the tremendous potential of satellite data for (sustainable) economics and finance, some key limitations remain, which can affect their capacity for bridging these data gaps:

(1) **Temporal consistency:** Some environmentally relevant datasets might have poor temporal consistency due to missingness. This issue tends to compound over time, affects coverage and through this impacts availability, which in turn makes long-term environmental monitoring more challenging.

(2) **Accuracy:** The precision of readily available spatial datasets varies significantly, which affects their reliability. There are two main categories of spatial datasets: vector files and raster files. Vector files consist of geometric shapes used to represent man-made delineations such as country boundaries or biodiversity protected areas. Raster files, on the other hand, are composed of grid cells (or pixels), each assigned a specific value to represent information like flood risk or forest loss. Discrepancies between these datasets, particularly in terms of boundary definitions, are not uncommon and often necessitate costly ground truth validation to ensure data accuracy. This situation suggests a possible impact on accessibility due to cost barriers, and affects reliability due to potential errors and the need for external validation. Additionally, merging datasets involves aligning spatial scales (e.g.: geocoding economic data), while maintaining the integrity over time, which is by itself challenging (e.g.: an asset's area may change over time from being non-protected to protected). This impacts auditability and adds layers of complexity in ensuring data reliability. Finally, identification of the region of interest (RoI) might therefore be a challenge in itself. This underscores a significant issue affecting both reliability and comparability due to ambiguous data interpretations.

(3) **Spatial resolution:** Almost all publicly available raster datasets tend to have low spatial resolution (above 500 square meters), limiting the relevancy of the tasks which could be applied to (e.g.: deforestation and land degradations usually require finer resolution). This underscores a significant issue affecting both reliability and comparability due to ambiguous data interpretations. Data interdependence: newly available datasets often draw observational points from different datasets, with the possibility of compounding previous errors.

(4) **Relevancy:** Parametrization of information makes it technically difficult to quantify variables of some economically relevant topics (e.g.: Normalized Difference Vegetation or NDVI and Normalized Burn Ration or NBR are usually applied in to study the impact of wildfires, though depending on the time of the year, type of vegetation and atmospheric conditions one metric might be better than the other.); therefore several studies tend to be biased towards the most technically feasible metrics. This can lead to issues in comparability when different studies or datasets use different parameters or indices based on their technical feasibility rather than their applicability.

From Parametrization to Environmental Metrics and Economic Materiality

Analyzing the Economic Impact of a Wildfire (Galicia, 14/10/2017)

Computing the impact on local firms and collateral can provide a tangible measure of economic materiality. However, this process is challenging due to the need for high-resolution data and accurate economic modeling that can translate environmental damage into financial terms

Parametrization and Region of Interest (RoI) Identification:

- Satellite choice is key: Landsat's finer resolution (30 meters per pixel) is balanced against its 16-day revisit time, while MODIS offers broader coverage with daily updates at a coarser 250-500 meters per pixel resolution, impacting the detail and timeliness of data.
- RoI alignment is critical: Landsat's swath of 185 km might not match the ROI exactly, leading to data gaps, Particularly in areas outside the direct pass. A defined RoI like a 20 km radius can provide a focused view but may miss some impacts outside this range. Techniques like data interpolation, using overlapping satellite passes, or integrating data from multiple satellites could help mitigate these gaps.
- Preprocessing complexities: Switching between Landsat and MODIS can present challenges, particularly in cloud-prone regions like Galicia. While manual cloud masking is necessary for certain satellites, automatic cloud masking by others like MODIS is available, but the resulting cloud-free data sample is not daily and may compromise data frequency.

Environmental Metrics:

- Selecting the right metrics like NDVI and NBR is essential for quantifying fire damage and vegetation health. It is also important to understand historical values of those metrics in the RoI, and expected variations. A 10% or 20% change could be way to big or small. A threshold must be chosen based on the normal variability and ecological characteristics of the region, factoring in seasonal variations.
- Additional indices like EVI or SAVI could provide deeper insights in specific scenarios, such as regions with high biomass or varying soil reflectance, enabling a tailored approach to environmental impact assessment.

Economic Materiality:

- The economic impact analysis is not only about the direct damages such as property loss, but also indirect effects like supply chain interruptions, affected collateral in loans, and tourism downturns. This analysis requires an integration of fire damage data with local economic metrics.
- Specifically, it is vital to evaluate spatial dependence. This dependence often reflects the physical spread of the fire. The physical spread of a fire can differently affect adjacent sectors such as agriculture, collateral securities and tourism.
- Addressing spatial dependency involves employing spatial econometric models that can dissect and quantify these intertwined impacts. Techniques like spatial autoregressive models (SAR) or spatial error models (SEM) could be employed to correct for spatial autocorrelation in the data, ensuring that the estimated economic impacts accurately reflect the localized nature of the fire's damage.
- Collaboration with local authorities ensures that findings are grounded in reality

4. Literature review: satellite data in economics and finance

Satellite data has emerged as a powerful tool in some specific domains of economic and financial research, offering novel insights and harnessing different methodologies across various domains. In others, however, it remains underexploited. This literature review aims to segment and categorize those streams of the scientific literature which have successfully used satellite data. Generally, the successful application of satellite data tends to sit in two primary areas: (i) development economics, for tracking economic growth in developing countries or tumultuous times, such as the Covid-19 pandemic;

and (ii) capital markets, e.g., in commodities trading (including estimating oil reserves) as well as equity trading. An illustrative example of such applications can be retail expenditure forecasting using satellite imagery in commercial areas such as parking lots.

First and foremost, satellite data has proven invaluable in monitoring and understanding economic growth in developing regions. Studies such as Ebener et al. (2005), Ghosh et al. (2009), Henderson, Storeygard, and Weil (2012), and Pinkovskiy and Sala-i Martin (2016) have utilized nighttime lights data as a proxy for economic activity, demonstrating its efficacy in capturing changes in GDP and economic development over time. Moreover, the use of high-resolution satellite imagery has facilitated the assessment of urbanization patterns, infrastructure development, and land use changes, offering nuanced insights into regional economic progress.

The nascent literature has also identified limits to satellite data. Specifically, it is noted that this data source tends to lose its informative power for advanced economies generally situated in the Global North (Sutton et al. 2007; Chen and Nordhaus 2011), as when a country grows, night-time luminosity tends to de-correlate from production and consumption metrics. This induced a move towards hitherto less frequently used types of remotely sensed data, such as NO_2 pollution for nowcasting industrial production (e.g., Bricongne, Meunier, and Pical 2021; Jiang et al. 2020; Zhou, Zhou, and Ge 2018). Since this substream of the literature suggests a direction of causality in which economic activity drives pollution, this link can also be used to detect large economic recessions that lead to a drop in NO_2 pollution. Castellanos and Boersma (2012) study the reduction in pollution in Europe during the global financial crisis of 2008. Similarly, Russell, Valin, and Cohen (2012) offer similar insights for the US, as do Du and Xie (2017) for China. More recently, Tobías et al. (2020) use pollution data to assess the impact of the lockdowns during the Covid-19 pandemic in Europe, and Le et al. (2020) and Beyer, Franco-Bedoya, Sebastian, and Galdo, Virgilio (2021) provide analogous findings for China and India, respectively.

For Global South economies, previous studies such as Kerimray et al. (2020) and Keola and Hayakawa (2021) document that changes in NO_2 pollution followed lockdown policies. Related to this, Franke et al. (2009) and de Ruyter de Wildt, Eskes, and Boersma (2012) use satellite imagery to track shipping lanes and study world trade patterns.

Satellite data has also influenced capital markets, for instance in the field of commodities trading, by offering insights into supply chains, market trends, and natural resources availability. As an example, satellite imagery has been used to monitor oil storage facilities and track tanker movements, providing crucial information for assessing global oil supply and demand dynamics, as well as oil spill detection Tysiac, Strelets, and Tuszyńska (2022).

Moreover, the literature on consumer spending estimation has been revolutionized by satellite imagery: Feng and Fay (2022) and Kang, Stice-Lawrence, and Wong (2021), for instance, use satellite images of retail parking lots to estimate consumer spending. By counting cars in the lots, the researchers were able to accurately predict store-level sales, demonstrating the potential of satellite data in retail analytics and economic forecasting. This, in turn, gives rise to an application in equity trading where international retail company revenues can be estimated ahead of quarterly earnings announcements for market timing strategies. Notwithstanding, Katona et al. (2018) suggest that access to this source of alternative data might have had an impact on information asymmetry among market participants without enhancing price discovery.

In the field of green finance, insurance markets are a prominent example of the pioneer usage of satellite data. In particular, this type of data has led to promising results in agricultural risk management through its potential to reduce monitoring costs and alleviate moral hazard as well as adverse selection issues Nagendra et al. (2022). Exploiting satellite data, insurers can efficiently price complex weather index insurance policies, protecting small farmers against crop damage De Leeuw et al. (2014). Hedging the risk of weather shocks, they can also increase their agricultural productivity Enenkel et al. (2019), which enables ethical decision-making in agricultural insurance claim settlement. The latter is crucial from a social perspective, as beneficiaries of these claims tend do be 'poor and powerless', as Nagendra, Narayanamurthy, and Moser (2022) put it.

Finally, as predictive analytics are increasingly being recognized as pivotal tools for climate finance, with applications reaching beyond insurance markets and catastrophe management (Alonso, Carbó, José Manuel, and Marqués, J Manuel 2023). As detailed by Ofodile et al. (2024), addressing the hurdles associated with data quality, model uncertainty, regulatory complexities, and the integration of climate-related factors in financial decision-making processes requires interdisciplinary collaboration and ongoing technological and financial innovation. This encompasses a wide range of techniques and information sources including novel climate models and satellite imagery.

In the context of the previous literature on satellite data for finance and economics, our proposition is as follows: While the data source is not new and has seen some success in specific domains, it remains under-utilized in others. We will subsequently analyze systematically whether the substream of the literature concerned with green finance can benefit from novel studies using satellite data. To this end, we briefly introduce Latent Dirichlet Allocation (LDA) in Section 5. The LDA model helps us uncover thematic clusters in a comprehensive dataset of scholarly papers on sustainable finance which already use satellite data. The use cases *not* uncovered by our analysis can inform us where future efforts of central banks, statisticians, and scholars may be targeted to effectively aid the green transition.

5. Topic modeling: satellite data in green finance

5.1. *Latent Dirichlet Allocation (LDA)*

As pointed out above, we rely on the LDA algorithm for the topic modeling task (Blei, Ng, and Jordan 2003). In selecting the most suitable methodology for topic modeling within this study, the choice of LDA over alternatives like BERTopic or Topic2vec is underpinned by several key considerations. For instance, while BERTopic (Grootendorst 2022) and Topic2vec (Niu et al. 2015) exhibit commendable performance in capturing semantic relationships and contextual understanding, the choice of LDA is rooted in its interpretability, scalability, and established track record in topic modeling (Jelodar et al. 2019). LDA, a generative probabilistic model, allows for a clear interpretation of topics as probability distributions over words, enabling a more straightforward comprehension of underlying themes within textual data. Additionally, LDA's computational efficiency and scalability make it well-suited for handling large corpora, offering a pragmatic advantage in processing substantial volumes of text data commonly encountered in empirical studies. Moreover, the widespread use and extensive literature on LDA provide a robust foundation for comparison, evaluation, and benchmarking against prior research, enhancing the reliability and interpretability of the findings derived from the topic modeling exercise within this study.

The key practical advantage of LDA is that it allows to treat documents like a mixture of different topics, while topics are presented as a mixture of words. Furthermore, no label of the documents is required. This makes it highly flexible and applicable to a wide range of domains and datasets, which fits the reality observed in climate finance studies, since different topics can partially overlap within a document. Interestingly, LDA is based on a generative probabilistic model, learning the topic-word distributions and the document-topic proportions from the data. Last but not least, LDA is easily scalable, as it handles large-scale datasets efficiently, which makes it valuable to fulfill our task at hand.

The procedure for extracting the topics consists of a variety of steps required for training, tuning, and applying the resulting LDA model to the corpus, as an unsupervised learning technique. We include a detailed description of this process in the Appendix, Section A.

5.2. *Data collection*

To conduct a systematic literature review, we use Harzing's Publish or Perish, a free application which enables large-scale literature searches. The user interface resembles Google Scholar and similar applications, and thereby allows searching by authors, years, journals, titles, and keyword combinations. The application also enables searches of various databases, among them Google Scholar, CrossRef, Pubmed, and others.

For the literature review, we use Google Scholar, CrossRef, OpenAlex, Semantic Scholar, and Scopus. Based on domain expertise, we decide on a list of keywords for our search. All combinations of these keywords, including mandatory mentions within titles and/or abstracts of the found papers as well as optional mentions, are considered. This means that, for instance, we use both "satellite data" and "climate finance" as well as satellite data climate finance separately as a combination of search terms.

The resulting total number of search word combinations is 112. We search each of the aforementioned databases (Google Scholar, CrossRef, OpenAlex, Semantic Scholar, and Scopus) for each of these terms. Within each search, we choose a maximum number of papers to be returned of 200. There are important differences between the matching paper results returned by each database: First, Google Scholar has taken precautions against automated data extraction so that we needed to limit the number of maximum returned papers in order to prevent our IPs being blocked. Second, Scopus only returns papers which fit the search well enough instead of returning all papers in decreasing order of "fittingness", which differs from the other platforms. Third, the scopes and information retrieval systems of all databases differ, as is made evident by the fact that the returned lists of papers do not overlap fully. The latter is one main reason why we use four databases, namely, to limit the results being influenced (or biased) by a single database's characteristics, and in turn maximize the number of results.

Due to these differences, the initial and final samples of papers do not consist of

Table 1. List of databases used for data collection

Database	**Initial sample**	**Unique-observation sample**
CrossRef	22,400	5,016
Semantic Scholar	22,400	4,842
OpenAlex	20,700	3,748
Scopus	3,681	1,822
Google Scholar	2,419	1,799
Total	71,600	17,227
Final sample after filtering	226	

equal shares from each database. To obtain our final sample of papers relevant to our research question, we take several filtering steps. Table 1 illustrates the sample decomposition before and after filtering and across databases.

The first step after collecting all papers is to remove duplicates. This step changes the sample from the initial sample to the unique-observation sample (i.e., sample without duplicates). Subsequently, we remove results with empty author information, results which author information contains only non-Roman letters, are published in appropriate media, and whose abstracts contain (i) satellite- or remote sensing-specific terminology as well as (ii) finance- or economics-specific terminology. The last filtering step is the most restrictive and ensures we only consider adequate papers for our analysis. During this work, we also add any papers which we come across "manually" and deem fitting for our purposes. The resulting final number of papers is 226. With this final sample, we conduct the NLP analyses described in the following sections.

5.3. *Uncovering thematic areas*

There are two main challenges when it comes to clustering topics in a corpus of texts. First, there is no one-size-fits-all approach to finding the optimal number of topics, i.e., the process always includes some trial and error. To aid the parameter selection process, the literature suggests several metrics, such as the perplexity (Blei, Ng, and Jordan 2003) and coherence scores (Röder, Both, and Hinneburg 2015). Increasing the number of topics usually improves these statistical measures during topic modeling. Simultaneously, however, a higher number of topics is associated with higher computational cost during training. In our case, we decide to estimate an LDA model with five topics, informed by the rate of perplexity change following Zhao et al. (2015).[10]

A further challenge is selecting a number of topics which not only "make sense" to the ML algorithm, but also to humans. To ensure a human-interpretable labeling of the resulting topics, we conduct a qualitative review with human expert judgment, in which we verify that the words associated with each topic align roughly with the experts' domain knowledge of the established climate finance literature. Upon estimating the LDA model, we label the topics using a two-step approach: firstly, we examine the tokens with the highest probability for each topic, as detailed in Table C1. Then, a more thorough analysis of the clusters (see more details in the Appendix, Section B) allows us to identify the following set of topics: Topic 1 as *Physical risk*, Topic 2

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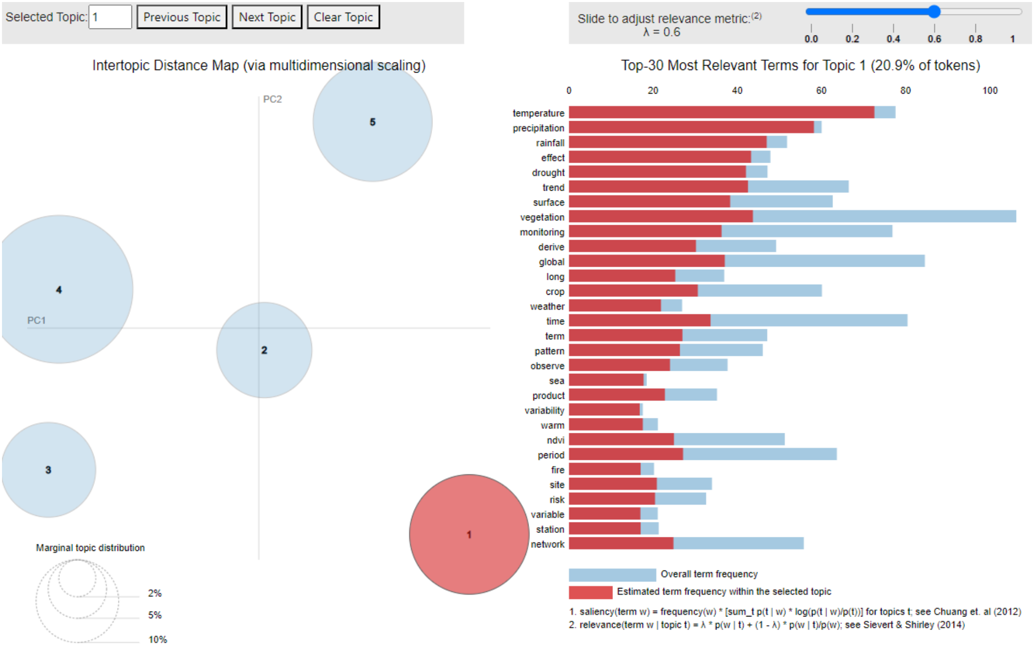
[10] Figure C1 in the Appendix displays the relevant metrics and training times for model versions ranging from one to ten topics.

as *Deforestation*, Topic 3 as *Energy and emissions*, Topic 4 as *Agricultural risk*, and Topic 5 as *Land use and land cover*.

For illustrative purposes, we outline the iterative, human-in-the-loop process of how we arrive at our final number and demarcation of topics. After reviewing the most frequent terms for each topic (see Table C1 in the Appendix), we assess the topics based on the relevance metric [11]. For instance, Figure 1 displays the intertopic distance map, which we use to fine-tune the topic selection of our LDA model. The visualization presented in this map is indicative of topic differentiation, i.e., a wider distance corresponds to a stricter differentiation. The term-relevance chart, which shows the importance and the relevance metric of single terms for the selected topic, can be seen on the right-hand side of Figure 1. For Topic 1, we find significant emphasis on terms such as “weather”, “temperature”, “rainfall”, and “drought”. This emphasis enables a distinction of Topic 1 from the other topics, underscoring its semantic concentration on the impacts of extreme weather events and acute or chronic physical risks. Consequently, we categorize this topic as *Physical risk*. A similar methodology is applied to the remaining topics, with term-relevance charts analogous to Figure 1 provided in Figures C2 through C6.



1. saliency(term w) = frequency(w) * [sum_t p(t | w) * log(p(t | w)/p(t))] for topics t; see Chuang et. al (2012)
2. relevance(term w | topic t) = λ * p(w | t) + (1 - λ) * p(w | t)/p(w); see Sievert & Shirley (2014)

Figure 1. Intertopic distance map, and Top30 most relevant terms for Topic1.

Uncovering one topic can inform the labeling of others due to their interconnected nature. This interconnectedness enable us to address their practical implications in the field of green finance, where each of our topics aligns with emerging financial products in the field. For example, weather forecasting (Topic 1: Physical risk) is crucial for renewable energy trading (Ghoddusi, Creamer, and Rafizadeh 2019), which is closely linked to the discussions in Topic 3 (Energy and emissions). In addition, as highlighted by Topic 3, assessing carbon emissions over the value chain is essential for creating effective carbon tax policies and facilitating carbon offset trading in secondary markets, (Borowski 2021) and (TSVCM 2021). This assessment is a critical step in the design

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[11] Using $\lambda = 0.6$ and the PyLDAvis Python library proposed by Sievert and Shirley (2014)

and implementation of financial mechanisms that aim to reduce carbon footprints.

On another note, the emphasis on ecosystem health as the main indicator in nature finance (see, for instance, TNFD 2023; Schimanski et al. 2023), aligns with the research focus of Topic 2 (Deforestation) and Topic 5 (Land use and land cover). Their practical implication is exemplified by the partnership of World Bank and ESA, which leverages satellite data to monitor deforestation activities in the Peruvian Amazon. Insights from this collaboration could potentially help developing green finance products, like Sustainability-Linked Bonds (ESA 2023), or enabling the verification of commitments in blue bonds (Thompson 2022).[12]

Lastly, our results support the application of satellite data to better assess agricultural risk (Topic 4). This is particularly relevant for a just transition where small farmers must adapt to current changes in climate. The importance of this facet is underscored by, for instance, the joint venture between IFAD and ESA (IFAD 2023) and the Catalogue of Geospatial Tools and Applications for Climate Investments of IFAD (2022).

6. Conclusion and policy discussion

International central banks have identified the need to bridge climate-related data gaps to enable green finance to scale up. This need comes at a time where pressures on financial institutions are increasing along three major dimensions: Calls for increased voluntary and mandatory disclosure and regulation (e.g., the launch of EU Taxonomy, CSRD, and SFDR); the need to address "double materiality", which recognizes not only the financial materiality to companies arising from climate risks and opportunities but also the materiality for society and the environment arising from the companies' operations, which in turn can result in financial risks (Gourdel et al. 2022), and the growing importance for central banks around the topic of the "environment" (WWF 2023), and biodiversity (NGFS 2023).

A potential candidate to assist covering climate-related data gaps as defined by NGFS (2022) is satellite data. This data source comprises spatio-temporal information retrieved from satellites and sensors that orbit the Earth. EO systems might potentially open bottlenecks in several operational problems by increasing the widespread availability of climate-related data, adding new layers of information (geo-location) to currently available data, and/or enhancing the reliability of self-reported data from corporates. However, they also faced important challenges and decisions that need to be addressed in order to use this information. We point out potential limitations of satellite data in addressing climate data gaps: availability (e.g., coverage, granularity, accessibility), reliability (e.g., quality, auditability, transparency), and comparability (due to the absence of a unified reporting standard). While EO systems can enhance data availability, accessibility remains limited, with barriers such as proprietary databases and high costs for newcomers needing to process raw data.

On the other hand, satellite data boasts impressive advantages, such as general high quality, auditability, and transparency, positioning it as a viable candidate to improve digital measurement and reporting systems especially in the field of green finance. However, the fact that parametrization needs to be undertaken individually by each

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[12] Water resources, including rivers, oceans, floods, etc., occur in Topics 1, 4, and 5 of our LDA model.

user and use case, complicates the comparability of results based on spatial analysis.

We have already seen the use of this information in several cases. In emerging countries, information such as night-time luminosity has proven valuable for fore- and nowcasting indicators such as GDP growth and beyond. Similarly, in times of turmoil such as the COVID-19 pandemic, satellite imagery was useful to track urban mobility and estimate the effect of fiscal subsidies to boost economic activity locally. Within the financial literature, remote sensing has been used to estimate oil reserves, count cars in parking lots to estimate consumer spending at large retailers, and assist investors in market-timing strategies for such retailers' stocks. In the domain of green finance use cases, satellite data has been somewhat established in the insurance sector. However, we propose that today, there are more urgent thematic areas where researchers are researchers could harness this novel and largely free data source to solve a variety of problems.

In order to provide a more systematic analysis of the potential of this data for sustainable finance we use a semi-automated review of the scientific literature on the application of EO systems for green finance. To this end, we collect a corpus of scientific studies and, using NLP techniques (LDA), we uncover five application domains where researchers are exploring the value of EO systems. In particular, we find that (1) physical risk materialization (including both acute and chronic risk), (2) deforestation, (3) energy and emissions, (4) agricultural risk, and (5) land use and land cover, are core areas where satellite data might enable new green financial products and markets, such as sustainability linked bonds or blue bonds, nature finance, or voluntary carbon markets. Our results are echoed by innovative private sector players (e.g., DrivenDataLabs (2023)) who offer services based on artificial intelligence and new data types from EO systems in different business areas, such as natural resource management, disaster resilience, biodiversity conservation, energy efficiency, or upstream services.

We conclude by stating that satellite data shall not be an isolated area of research to fill in climate data gaps. It can work together with improved observational data, leveraging new technologies like machine learning or landscape audio. Used in this fashion, it can enable and new layers of information, and thereby boost new insights from ground-based data. Overall, although EO systems in green finance are still emerging, their potential has piqued the interest of central banks, as a potential public good, prompting exploration and collaboration on international platforms like the NGFS or BISIH to experiment, monitor, and track new developments.

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Appendix A. LDA: topic modeling

A necessary first step in topic modeling is processing the corpus of documents by tokenizing each document into a collection of their individual words where order is unimportant (i.e.: each document is treated as a "bag of words"). Then, stopwords that have no topic context (such as "and", "of", "the"), are removed, as well as common terms that are highly repeated in the corpus, which we identify because they appear in more than half of the documents, or rare terms for which we set a threshold of being in less than two documents. We deem that both categories of terms contain little meaning to contribute to a relevant topic.[13] Remaining words in a document are lemmatized to generate the words' root, and accurately capture unique terms usage.[14]. For simplicity, we keep our analysis to single word tokens as we find that it allows us to easily label the topics at the final stage.

Once the corpus is preprocessed, we count with D documents that together contain N unique tokens that we can represent by an N x D matrix W with entries $w_{n,d}$, which in turn are the number of occurrences of token n in document d. Thus, the total number of tokens in document d is $N_d = \sum_{n=0}^{N} w_{n,d}$. The LDA model consists of two matrices, $\beta_{N\times K}$ and $\theta_{K\times D}$, where K is the total number of topics. For topic k, the vector β_k contains the N token weights, which act as the probabilities $P(n|k)$ that the token n contribute to a document's bag of words, conditional on the topic k contributing to the document. That is, $P(n|k) = \beta_k$, i.e.: the weight of token n in topic k. Therefore, $\sum_{n=1}^{N} \beta_{n,k} = 1$. For document d, the vector θ_d contains the K topic weights – which act as the probability $P(k|d)$ that topic k appears in the document. Thus, $P(k|d) = \theta_{k,d}$, i.e.: the weight of topic k in document d. Similarly, $\sum_{n=1}^{N} \theta_{k,d} = 1$. When these probabilities are significant, we may say that a topic k is relevant in document d. Finally, this setting allows us to decompose the probability of a token n occurring in a document d in the following equation (Hofmann 2001):

$$P(n|d) = \sum_{k=1}^{K} P(n|k) \cdot P(k|d) = \sum_{k=1}^{K} \beta_{n,k} \cdot \theta_{n,d} \tag{A1}$$

Topic modeling involves reducing the dimensions of these matrices to end up with the same number of rows (documents) but a restricted number of columns which represent the topics. To this purpose LDA assumes a particular Dirichlet distribution that can be used to produce probability vectors β_k and θ_d, that allow an assumption to be made about how topics are distributed across tokens and documents. Using two external inputs, α and β, as Dirichlet priors, we can determine the generative process in the LDA (Blei 2012; Blei, Ng, and Jordan 2003). α determines θ_d or per-document topic distribution, and the β parameter determines β_k or per-topic token distribution.

The LDA posteriors are a result of the trade-off between two inherently conflicting

---

[13] We decide not to include bi-grams or tri-grams in this process as we deem that common candidates like "climate change" or "green bonds" would fall under the definition of common terms when split into two. Therefore, we do not expect to change our results. Though, further research could be carried out to perform this robustness check.

[14] While stemming consists on the removal of suffixes without considering the context or the actual meaning of the word, which can sometimes lead to the generation of non-interpretable words, lemmatization is the process of grouping together different forms of the same word, allowing to work with immediately interpretable tokens.

goals. Firstly, that only a relatively small number of topics are expected in a well-written document, and secondly that only high probability should be assigned to a small number of tokens that belong to highly informative topics. The trade-off exists because if we assign, for instance, a single topic to a single document, thus succeeding at the first goal, the second goal becomes difficult to achieve because all tokens in the document must have a relatively high probability of belonging to that topic. The estimation of the LDA model requires a Bayesian updating from its initial semi-random allocation of topics to tokens and documents, to converge to a probabilistic distribution of topics across documents. Technically, the process will be completed when we find matrices $\beta_{N\times K}$ and $\theta_{K\times D}$ that most likely have produced the observed data W. In our case, the Gensim implementation in Python, based on a Bayesian approach, finds the best configuration of the model automatically as well as several settings related to numerical efficiency (Hofmann 2001). In order not to stop at a local optimum we use a high enough number of iterations, in particular we needed 40,000 passes to reach a stable solution.

Appendix B. Clusters analysis

Reviewing the top terms for each topic provides us with an initial understanding into their potential labels. However, this approach does not remove all uncertainty in assigning sufficiently different and sensible topics: some tokens, such as ‘vegetation’ in topics 1 and 2 and ‘land’ in topics 4 and 5, can be prevalent across multiple topics. Hence, we further scrutinize the top terms using the relevance metric, which prioritizes terms based on their significance within a topic relative to their presence in other topics. The relevance metric is defined as follows: for a given term t, its relevance to topic k is defined as follows:

$$\lambda \log(\beta_{k,t}) + (1-\lambda)\log(\frac{\beta_{k,t}}{p_t}), \tag{B1}$$

where $\beta_{k,t}$ is the probability of term t in topic k, p_t is the marginal probability of term t across all topics, and λ is a parameter that balances term frequency within a specific topic against its frequency across all topics. By applying this metric, we identify the following set of topics: Topic 1 as *Physical risk*, Topic 2 as *Deforestation*, Topic 3 as *Energy and emissions*, Topic 4 as *Agricultural risk*, and Topic 5 as *Land use and land cover.*

Appendix C. Figures and Tables

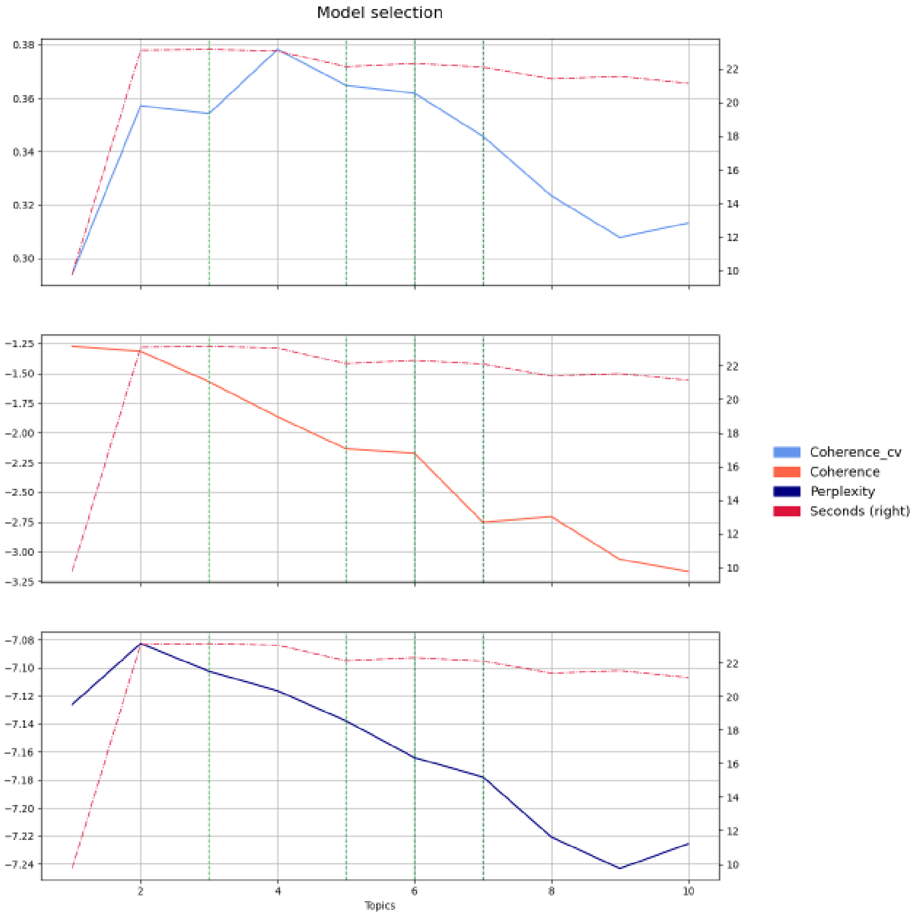
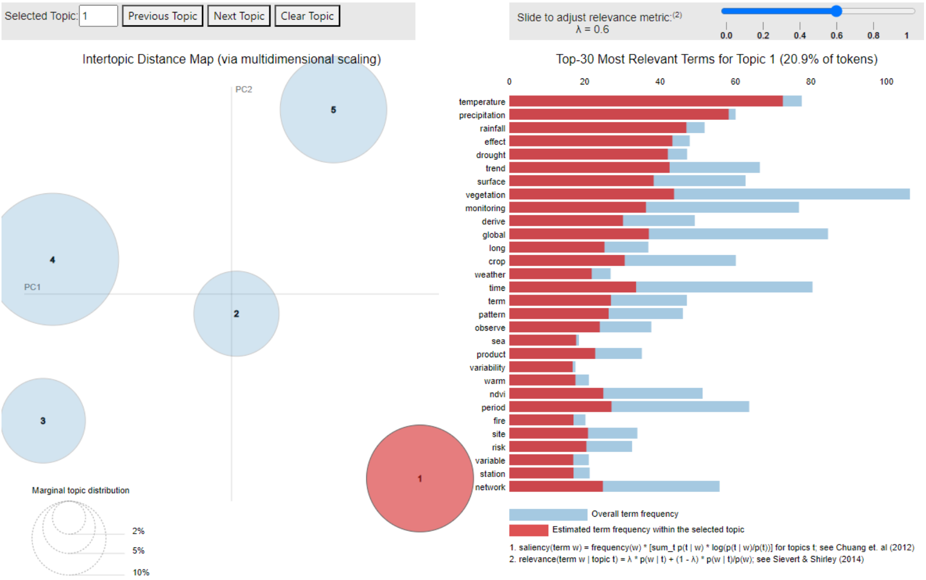
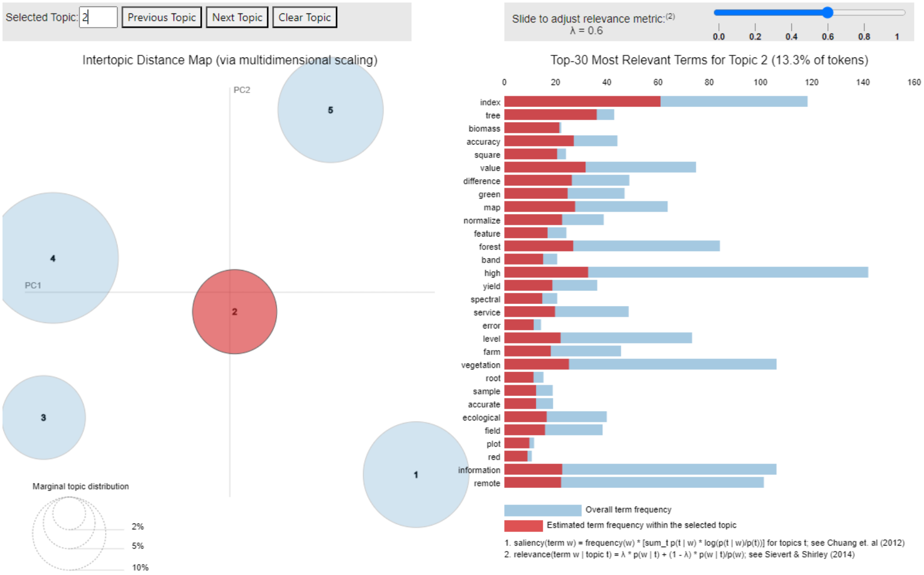


Figure C1. LDA model selection metrics



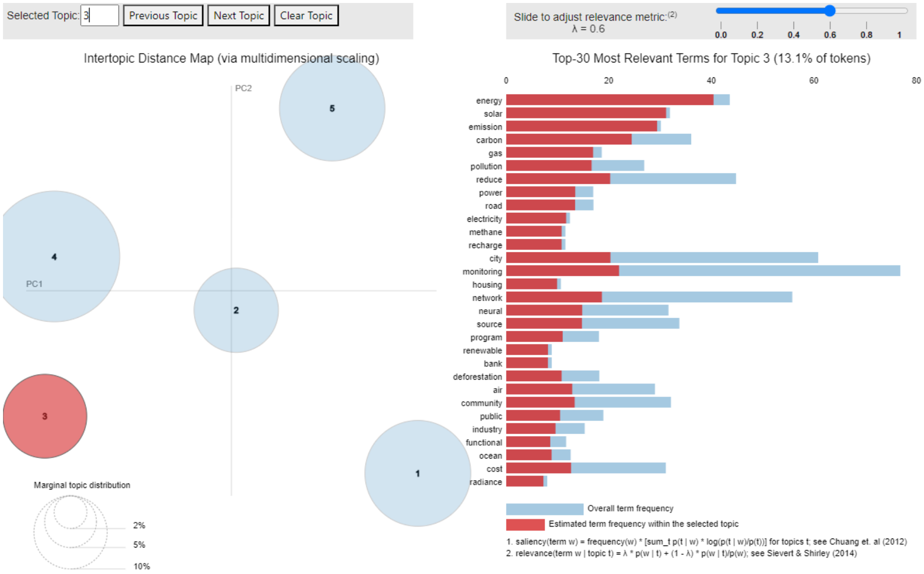
1. saliency(term w) = frequency(w) * [sum_t p(t | w) * log(p(t | w)/p(t))] for topics t; see Chuang et. al (2012)
2. relevance(term w | topic t) = λ * p(w | t) + (1 - λ) * p(w | t)/p(w); see Sievert & Shirley (2014)

Figure C2. Intertopic distance map, and Top30 most relevant terms for Topic1.



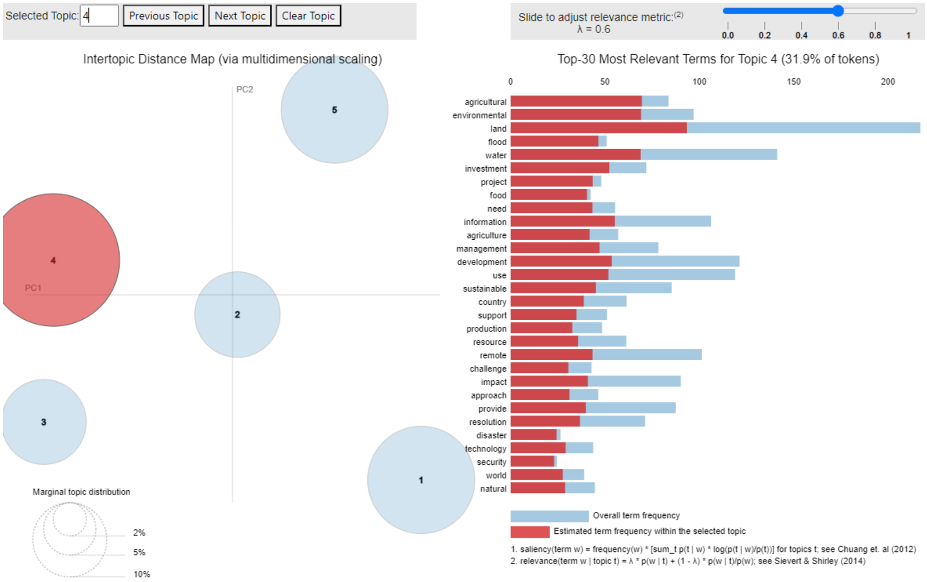
1. saliency(term w) = frequency(w) * [sum_t p(t | w) * log(p(t | w)/p(t))] for topics t; see Chuang et. al (2012)
2. relevance(term w | topic t) = λ * p(w | t) + (1 - λ) * p(w | t)/p(w); see Sievert & Shirley (2014)

Figure C3. Intertopic distance map, and Top30 most relevant terms for Topic2.



1. saliency(term w) = frequency(w) * [sum_t p(t | w) * log(p(t | w)/p(t))] for topics t; see Chuang et. al (2012)
2. relevance(term w | topic t) = λ * p(w | t) + (1 - λ) * p(w | t)/p(w); see Sievert & Shirley (2014)

Figure C4. Intertopic distance map, and Top30 most relevant terms for Topic3.

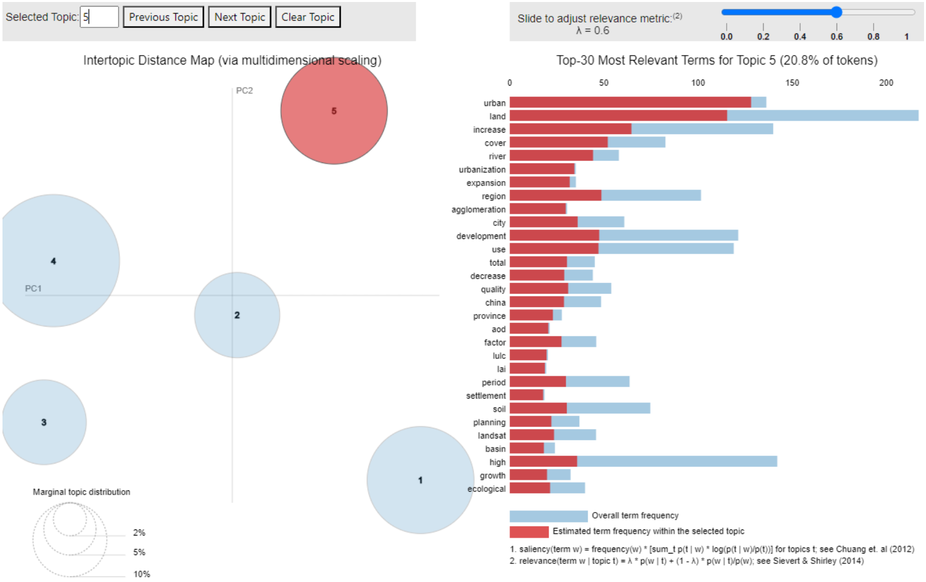


Selected Topic: 4

Slide to adjust relevance metric:(2)
λ = 0.6

1. saliency(term w) = frequency(w) * [sum_t p(t | w) * log(p(t | w)/p(t))] for topics t; see Chuang et. al (2012)
2. relevance(term w | topic t) = λ * p(w | t) + (1 - λ) * p(w | t)/p(w); see Sievert & Shirley (2014)

Figure C5. Intertopic distance map, and Top30 most relevant terms for Topic4.



Selected Topic: 5

Slide to adjust relevance metric:(2)
λ = 0.6

1. saliency(term w) = frequency(w) * [sum_t p(t | w) * log(p(t | w)/p(t))] for topics t; see Chuang et. al (2012)
2. relevance(term w | topic t) = λ * p(w | t) + (1 - λ) * p(w | t)/p(w); see Sievert & Shirley (2014)

Figure C6. Intertopic distance map, and Top30 most relevant terms for Topic5.

Table C1. Probabilities of tokens per topic

Topic	**1**		**2**		**3**		**4**		**5**	
1	0.015	temperature	0.020	index	0.013	energy	0.012	land	0.026	urban
2	0.012	precipitation	0.012	tree	0.010	solar	0.009	agricultural	0.024	land
3	0.010	rainfall	0.010	high	0.010	emission	0.009	environmental	0.013	increase
4	0.009	vegetation	0.010	value	0.008	carbon	0.009	water	0.011	cover
5	0.009	effect	0.009	map	0.007	monitoring	0.007	information	0.010	region
6	0.009	trend	0.009	accuracy	0.007	city	0.007	development	0.010	development
7	0.009	drought	0.009	forest	0.007	reduce	0.007	investment	0.010	use
8	0.009	surface	0.008	difference	0.006	network	0.007	use	0.009	river
9	0.008	global	0.008	vegetation	0.005	gas	0.067	management	0.007	city
10	0.007	monitoring	0.008	green	0.005	pollution	0.006	flood	0.007	high
Label	**Physical risk**		**Deforestation**		**Energy and emissions**		**Agricultural risk**		**Land Use and Land Cover**	

Houston, we have a problem:
Can satellite data bridge the climate-related data gap?

Andres Alonso, Jose Manuel Carbo, **Emily Kormanyos**, Elena Triebskorn
Deutsche Bundesbank and Banco de España

IFC Workshop on "Addressing Climate Change Data Needs: The Global Debate and Central Banks' Contribution"

Sustainable Finance Data Hub

Agenda

- The role of technology in bridging climate-related data gaps
- Satellite data for green finance: Is this time different?
- Use cases: ML-supported literature review
- Outlook and conclusions

Motivation
The role of technology in bridging climate data gaps

Increasing focus on climate-related and sustainable finance data

- Central banks have **data needs** which they should close with **collaborative efforts** using **novel**, **unstructured** data sources (IFC, NGFS)
- Current efforts include:
    - **ECB** statistical indicators
    - **G20** data gaps initiative
    - **BIS** Innovation Hub (BISIH) and Network (BISIN):
        - Project Gaia, Project Viridis

Regulatory landscape

- New **directives** and **regulatory requirements** to improve data landscape:
    - ESAP – ESEF
    - CSRD, TCFD, TNFD, …
- But **timeframe** and **extent** of (full) coverage until data availability is **not clear**

In the meantime, bridging technology is required

- **Technological innovation**:
    - as **bridge technology until** official data becomes available

      and/or
    - to **augment** / extend official data **when** it becomes available
- One of several promising candidates is geospatial data (esp. **Earth Observation** (EO) systems)

TNFD Taskforce on Nature-related Financial Disclosures

BIS Innovation Hub

PROJECT VIRIDIS

G20 DATA GAPS INITIATIVE 3 DELIVERING INSIGHTS FOR ACTION

TCFD TASK FORCE ON CLIMATE-RELATED FINANCIAL DISCLOSURES

ISSB

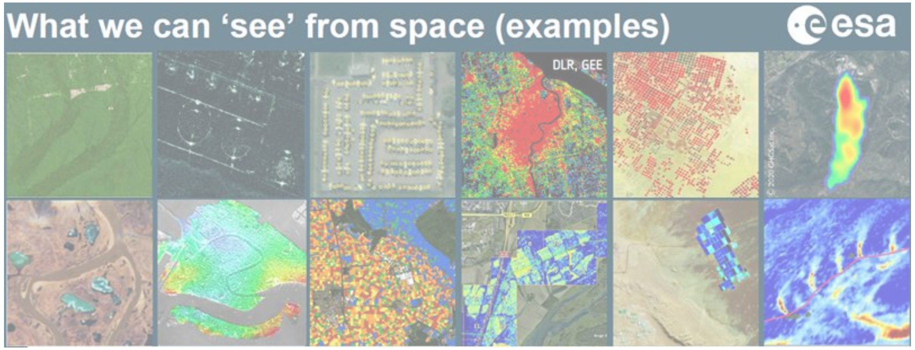
Motivation & project overview
Why do we need to take (another) look at satellite data?

Situation

- Satellite data **available**, mostly **freely accessible**
- Already used in the **Global South**
  - E.g., Mexico, Egypt
- Limited use in the **Global North** due to availability of high-quality, granular, and timely **official statistics**

What we do

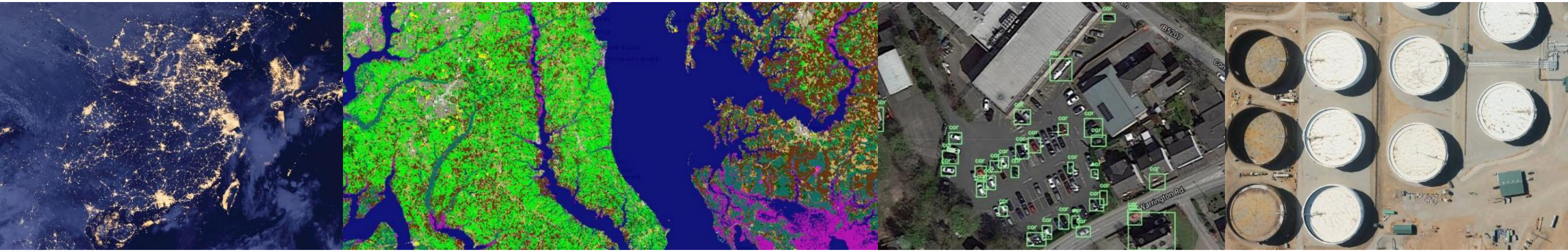
- Raise and help answer the question:
  - Is **sustainable finance a new frontier** for satellite data?
- Systematic literature review, topic modeling
  - Identify **where satellite data is successful** (e.g., insurance sector, agriculture, …)
  - Identify **a gap in the literature** using satellite data for sustainable finance



Successful use of EO data
Specific examples and future potential for green finance

- **Two primary areas** of successful application:
  - Development economics (tracking/estimating economic growth in Global South economies)
  - Capital markets (esp. commodity and equity trading)
- **High potential of EO data** for predictive analytics in climate finance

- Specific examples:
  - **Nighttime lights** to proxy economic activity
  - Monitor urbanization patterns, infrastructure development, and land use changes (land use and land cover = **LULC**)
  - **NO_2** pollution → environmental impact of economic activity
  - **Oil storage facility** monitoring → commodities trading
  - Retail **parking lots** → consumer spending
  - Insurance markets: agricultural risk management



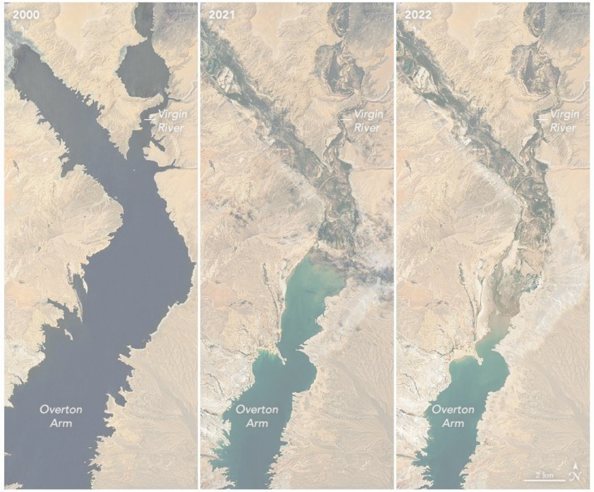
Satellite data in sustainable finance
Our value proposition and contribution

Our proposition

- **Varying effects** of climate change within continents, countries, cities:
  - Transition and physical risks are **not evenly** distributed
    - **Climate finance is spatial**
  - Traditional data and models tend to **aggregate too broadly** over heterogeneously affected areas
- Satellite data can:
  - **address** these shortcomings of traditional data in the Global South and Global North
  - **enhance** the granularity (resolution) of traditional data & official statistics

But barriers to the success of satellite data remain

- Working with satellite data can be **difficult**:
  - Raster mapping
  - Link to official statistics?
  - Technological barriers (software usage, coding)
- We illustrate **typical challenges** and how to address them:
  - Econometrics
  - Parametrization (obtaining a series / variable from EO data)



Systematic literature review aided by ML

Uncover clusters in the literature to derive use cases

Where has satellite data (not) seen success?

- While satellite data has seen success in **some domains**, it remains underused in others
- Conduct **large-scale literature** search
- Build topic model (**LDA**) to find **thematic clusters**
  - where EO data is used successfully vs.
  - where future efforts can use it to aid the green transition and inform central banks, official statistics, and academia

Approach to systematic literature review

- We use the **Publish or Perish** software for systematic literature search
- **Keyword combinations** for search queries based on domain expertise
- **Filter** search results to obtain final sample of relevant papers

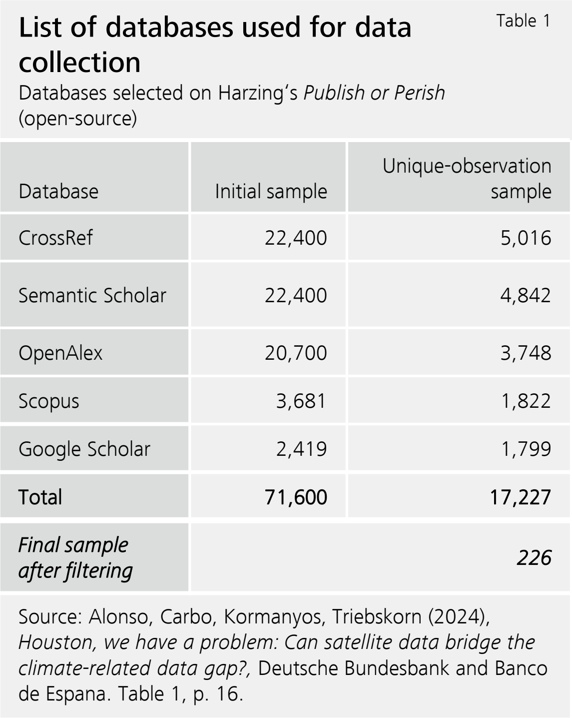


Table 1

List of databases used for data collection

Databases selected on Harzing's *Publish or Perish* (open-source)

Database	Initial sample	Unique-observation sample
CrossRef	22,400	5,016
Semantic Scholar	22,400	4,842
OpenAlex	20,700	3,748
Scopus	3,681	1,822
Google Scholar	2,419	1,799
Total	71,600	17,227
Final sample after filtering		*226*

Source: Alonso, Carbo, Kormanyos, Triebskorn (2024), *Houston, we have a problem: Can satellite data bridge the climate-related data gap?*, Deutsche Bundesbank and Banco de Espana. Table 1, p. 16.

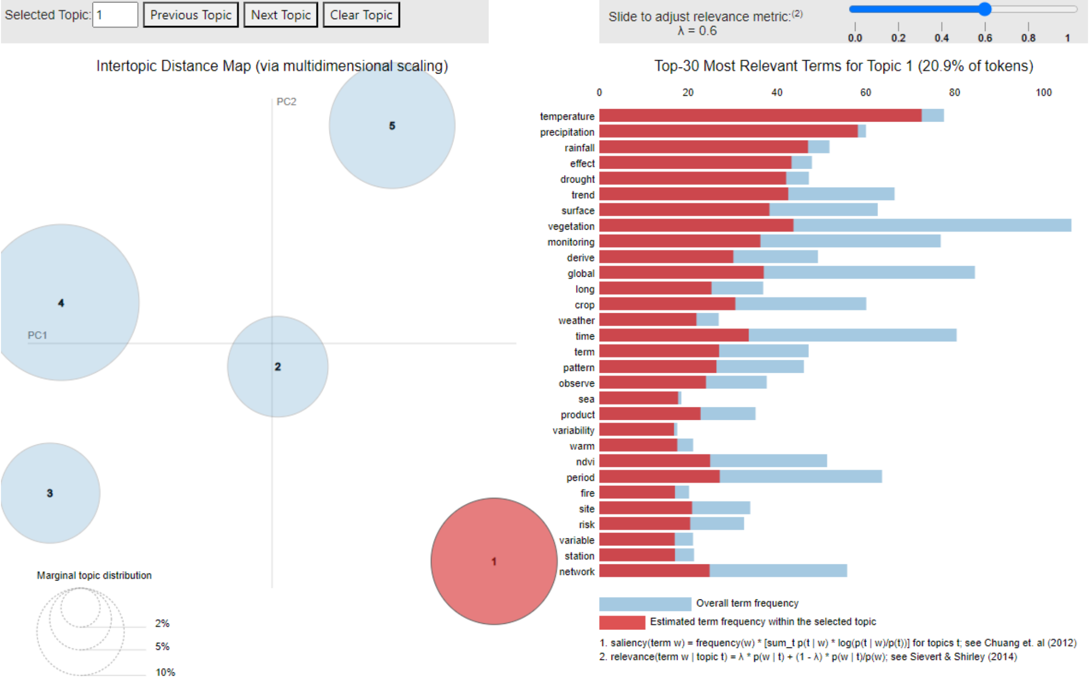
Finding optimal clusters

Iterative, human-in-the-loop process reveals thematic clusters in LDA topics

Topic model development

- **Challenges**:
  - Optimal number of topics
  - Balance statistical metrics with costs
- Interpretable topic labeling based on **token analysis** and **relevance** metrics
- **Iterative** process:
  - **Fine-tune** topics using **intertopic distance** maps and domain knowledge on **practical implications** for green finance

Intertopic distance map: topic 1 (physical risk)



Selected Topic: 1

Slide to adjust relevance metric:[2] λ = 0.6

1. saliency(term w) = frequency(w) * [sum_t p(t | w) * log(p(t | w)/p(t))] for topics t; see Chuang et. al (2012)
2. relevance(term w | topic t) = λ * p(w | t) + (1 - λ) * p(w | t)/p(w); see Sievert & Shirley (2014)

Topic modeling results
Five distinct topics show current proliferation of EO data in the literature

LDA results

Table 2

Ten most frequent tokens, including each token's probability, per topic

Topic →	1	2	3	4	5
1	0.015 temperature	0.020 index	0.013 energy	0.012 land	0.026 urban
2	0.012 precipitation	0.012 tree	0.010 solar	0.009 agricultural	0.024 land
3	0.010 rainfall	0.010 high	0.010 emission	0.009 environment	0.013 increase
4	0.009 vegetation	0.010 value	0.008 carbon	0.009 water	0.011 cover
5	0.009 effect	0.009 map	0.007 monitoring	0.007 information	0.010 region
6	0.009 trend	0.009 accuracy	0.007 city	0.007 development	0.010 development
7	0.009 drought	0.009 forest	0.007 reduce	0.007 investment	0.010 use
8	0.009 surface	0.008 difference	0.006 network	0.007 use	0.009 river
9	0.008 global	0.008 vegetation	0.005 gas	0.007 management	0.007 city
10	0.007 monitoring	0.008 green	0.005 pollution	0.006 flood	0.007 high
Topic label	Physical risk	Deforestation	Energy and emissions	Agricultural risk	Land use and land cover

Source: Alonso, Carbo, Kormanyos, Triebskorn (2024), *Houston, we have a problem: Can satellite data bridge the climate-related data gap?,* Deutsche Bundesbank and Banco de Espana. Table A1, p. 30.

Conclusion and way forward

1

NOVEL DATA FOR CENTRAL BANKS

- **Promising option** to **bridge** climate-related **data gaps** of central banks
- EO data has **demonstrated usefulness** in diverse economic areas

2

POTENTIAL AND LIMITATIONS

- Core thematic areas where EO data can **support green finance**: physical risk, deforestation, energy and emissions, agricultural risk, and land use and land cover
- Despite **challenges** (accessibility and comparability), EO data has **high quality**, **auditability**, and **transparency**, positioning it as a **viable asset** to green finance

3

NEXT STEPS AND COLLABORATIVE EFFORTS

- EO data should be **integrated** with other data sources and technologies (e.g., ML/AI) to **maximize its potential**
- **Collaborative efforts** are needed to monitor developments and foster experimentation (e.g., BISIN, NGFS)
- **Next step**: derive **helpful**, **novel use cases** for EO data in sustainable finance for central banks and other FI

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Appendix

Satellite data specificities
Gaining and understanding on EO data for green finance and beyond

Understanding satellite data

- Satellite types:
  - Communication, earth observation, navigation, astronomical satellites
  - Focus primarily on earth observation satellites for environmental monitoring and geographic mapping
- Instruments and sensors:
  - Multiple instruments with multiple sensors each
  - Sensors detect light in certain spectral bands
  - Different levels of spatial resolution for each sensor
  - One pixel corresponds to a certain geographic area
- Passive vs. Active sensors:
  - Passive sensors collect radiated photons from earth or sun
  - Active sensors send signals to earth and measure reflections, useful for penetrating clouds and capturing night images

Utilizing satellite data

- Data applications:
  - Measures various earth features like temperature, terrain, pollutants
  - Forms different types of images and videos, from natural color to false-color
- Metrics and indices:
  - Examples include NDVI, NBR, NDWI → ecosystem impact, wildfires, water scarcity
- Economic relevance:
  - Satellite data offers real-time, global coverage for tracking environmental health, land use, and deforestation rates
- Challenges:
  - Data access, cleaning, and pre-processing are significant hurdles
  - Econometric modeling required for interpreting raw data
  - Challenges to economic materiality in sustainable finance applications

Econometric modeling

- Spatial dependency and autocorrelation:
  - Proximity of geo-locations leads to spatial (auto-)correlation, violating independence assumptions in econometric models
- Spatial heterogeneity:
  - Relationships between predictor and outcome variables vary spatially
  - Requires different estimates for different regions
    - Spatial weights Address both spatial dependency and heterogeneity
    - Deriving weights can be challenging and increase model complexity
- In addition to classical issues:
  - Endogeneity
  - Sparsity
  - Missingness

ML and AI algorithms can handle nonlinearity, spatial heterogeneity, and clustering issues

Local Projections (Jordà, 2005, 2023) are suited to estimate responses to climate shocks

Understanding satellite data

Color bands and sustainability metrics

Understanding satellite color bands

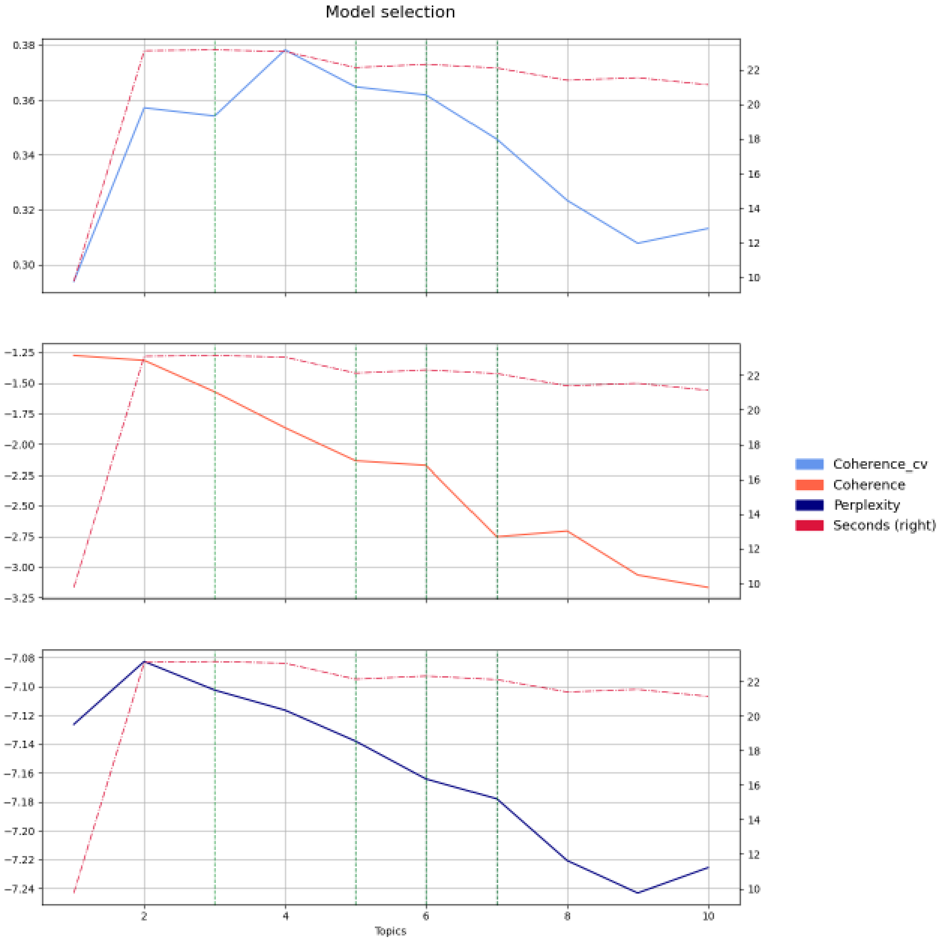
- Landsat collects 8 color bands:
  - B1 captures deep blue and violet light, useful for identifying aerosol particles
  - B2 captures blue light to differentiate water bodies
  - B3 captures green light, essential for assessing vegetation health
  - B4 captures red light, helpful in identifying plant types
  - B5 captures near-infrared light, indicating plant health and density
  - B6 captures shortwave infrared light (SWIR 1), useful for soil and vegetation moisture differentiation
  - B7 captures shortwave infrared light (SWIR 2), mapping geological features and vegetation
  - B8 captures panchromatic light, offering detailed landscape imagery

Examples of metrics derived from EO data

- NDVI (Normalized Difference Vegetation Index):
  - Measures vegetation health by contrasting near-infrared and red light
  - Useful for monitoring vegetation over time, including pre- and post-fire conditions
- NBR (Normalized Burn Ratio):
  - Specifically designed for identifying burned areas and estimating burn severity
  - Lower values indicate higher burn severity, aiding in fire impact analysis
- NDWI (Normalized Difference Water Index):
  - Optimized for water body detection by highlighting liquid water absorption and reflectance
  - Effective in delineating open water features and monitoring changes in water content of leaves

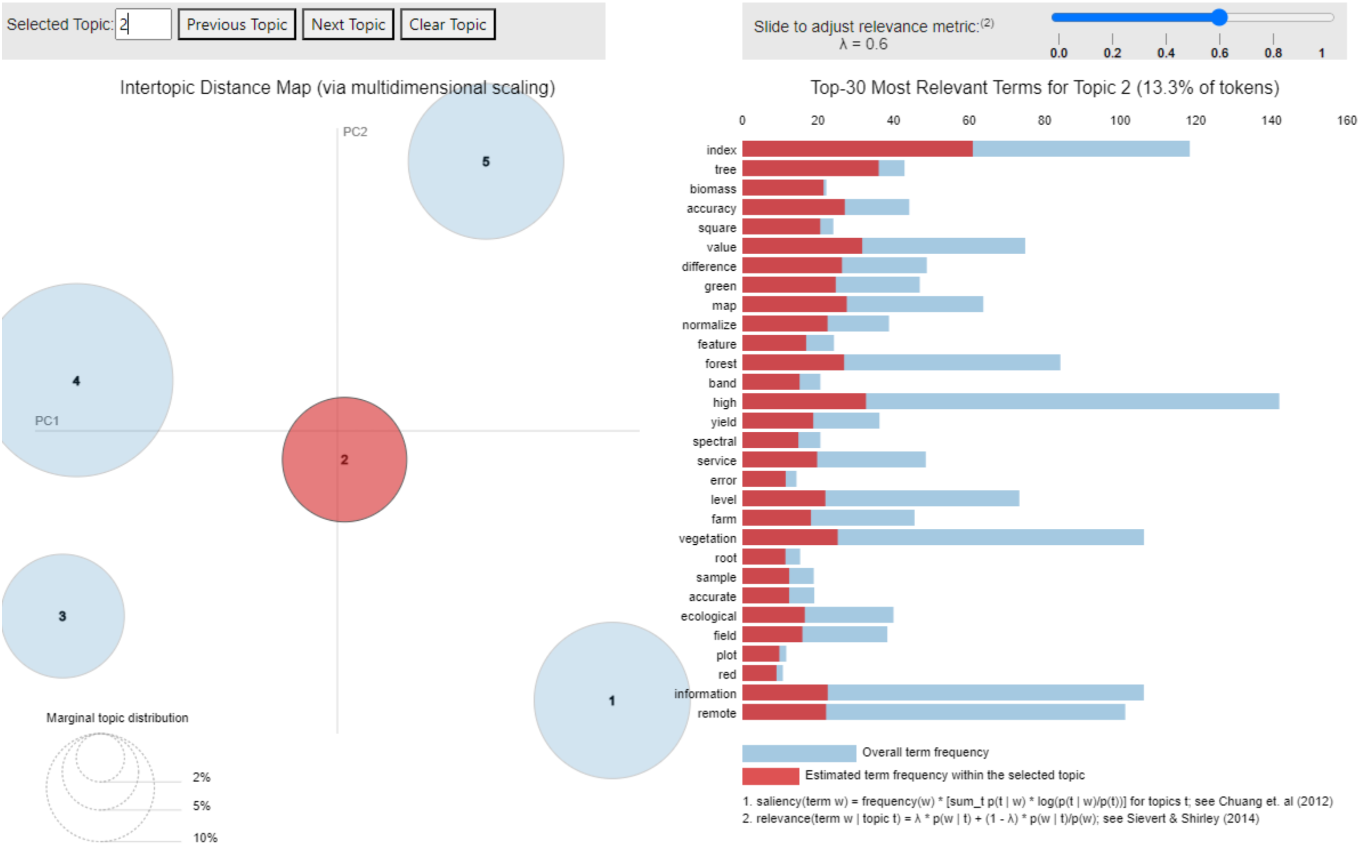
Topic model selection

LDA metrics



Topic model development – intertopic distance

Topic 2: deforestation



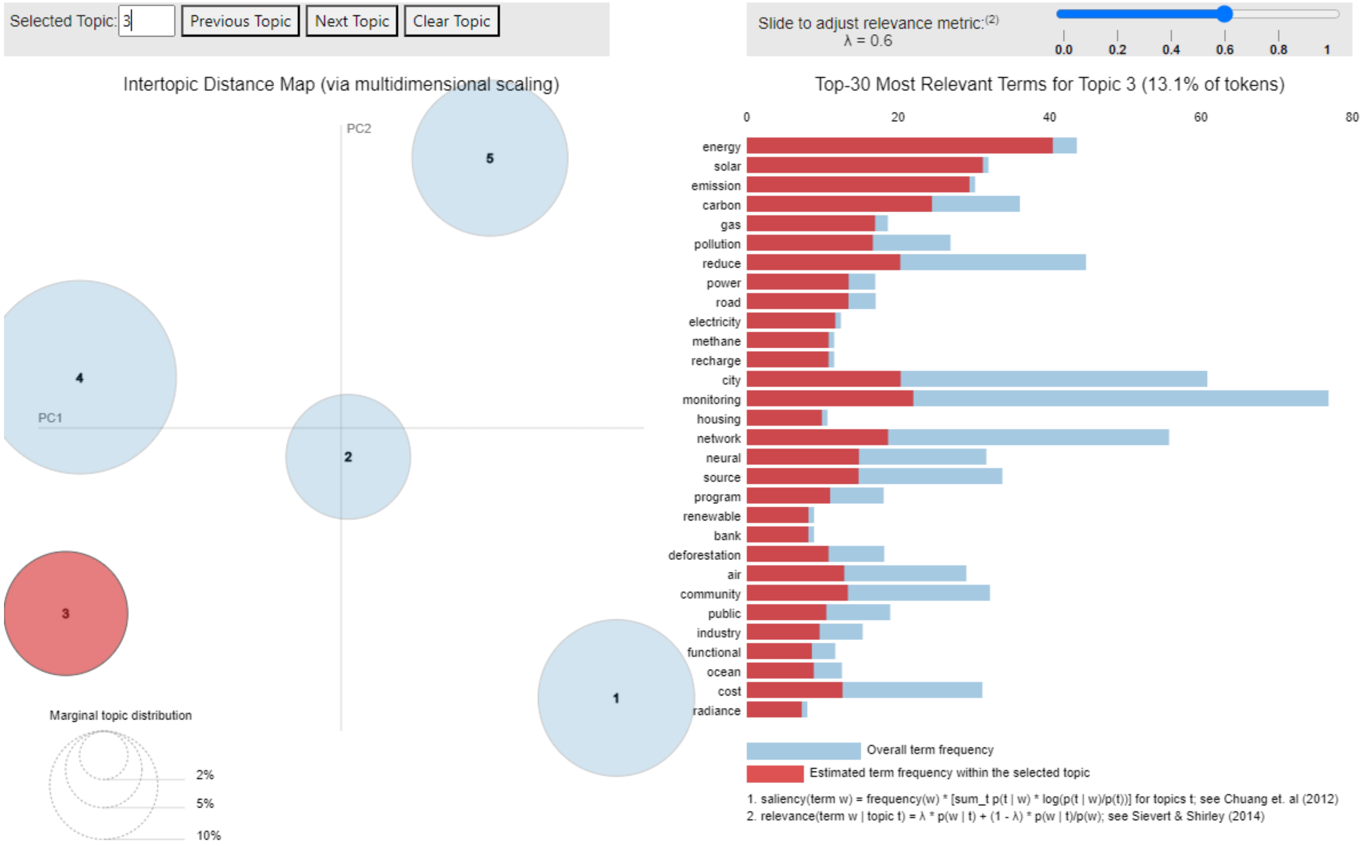
Selected Topic: 2

Slide to adjust relevance metric:(2) λ = 0.6

1. saliency(term w) = frequency(w) * [sum_t p(t | w) * log(p(t | w)/p(t))] for topics t; see Chuang et. al (2012)
2. relevance(term w | topic t) = λ * p(w | t) + (1 - λ) * p(w | t)/p(w); see Sievert & Shirley (2014)

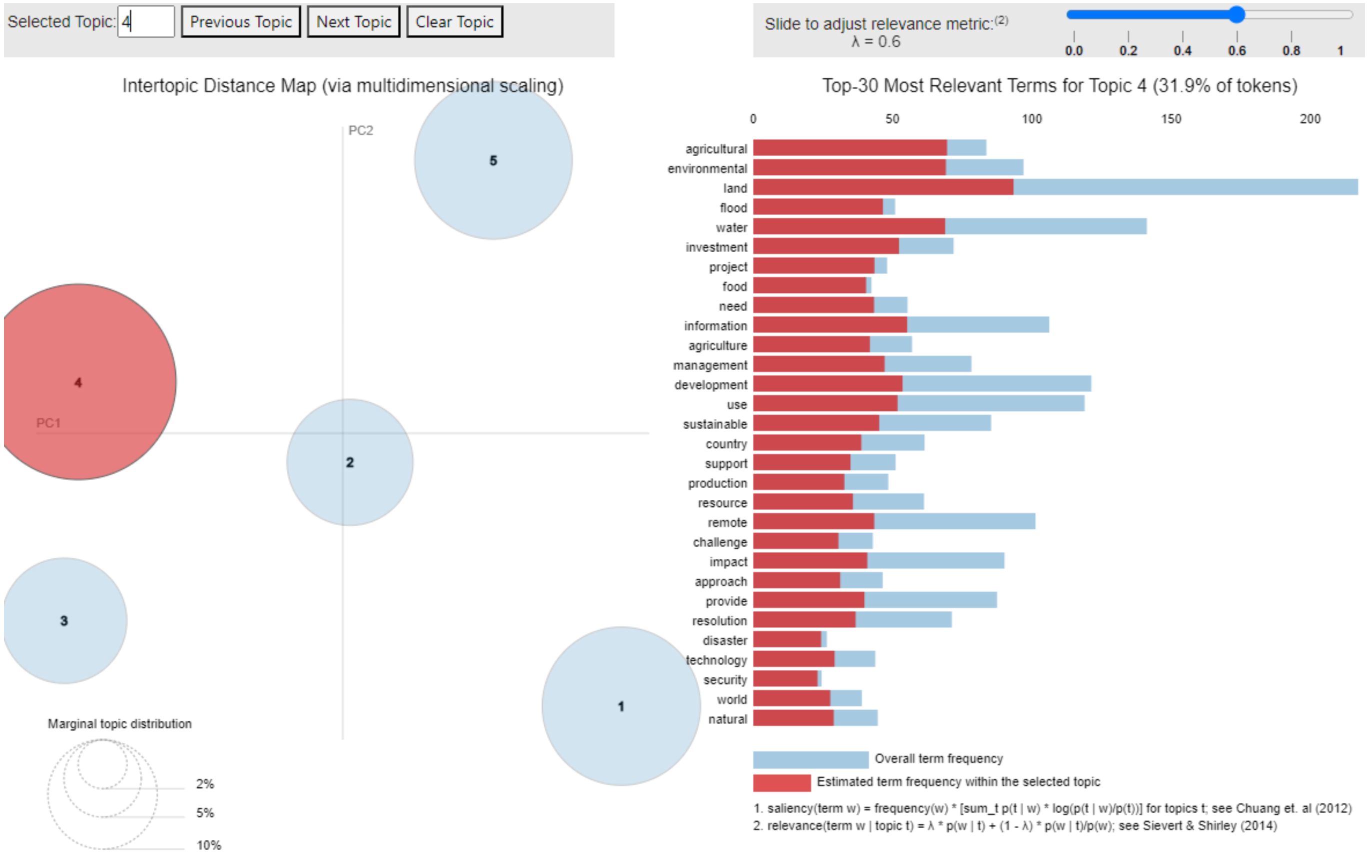
Topic model development – intertopic distance

Topic 3: energy and emissions



1. saliency(term w) = frequency(w) * [sum_t p(t | w) * log(p(t | w)/p(t))] for topics t; see Chuang et. al (2012)
2. relevance(term w | topic t) = λ * p(w | t) + (1 - λ) * p(w | t)/p(w); see Sievert & Shirley (2014)

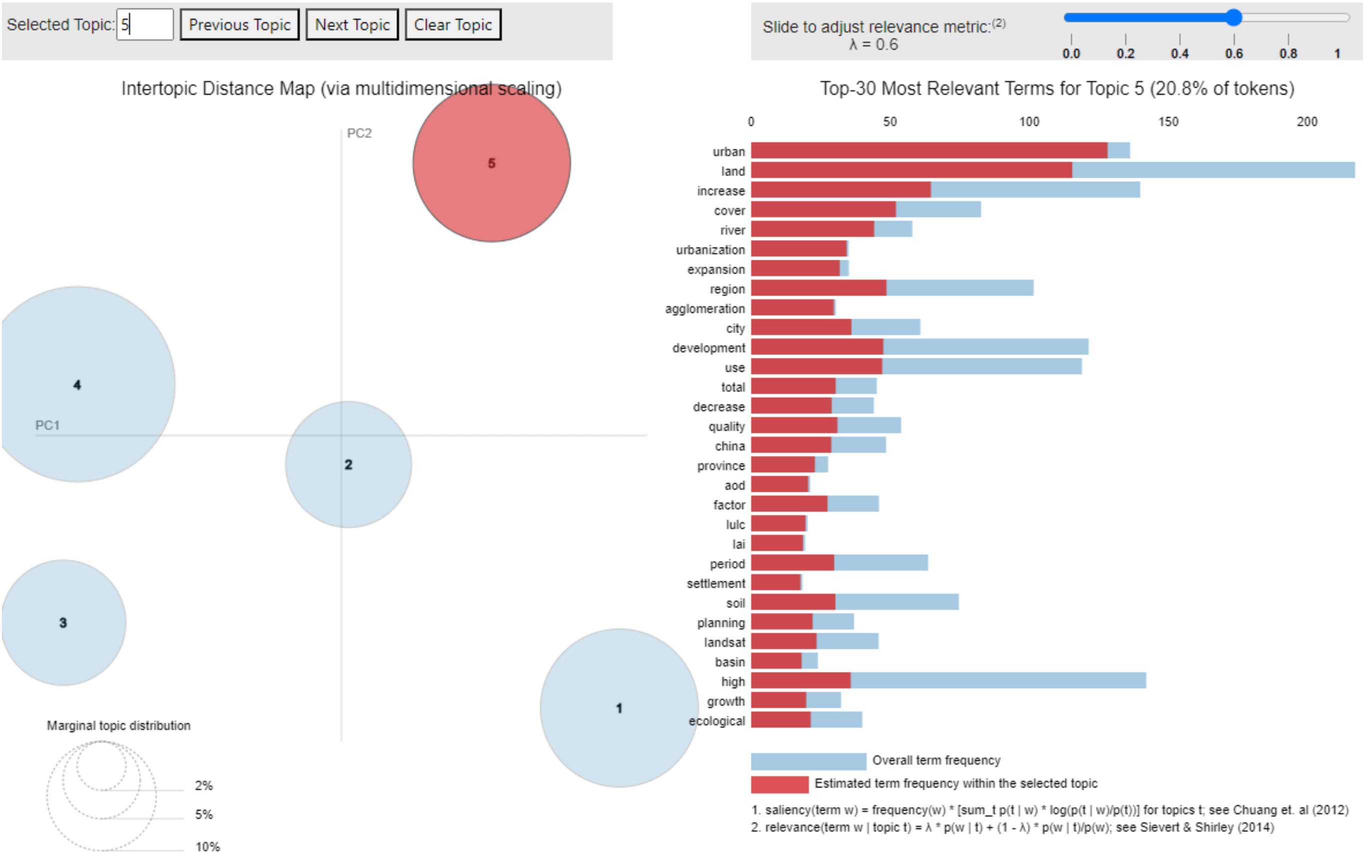
Topic model development – intertopic distance
Topic 4: agricultural risk



1. saliency(term w) = frequency(w) * [sum_t p(t | w) * log(p(t | w)/p(t))] for topics t; see Chuang et. al (2012)
2. relevance(term w | topic t) = λ * p(w | t) + (1 - λ) * p(w | t)/p(w); see Sievert & Shirley (2014)

Topic model development – intertopic distance

Topic 5: land use and land cover (LULC)



Selected Topic: 5

Slide to adjust relevance metric:(2) λ = 0.6

Intertopic Distance Map (via multidimensional scaling)

Top-30 Most Relevant Terms for Topic 5 (20.8% of tokens)

1. saliency(term w) = frequency(w) * [sum_t p(t | w) * log(p(t | w)/p(t))] for topics t; see Chuang et. al (2012)
2. relevance(term w | topic t) = λ * p(w | t) + (1 - λ) * p(w | t)/p(w); see Sievert & Shirley (2014)

IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

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Refining ESG models: embedding natural capital valuation beyond box-ticking compliance towards confronting planetary boundaries[1]

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

Refining ESG Models: Embedding Natural Capital Valuation Beyond Box-Ticking Compliance Towards Confronting Planetary Boundaries

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Abstract

This paper examines Environmental, Social, and Governance (ESG) frameworks in current environmental management practices, uncovering significant flaws, especially in their capacity to adequately evaluate the impact of sustainability initiatives on global challenges such as climate change and land degradation. It explores the intrinsic shortcomings of existing ESG models, including their reliance on simplified theoretical models and the absence of concrete, quantifiable metrics, which may lead to greenwashing. A crucial point of criticism is the lack of sufficient emphasis on the social and governance dimensions in relation to environmental issues, which are essential in supporting the environmental pillar of ESG. This paper proposes an improved methodology that incorporates a detailed valuation of natural capital to better measure impacts within the environmental pillar of ESG. Furthermore, it introduces an innovative approach to natural capital valuation using an actuarial balance framework focused on loss distribution analysis, enhancing the ability to quantify and manage long-term environmental risks effectively.

Keywords: ESG, sustainability, natural capital valuation, ecosytem.

JEL classification: Q50, O30, C80, G2, R52

1. Introduction

This paper critically examines the flaws within current Environmental, Social, and Governance (ESG) frameworks, particularly in their capacity to adequately assess sustainability initiatives' impact on pressing global issues such as climate change and land degradation. One of the primary shortcomings of these models is their reliance on simplified theoretical frameworks that lack concrete, quantifiable metrics, leading to the risk of greenwashing, where companies exaggerate their environmental contributions (Macpherson & Gasperini, 2021; Singhania & Saini, 2023). Additionally, these models often fail to emphasize the interconnected roles of the social and governance pillars in supporting environmental outcomes, further limiting their effectiveness.

A critical issue highlighted is the over-reliance on theoretical models without sufficient empirical foundations, resulting in an oversimplification of environmental impacts (Rook & Monk, 2019). The absence of tangible, measurable metrics makes it challenging to objectively evaluate sustainability efforts or compare entities meaningfully. This oversimplification is compounded by rigid assumptions in these models, which restrict their applicability across varying contexts and scenarios. Furthermore, the complexity of ESG frameworks mirrors the pitfalls found in expert-based credit scoring systems,

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Disclaimer: The views expressed are those of the authors and do not necessarily reflect the official view of the Hacettepe University and Central Bank of the Republic of Türkiye where high operational costs, subjective biases, and lack of transparency undermine their reliability (Park & Oh, 2022).

ESG models are also criticized for overparameterization, which can dilute important factors and distort risk scores, creating a disconnect between high ESG ratings and actual sustainability outcomes. This disconnect often stems from insufficient weighting of the social and governance components, which are crucial for tangible environmental impact, particularly in areas like land degradation neutrality. The challenges of data collection under ESG initiatives, including cost, speed, and reliability (Cruz & Matos, 2023), further exacerbate the limitations of these frameworks, casting doubt on their overall effectiveness.

Obtaining high-quality ESG data is fraught with challenges, primarily due to the inconsistency in reporting practices and the absence of standardized frameworks. This leads to significant discrepancies in the data reported across companies, making comparisons difficult (Kotsantonis & Serafeim, 2019). The presence of data gaps and differing methodologies for filling these gaps further complicates analysis and often results in disagreements among data providers (Amel-Zadeh & Serafeim, 2018). Interestingly, more public disclosure can increase the variation in ESG ratings due to differing interpretations by stakeholders, highlighting the complexities involved in acquiring reliable and comparable data (Kotsantonis & Serafeim, 2019).

Additionally, ESG rating systems are undermined by varying methodologies, with some agencies using as many as 1000 data points or metrics while others rely on fewer than 100. This raises the issue of quality versus quantity, as an abundance of metrics can lead to overparameterization and obscure key indicators, thereby facilitating greenwashing. Models that fail to fully account for the complexities of real-world ecosystems increase model risk, especially when limited field studies are used. Furthermore, unified models with two-dimensional industry-specific approaches often rely on sector classifications that are not aligned with international standards, making cross-industry and regional comparisons difficult.

The lack of a common taxonomy across more than 600 ESG frameworks globally (Ernest & Young, 2021), further complicates standardization efforts, as even sophisticated frameworks like the European Union taxonomy are not fully applicable in developing countries. This underscores the need for global cooperation to align ESG standards with the Paris Agreement's goals. Moreover, larger companies tend to face less scrutiny in environmental evaluations, making it critical to introduce green ratios akin to financial metrics in the Basel framework to improve transparency in sustainability performance, particularly for the "E" (environmental) pillar.

ESG ratings are often based on voluntary corporate disclosures, with assessments focused on data availability rather than quality. This reliance on incomplete or inconsistent data leads to significant data gaps and risks greenwashing. Furthermore, companies can contest low scores through non-transparent bilateral processes with rating agencies, highlighting the need for an independent, transparent intermediary system to manage disputes and ensure accountability.

Finally, the customer-vendor dynamic between companies and rating agencies, where companies pay for their ratings, raises concerns about bias. To mitigate this, independent supervisory bodies should regularly audit ESG ratings to ensure their fairness and reliability.

Moreover, impact-based valuation models should be used to account for the complexities of ecological systems and the contributions of vulnerable social groups, as opposed to relying solely on market mechanisms. The Planetary Boundaries framework, which identifies critical environmental thresholds, offers a vital tool for evaluating corporate sustainability and emphasizes the need for reforms in ESG rating systems to better align with the Earth's ecological limits.

To address most of these gaps, this paper proposes incorporating natural capital valuation into the environmental pillar of ESG. Recognizing the degradation of ecosystem services, this approach would integrate tools like Co$tingNature (https://www.policysupport.org/costingnature) within satellite-based decision support systems. Furthermore, the paper suggests adopting a loss-based actuarial balance model to enhance the valuation of natural capital and better understand long-term environmental risks. As a case study on land degradation neutrality demonstrates, sustainable agricultural practices can not only reduce carbon footprints but also improve food quality and sovereignty.

We also suggest integrating environmental responsibility into governance and social practices for sustainability. The argument that the governance and social pillars of ESG do not directly address planetary boundaries is rooted in their current focus on corporate ethics, transparency, and social issues. While these areas are essential for responsible business practices, they often lack the direct engagement with ecological sustainability seen in the environmental pillar. To enhance their impact, both the governance and social pillars can be reframed to more closely align with environmental goals.

For the governance pillar, this could involve integrating environmental responsibility into corporate decision-making processes. This would mean embedding sustainability into governance frameworks, such as ensuring supply chain sustainability and proactively managing risks related to environmental disasters. Studies highlight the growing need for ESG governance to evolve beyond corporate efficiency, incorporating broader stakeholder interests and ecological concerns, thus fostering long-term sustainability (Monteiro et al, 2021).

The social pillar, meanwhile, could be expanded to emphasize environmental health and safety, community engagement in conservation efforts, and training for human capital on sustainable practices. This would create a more robust link between social policies and environmental sustainability, ensuring that labor practices, community relations, and employee development all support ecological goals (de Souza Barbosa et al, 2023).

Incorporating strategies like the circular economy and nature-based solutions into the environmental pillar would further align business practices with planetary boundaries. This would not only ensure a more holistic ESG framework but also drive innovation and accountability toward global environmental objectives. By doing so, the governance and social dimensions of ESG would contribute more directly to ecological sustainability, reinforcing the interconnectedness of business, society, and the environment.

2. Natural Capital Value Integrated ESG Model for Food Systems

The integration of sustainable farming methodologies, such as agroecology, permaculture, and regenerative agriculture, is pivotal in mitigating environmental degradation. These practices are complemented by judicious resource management strategies, including the implementation of rainwater harvesting, drip irrigation, and soil health enhancement techniques like composting, cover cropping, and minimized tillage. These practices, which align with Rockström et al. (2009)'s *planetary boundaries* framework, are essential for maintaining agricultural operations within safe environmental limits, ensuring long-term resilience and preventing irreversible ecological damage. By adhering to the thresholds for key environmental processes like climate regulation, land use, and nitrogen cycles, these farming methods contribute to the overall health of ecosystems while addressing critical challenges like climate change and biodiversity loss.

Furthermore, the preservation of biodiversity through species diversification and intercropping is crucial for maintaining ecological equilibrium. Costanza et al. (1997) provided a foundational framework for valuing ecosystem services, demonstrating the immense economic value of these practices in maintaining long-term environmental sustainability. In this context, integrating these services into agricultural practices is vital for both ecological integrity and economic resilience.

In the realm of climate action, the adoption of agroforestry and other carbon sequestration methods, alongside adaptation strategies to counteract the effects of climate change, plays a significant role. Additionally, waste reduction is achieved through upcycling, the responsible disposal of agricultural chemicals, and the recycling of farm by-products, thereby contributing to the overall sustainability of agricultural ecosystems. Daily & Matson (2008) emphasize the importance of incorporating ecosystem services into decision-making processes, reinforcing the need for comprehensive strategies that go beyond carbon footprint reduction to include biodiversity and nutrient management, such as nitrogen sequestration strategies. This ensures a more holistic approach to environmental stewardship, addressing not only greenhouse gas emissions but also nutrient pollution and land degradation.

In addressing the environmental component, it is insufficient to merely target a specific carbon footprint reduction. There is a pressing need to also integrate nitrogen sequestration strategies. This is because the challenges extend beyond CO2 levels to encompass land degradation. The comprehensive approach should therefore encompass both carbon and nitrogen management practices to mitigate not only the atmospheric concentration of greenhouse gases but also to address soil health and prevent further degradation of terrestrial ecosystems. In addition to traditional carbon footprint considerations, the concept of a 'nitrogen footprint' should also become a focal point for green financing initiatives. Incorporating strategies for managing nitrogen into finance plans aimed at sustainability enables a broader approach to caring for the environment, addressing not just carbon emissions but also the pressing challenge of nutrient overload and its consequences for ecosystems.

The social pillar of the agricultural ESG framework is foundational to fostering ethical and sustainable agricultural methodologies. Central to this is the concept of worker well-being, which underscores the necessity for equitable employment conditions, prioritizing safe working environments, fair wages, and strict adherence to labor rights, including specific considerations for the unique challenges faced by indigenous people and migrant workers within the agricultural sector. Community Engagement expands the sector's social obligations, emphasizing the importance of forming positive connections with local communities, which includes supporting the economies and initiatives of indigenous populations and enhancing the integration and well-being of migrant workers and their families.

Addressing “Food Security” is crucial, with a focus on ensuring the production of abundant, accessible, and nutritious food, thus contributing to the resilience and sustainability of global food systems. The role of education and training is highlighted as essential for the empowerment and skill development of all workers, including indigenous and migrant communities, promoting sustainable agricultural practices and the use of innovative technologies. Health and safety are paramount, with a dedicated focus on safeguarding the health of all employees and consumers, particularly addressing the specific health risks and needs of indigenous people and migrant workers, through responsible management of agricultural inputs and the elimination of hazardous practices. Collectively, these components advocate for a socially responsible agricultural sector that champions the welfare of all workers, the engagement and upliftment of communities, and the promotion of health and safety, all within the framework of sustainable and inclusive agricultural practices.

In the agricultural ESG framework, while the Governance pillar is essential, it often carries a relatively lighter emphasis compared to the Environmental and Social pillars. The Governance aspect underscores the importance of adhering to legal and regulatory standards across both local and international landscapes, ensuring transparency in reporting agricultural methodologies and operations. It advocates for the maintenance of Ethical Business Practices, highlighting the necessity for anti-corruption efforts and the promotion of equitable competition.

The valuation of natural capital emphasizes the quantification and incorporation of ecosystem services into agricultural practices. This involves not only recognizing services such as carbon sequestration, biodiversity, and water purification as critical components of agricultural sustainability but also implementing practices that actively enhance these services. For instance, adopting regenerative agricultural methods that rebuild soil organic matter and restore degraded soil biodiversity can significantly increase the natural capital value, thereby contributing to long-term environmental sustainability. Engaging communities in decision-making processes related to ecosystem management fosters a sense of stewardship and shared value, reinforcing the social fabric and ensuring that the benefits of natural capital are equitably shared. Embedding the concept of food sovereignty into the social pillar is crucial to fostering sustainability and resilience, especially as those who cultivate nutrient-rich foods that enhance natural capital often lack access to these very resources. Governance practices should facilitate risk management strategies that account for natural capital degradation risks, ensuring that agricultural operations are resilient to environmental changes and capable of sustaining their natural capital base over the long term.

An effective ESG model in agriculture would require continuous monitoring, reporting, and updating practices to align with the latest sustainability standards and stakeholder expectations. In the subsequent section, we examine a case study where natural capital valuation is incorporated into a decision support system powered by Geographic Information Systems (GIS) and Remote Sensing (RS), detailing the data requirements necessary for operating the system.

3. Reframing Natural Capital Valuation: Recognizing Humans as Providers of Ecosystem Services

Natural capital valuation traditionally views nature as the sole provider of ecosystem services, predominantly benefiting humans in a unidirectional manner. This perspective tends to overlook the significant role that social dynamics play within the ESG framework. In reality, some individuals themselves act as providers of ecosystem services to others, functioning within the broader context of natural capital. This concept challenges the traditional one-way view of ecosystem services, advocating for a more integrated, cyclical understanding where humans are both recipients and providers of these services.

It acknowledges the vital contributions humans make to the sustainability and functionality of ecological systems, emphasizing the interdependence between human and natural systems. This approach highlights the crucial roles of social structures, cultural knowledge, and community governance in sustaining and enhancing ecosystem services.

Adopting this perspective broadens the discussion on ecosystem services, asserting that sustainability involves more than just preserving the physical environment; it also requires nurturing and supporting the human capabilities and social infrastructures that effectively manage these systems. This enriched viewpoint fosters a deeper appreciation of the symbiotic relationships within ecosystems, promoting a more holistic approach to environmental stewardship and sustainability.

Integrating the concept that humans can be considered providers of ecosystem services into the social and governance pillars of ESG frameworks introduces significant ethical considerations, especially concerning labor practices. This perspective sheds light on issues surrounding the exploitation of cheap labor, framing it not only as a social and ethical issue but also as a matter of environmental sustainability. This redefined understanding can be effectively operationalized within the ESG framework to address the ethical use of human capital more comprehensively.

In the social pillar, it is critical to ensure fair compensation and labor practices. Workers, particularly those whose roles directly impact or manage natural resources, should be fairly compensated, reflecting the true value they add to the ecosystem services they help sustain. For instance, agricultural workers engaged in sustainable farming practices should be paid wages that recognize their contributions to biodiversity and soil health—both crucial for long-term ecological sustainability. Additionally, commitments to worker rights and safety need to be strengthened, especially for jobs involving direct environmental interaction, such as those in forestry, agriculture, and mining. This includes providing necessary safety equipment and training and ensuring that workers have a say in the management practices that affect their work and the ecosystems they engage with. Furthermore, investing in community development programs that improve local living standards and education supports sustainable practices and enhances community well-being, enabling workers and communities to implement sustainable practices in their daily lives and work.

Within the governance pillar, ethical supply chain management is essential. This involves implementing and enforcing strict guidelines in the supply chain to prevent the exploitation of cheap labor, particularly in industries that directly impact natural resources. Regular audits and transparency from suppliers regarding their labor practices are necessary to ensure that all parts of the supply chain adhere to high ethical standards concerning labor. Developing sustainable procurement policies that prioritize products and services adhering to recognized labor and environmental standards is also crucial. This includes favoring suppliers who pay fair wages, use sustainable practices, and actively contribute to the preservation of ecosystem services. Additionally, active engagement with stakeholders—including labor unions, community groups, and NGOs—is vital for monitoring and discussing labor practices. This engagement helps ensure that the company’s labor practices support its environmental goals and align with broader ESG objectives.

Overall, by considering humans as active providers of ecosystem services, ESG frameworks can promote a more holistic approach to sustainability, emphasizing the need for ethical labor practices that support both human welfare and environmental health.

Case Study: Integrating Natural Capital Valuation into Türkiye's LDN DSS

The land degradation neutrality decision support system[3] (LDN DSS) refers to a comprehensive tool or framework designed to assist in decision-making processes related to land management and conservation efforts in Türkiye. Its primary aim would be to achieve land degradation neutrality (LDN), a key sustainability target that aims to maintain or improve the health and productivity of land resources by balancing the loss of productive lands with the restoration of degraded areas.

The system integrates various data sources, including GIS & RS, and other environmental and socio-economic datasets, to assess current land conditions, identify degradation hotspots, predict future degradation trends, and evaluate the effectiveness of different land management practices. By doing so, it supports policymakers, land managers, and other stakeholders in making informed decisions that contribute to sustainable land use, restoration of degraded lands, and overall environmental conservation, aligning with Türkiye's commitments to global sustainability goals and conventions.

Co$tingNature is a web-based tool designed for environmental policy support, providing comprehensive analyses of ecosystem services, biodiversity, and the environmental impacts of development. It helps in assessing the value of nature in specific areas, enabling policymakers, conservationists, and researchers to make informed decisions regarding land use, conservation strategies, and sustainable development.

The tool utilizes advanced algorithms and incorporates a wide range of data, including GIS data, RS data, biodiversity distribution, and socio-economic information. Co$tingNature can model and map various ecosystem services like carbon storage and sequestration, water resources management, and biodiversity conservation. It also assesses the potential impacts of human activities and climate change on these services.

By providing insights into how different land-use decisions might affect ecosystem services and biodiversity, Co$tingNature supports the planning and implementation of conservation actions, sustainable land management, and development projects that minimize environmental impacts. It's particularly useful for identifying areas of high conservation value, understanding the trade-offs between development and conservation, and prioritizing areas for ecosystem service protection or restoration.

The integration process began with leveraging Co$tingNature to conduct a comprehensive valuation of ecosystem services across Türkiye's diverse biomes. This step involved detailed mapping and assessment, focusing on services critical to the country's ecological and economic well-being, such as water regulation, soil stabilization, and carbon sequestration.

Utilizing Co$tingNature's advanced algorithms, the project team analyzed biodiversity patterns within Türkiye, identifying key conservation areas and biodiversity hotspots. This analysis informed strategic conservation planning within the LDN DSS framework, ensuring the protection of vital habitats and species.

The integrated system employed Co$tingNature's scenario modeling capabilities to simulate various land management strategies and their potential impacts on ecosystem services and biodiversity. This allowed for the identification of land use practices that align with LDN goals while optimizing environmental and social benefits.

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[3] https://projectgeffao.users.earthengine.app/view/ldn-turkey

Insights and visualizations generated through the integrated system were shared with a broad spectrum of stakeholders, including policymakers, landowners, and conservationists. This facilitated informed decision-making and policy development, with a strong emphasis on evidence-based conservation and land management strategies.

The integration significantly enhanced the LDN DSS's ability to quantify the economic value of natural capital, providing a more holistic view of land management implications. Conservation priorities were more accurately identified, enabling targeted action in areas of critical ecological significance. Land use policies and strategies developed through the integrated system were grounded in comprehensive environmental data, leading to more sustainable and effective land management practices. Increased stakeholder engagement and collaboration were observed, with the transparent sharing of data and findings fostering consensus and collective action towards LDN goals.

The integration of Co$tingNature into Türkiye's LDN DSS represents a pioneering approach to sustainable land management, where the intrinsic value of natural capital is meticulously accounted for. This case study exemplifies how leveraging advanced tools and frameworks can significantly bolster national efforts to achieve LDN, ensuring that land management practices contribute positively to both ecological integrity and societal well-being.

4. Regulatory Financial Institutions' Role in Advancing Sustainable Land Management through LDN DSS-Co$tingNature Collaboration

The collaboration between the LDN DSS-Co$tingNature case study and the banking system of Türkiye could catalyze a transformative approach to green financing, deeply rooted in principles related to performance criteria that underscore sustainability and conservation. This partnership could unfold as follows:

1. Green Financing Initiatives with Performance Criteria: By harnessing insights from the case study, the Banking system could refine green financing initiatives to include specific performance criteria that projects must meet to qualify for funding. These criteria would be based on the tangible impacts on ecosystem services and biodiversity conservation, thereby ensuring that investments not only align with LDN goals but also demonstrate measurable environmental benefits. Financial incentives, such as reduced interest rates, could be tied directly to these performance metrics, encouraging projects that have a significant positive impact on land sustainability.

2. Risk Management Through Environmental Criteria: The comprehensive understanding of environmental risks gleaned from the case study's integration of natural capital valuation offers a robust framework for the Banking system to enhance its risk management strategies. Incorporating environmental criteria into financial stability analyses would ensure that both the bank and associated financial institutions account for land degradation risks in their operations, promoting a more sustainable financial landscape.

3. Promoting Sustainable Land Management: Building on the economic insights from the case study, banks can take a leadership role in promoting the integration of sustainable land management and conservation into financial and economic strategies. This may include advocating for the adoption of regulations that prioritize green financing standards, and encouraging fiscal and monetary frameworks that support LDN and broader environmental sustainability goals. By fostering a financial

environment that aligns with ecological objectives, banks can help ensure that sustainability is central to economic decision-making.

4. Enhanced Sustainability Reporting: The financial authorities' drive to integrate natural capital and LDN considerations into sustainability reporting has the potential to transform transparency within the financial sector. By mandating that financial institutions report in accordance with green financing performance criteria, the bank would drive a shift towards more accountable and environmentally conscious financial practices, with institutions required to demonstrate their contribution to sustainable land management and conservation.

5. Capacity Building Aligned with Green Criteria: The banking system’s role in facilitating educational initiatives would further entrench the principles of green financing within the sector. Through targeted workshops and seminars that emphasize the integration of natural capital valuation and adherence to performance criteria in financial decision-making, the bank could cultivate a financial ecosystem that is well-versed in sustainable practices and equipped to support Türkiye's LDN ambitions.

In this collaborative model, the Central Banks stand to play a pivotal role in steering the nation's financial practices towards a model that not only supports economic growth but also prioritizes the preservation and enhancement of Türkiye's natural landscapes, aligning financial mechanisms with the imperative of environmental stewardship and land sustainability.

5. Actuarial Balance Approach to Natural Capital Valuation:

The actuarial balance approach could significantly enhance the Co$tingNature tool by adding a financial dimension that quantifies long-term economic risks associated with the loss of natural capital. Incorporating the actuarial balance concept into the evaluation of natural capital degradation necessitates a forward-looking and comprehensive analysis of the economic implications tied to environmental loss, set against the backdrop of the invaluable services provided by intact ecosystems. Actuaries, leveraging their proficiency in financial risk management and liability forecasting, engage in an exhaustive quantification of the costs stemming from the depletion of natural resources and the reduction of ecosystem services. This analysis extends its scope beyond immediate remediation costs to include a wider array of economic impacts, such as potential revenue losses from ecosystems that can no longer deliver essential services, leading to reduced agricultural yields, heightened flood risks, and deteriorating air and water quality.

The actuarial balance framework for natural capital helps us understand the long-term costs of damaging the environment, just like how insurance companies plan for the costs of accidents or medical bills in the future. Natural capital refers to the Earth's resources—like forests, rivers, soil, and biodiversity—that provide essential services such as clean air, water, and fertile land.

This framework helps us predict how much it will cost if these resources (natural capital) are degraded or lost, and how we can plan ahead to restore or protect them. By doing this, we ensure that we have enough resources (both financial and natural) to fix problems and maintain the benefits that nature provides us in the long run.

The act of evaluating claims associated with environmental damage is central to this actuarial scrutiny, offering a detailed perspective on both historical and contemporary trends in ecosystem degradation and their financial consequences. These insights are crucial for the development of environmental insurance products, wherein premiums and coverages are precisely tailored to mirror the assessed risks and forecasted claims, thus facilitating risk-aware pricing and encouraging policyholders to adopt risk-reducing measures.

Moreover, the actuarial balance approach aims to achieve a financial equilibrium, ensuring that reserves, insurance schemes, and strategic investments are sufficiently robust to shoulder the projected expenses for comprehensive ecosystem restoration, compensation for environmental harm, and adaptation to evolving environmental conditions. This equilibrium is essential for synchronizing financial and economic strategies with the principles of sustainable environmental management, advocating for initiatives that both alleviate the negative effects of natural capital degradation and actively support the restoration and sustainable governance of ecosystems.

Expanding the actuarial balance approach to include the valuation of natural capital unveils a robust framework for weaving environmental considerations into the fabric of financial decision-making and economic policy development. This broader viewpoint calls for a systemic environmental risk management strategy, integrating sustainability and conservation tenets into economic models and strategies. It emphasizes the need for a concerted effort among policymakers, corporations, insurers, and financial entities to cultivate a resilient, sustainable, and equitable economic infrastructure that aligns human ambitions with the ecological limits of our planet. In this context, reserve logic plays a crucial role, necessitating the accumulation of adequate financial reserves to address potential future environmental liabilities, thereby ensuring long-term sustainability and resilience. Such forward-looking policy decisions, informed by actuarial analyses, are instrumental in steering economic activities towards sustainability, facilitating the transition to an economic system that respects and preserves the delicate balance of our natural environment.

The actuarial balance approach to natural capital valuation distinguishes itself from other methods through its rigorous focus on risk assessment, financial liability forecasting, and the establishment of financial reserves to manage future uncertainties related to environmental degradation. Drawing parallels to the Cost of Illness (COI) approach used in medical research or disability compensation schemes, the actuarial approach focuses on the expenses required to rehabilitate the beneficiaries of natural capital, diverging from the commonly seen replacement cost of the capital itself in other natural capital valuation techniques.

6. Recommendations

To effectively address the complexities of natural capital valuation within ESG frameworks, a broad and integrated approach is essential. Central to this is the adoption of globally recognized frameworks such as the United Nations-Natural Capital Protocol (NCP) and the System of Environmental-Economic Accounting (SEEA) and guidance of Organisation for Economic Co-operation and Development (OECD), World Bank and European Union. These frameworks provide a standardized methodology for natural capital valuation that can be applied consistently across industries and regions. By aligning with these standards, companies can enhance comparability and transparency in their ESG reporting, making natural capital valuation more reliable and globally applicable. This alignment is particularly crucial for harmonizing practices between developed and developing countries, where economic and environmental conditions vary widely, yet the need for a unified approach remains critical.

Another key component in simplifying natural capital valuation is the use of proxy indicators that can represent broader ecosystem services. Proxy indicators such as carbon sequestration rates, biodiversity indices, and water-use efficiency metrics offer measurable, concrete ways to assess environmental health without the complexity of valuing each ecosystem service directly. These indicators can be incorporated into the "Environmental" pillar of ESG frameworks, enabling businesses to report progress in a way that is scientifically grounded and easy to track. This broader benchmarking approach allows for scalability and adaptability across different sectors, ensuring that companies from diverse industries can meaningfully participate in sustainability initiatives.

Technology plays an essential role in operationalizing these broader benchmarks. Advanced tools such as GIS, RS, and data analytics are critical for tracking changes in ecosystem services over time. These technologies offer real-time monitoring capabilities, providing accurate, up-to-date information that enhances the precision of natural capital valuation. By leveraging such tools, companies and regulators can improve transparency and make the valuation process more accessible, fostering trust among stakeholders. Moreover, technology-driven transparency allows for more dynamic engagement with communities, investors, and policymakers, ensuring that the assessment of natural capital is both credible and participatory.

Beyond the conventional focus on carbon emissions, expanding natural capital valuation to include additional environmental metrics such as biodiversity, water management, and land degradation neutrality is essential for a holistic approach to sustainability. These broader metrics capture the interconnectedness of ecosystem services and provide a more comprehensive view of sustainability. Integrating them into ESG frameworks ensures that companies address a full spectrum of environmental impacts, not just carbon reduction, making their sustainability strategies more resilient and comprehensive. For example, biodiversity and water management are critical resources that are often undervalued in traditional ESG models but are essential for long-term ecosystem resilience and global sustainability.

A forward-looking solution to the complexities of natural capital valuation is the adoption of actuarial models, as suggested in the paper. These models offer a method to assess long-term risks and financial liabilities associated with natural capital depletion. Actuarial methods help businesses forecast the financial impacts of environmental degradation, ensuring that they account for future liabilities while planning strategically. This financial foresight is critical for embedding natural capital valuation into long-term business planning, linking environmental outcomes directly to economic risks and opportunities. The actuarial approach complements broader benchmarks by providing a structured, data-driven way to assess and manage long-term sustainability risks.

For broader adoption, regulatory frameworks and government incentives must support the integration of natural capital valuation into ESG models. Policymakers should design tax breaks, subsidies, or preferential access to green financing for companies that demonstrate measurable improvements in ecosystem services such as carbon sequestration, biodiversity enhancement, or improved water management. These incentives create a financial rationale for businesses to incorporate natural capital into their strategic planning, aligning sustainability goals with economic rewards. Furthermore, linking financial incentives to broader benchmarks ensures that businesses are incentivized to adopt practices that improve multiple dimensions of natural capital, not just single metrics like carbon reduction.

Financial institutions also play a pivotal role by developing sustainability-linked loans and green bonds that are tied to broader natural capital benchmarks. These financial products can incentivize businesses to improve their environmental performance by offering favorable terms based on the achievement of sustainability targets. By integrating natural capital valuation into green financing mechanisms, businesses can align their environmental and financial strategies, creating a stronger market-driven incentive for sustainability. This integration ensures that financial and environmental sustainability goals are mutually reinforcing, driving long-term resilience across industries.

As for the data issues, we recommend the establishment of a Special Purpose Vehicle (SPV) involving a public-private-research entity partnership to address the data challenges outlined in the ESG framework. This SPV will standardize ESG data collection and reporting, ensuring transparency and comparability across sectors. By leveraging advanced technologies such as GIS and RS, it will enhance data accuracy and facilitate investment in sustainability-focused projects. Independent governance will ensure unbiased data management and prevent potential conflicts of interest in ESG evaluations.

In summary, overcoming the complexities of natural capital valuation requires a comprehensive strategy that integrates standardized frameworks, broader environmental benchmarks, advanced technologies, actuarial risk assessments, and supportive regulatory policies. To enhance natural capital valuation at the micro level, integrating methodologies akin to the NCP and leveraging frameworks such as the SEEA would be essential. These efforts would allow for more standardized, detailed environmental accounting, enabling businesses to align their sustainability practices with macro-level economic and environmental metrics. By aligning these elements with transparent reporting and market-driven incentives, companies can embed natural capital valuation into their ESG strategies in a meaningful and scalable way. This approach not only enhances the credibility of ESG assessments but also ensures that businesses contribute to the global effort to preserve and restore vital ecosystem services, aligning economic growth with environmental sustainability.

7. Conclusion

This study underscores the critical deficiencies within traditional ESG frameworks and highlights the potential for actuarial balance approaches to provide a more accurate and holistic valuation of natural capital. By incorporating detailed risk assessments, future liability forecasting, and financial reserve strategies, actuarial methods address the multifaceted nature of environmental impacts more effectively than current ESG assessments. The paper advocates for the adoption of these methodologies across different sectors, with a particular focus on agriculture, to ensure that sustainability assessments are not only comprehensive but also grounded in practical, actionable strategies. Furthermore, it calls for a broader application of these refined frameworks to drive meaningful environmental policies and practices that are capable of achieving true sustainability goals. Emphasizing the importance of collaboration among policymakers, businesses, insurers, and financial institutions, the paper suggests that a united approach will be essential for the successful integration of these innovative methodologies into established systems, ultimately leading to a sustainable alignment of economic activities with ecological sustainability.

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Refining ESG Models: Embedding Natural Capital Valuation Beyond Box-Ticking Compliance Towards Confronting Planetary Boundaries

CBRT-IFC Workshop on "Addressing Climate Change Data Needs: The Global Debate and Central Banks' Contribution"

İzmir, 7 May, 2024

Prof. Kasırga Yıldırak (Hacettepe University)
Ömer Kayhan Seyhun (Senior Specialist CBRT)

*The views expressed in this presentation are those of the author and do not necessarily reflect those of the CBRT and Hacettepe University

OVERVIEW

- Motivation/Planetary Boundaries

- Weaknesses of Typical ESG Approaches

- Natural Capital Valuation

- Embedding Natural Capital Valuation into Sustainability Risk Models

- Case Study:

i) Decision Support Systems, Natural Capital, Sustainable Agriculture & Land Degradation Neutrality
ii) Co$tingNature- Policy Support System

- Steps to Follow For Closing Data Gaps for effective ESG

MOTIVATION

Planetary Boundaries

- Stability & Resilience of Earth System
- Heavily Effected by Anthropogenic processes

Alarming

1) Climate Change ↑

2) Biodiversity Integrity (Loss) ↑

3) Biogeochemical flows ↑

4) Freshwater Use ↑

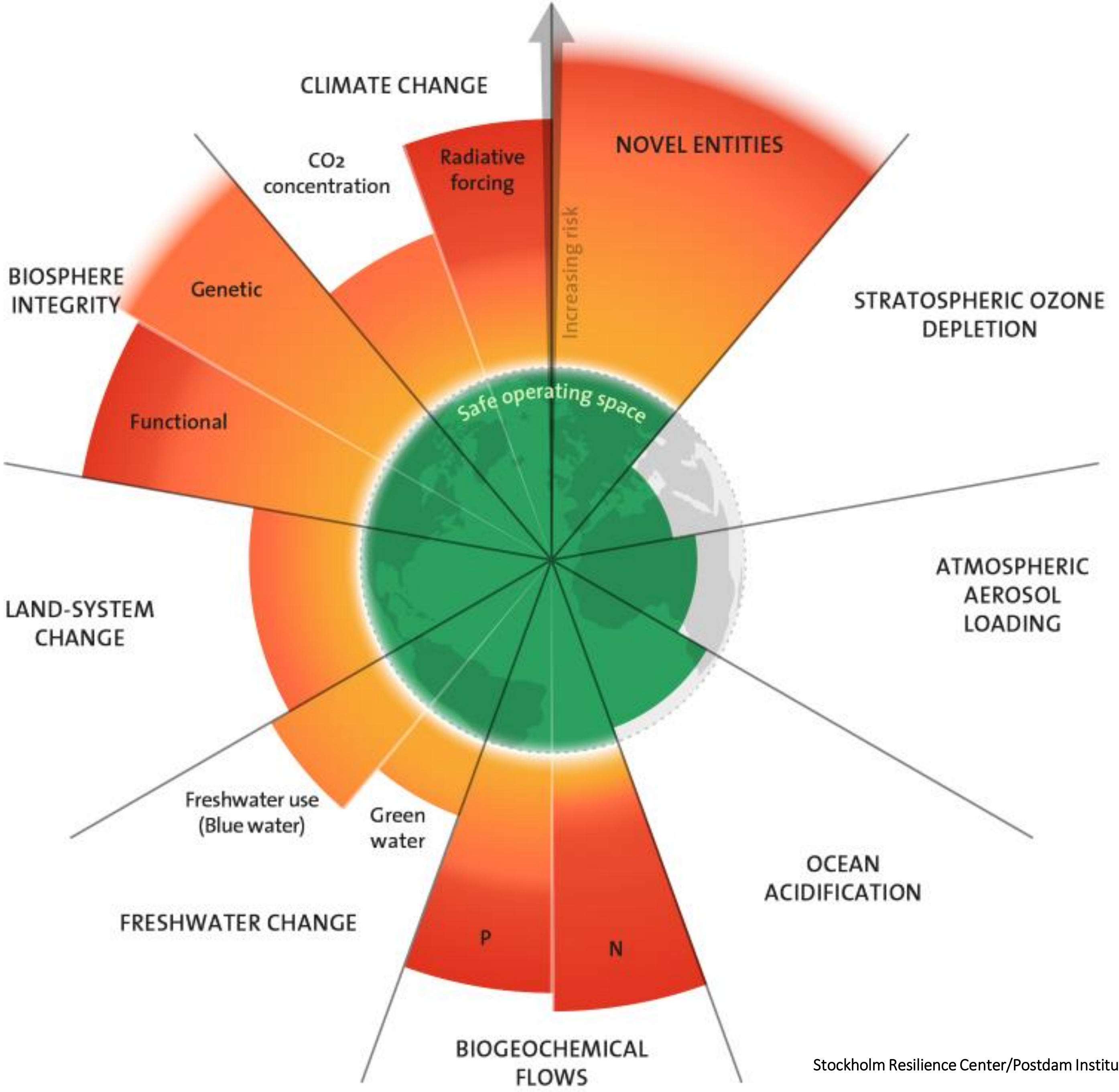
5) Land-System Change ↑

6) Novel Entitites (New Pollutants) ↑

7) Athmospheric Aerosol Loading (stable)

8) Ocean Acidification (closing to limit)

9) Stratospheric Ozone Depletion (stable)



Stockholm Resilience Center/Postdam Institute

MOTIVATION

Planetary Boundaries

Alarming

1) Climate Change ↑

2) Biodiversity Integrity (Loss) ↑

3) Biogeochemical flows ↑

4) Freshwater Use ↑

5) Land-System Change ↑

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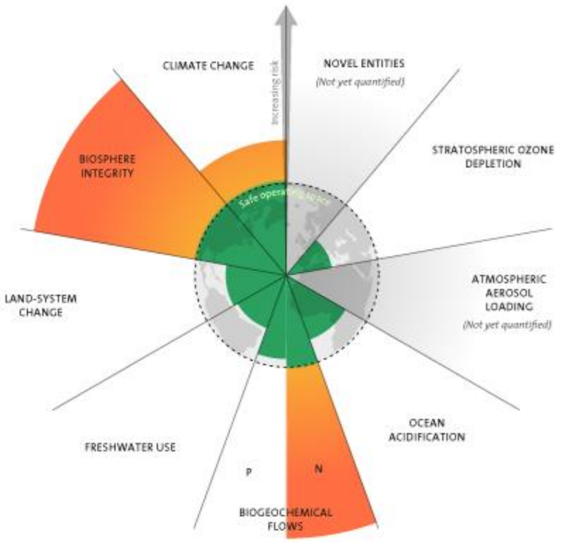
9) Stratospheric Ozone Depletion (stable)

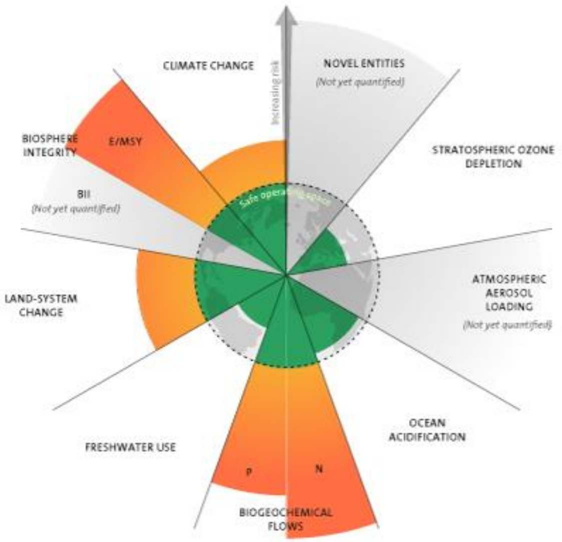
2009



7 boundaries assessed,

3 crossed

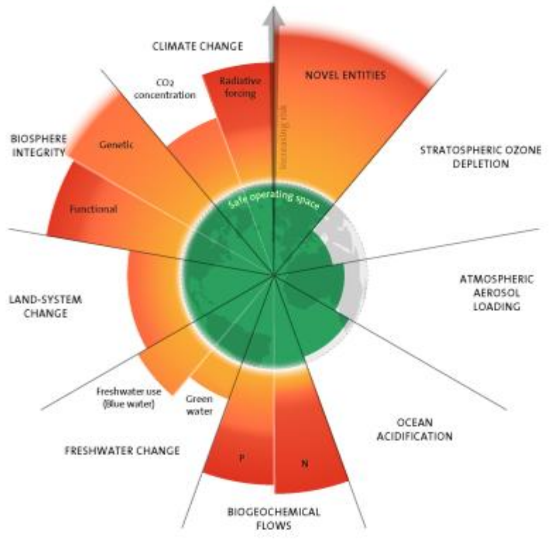
2015



7 boundaries assessed,

4 crossed

2023



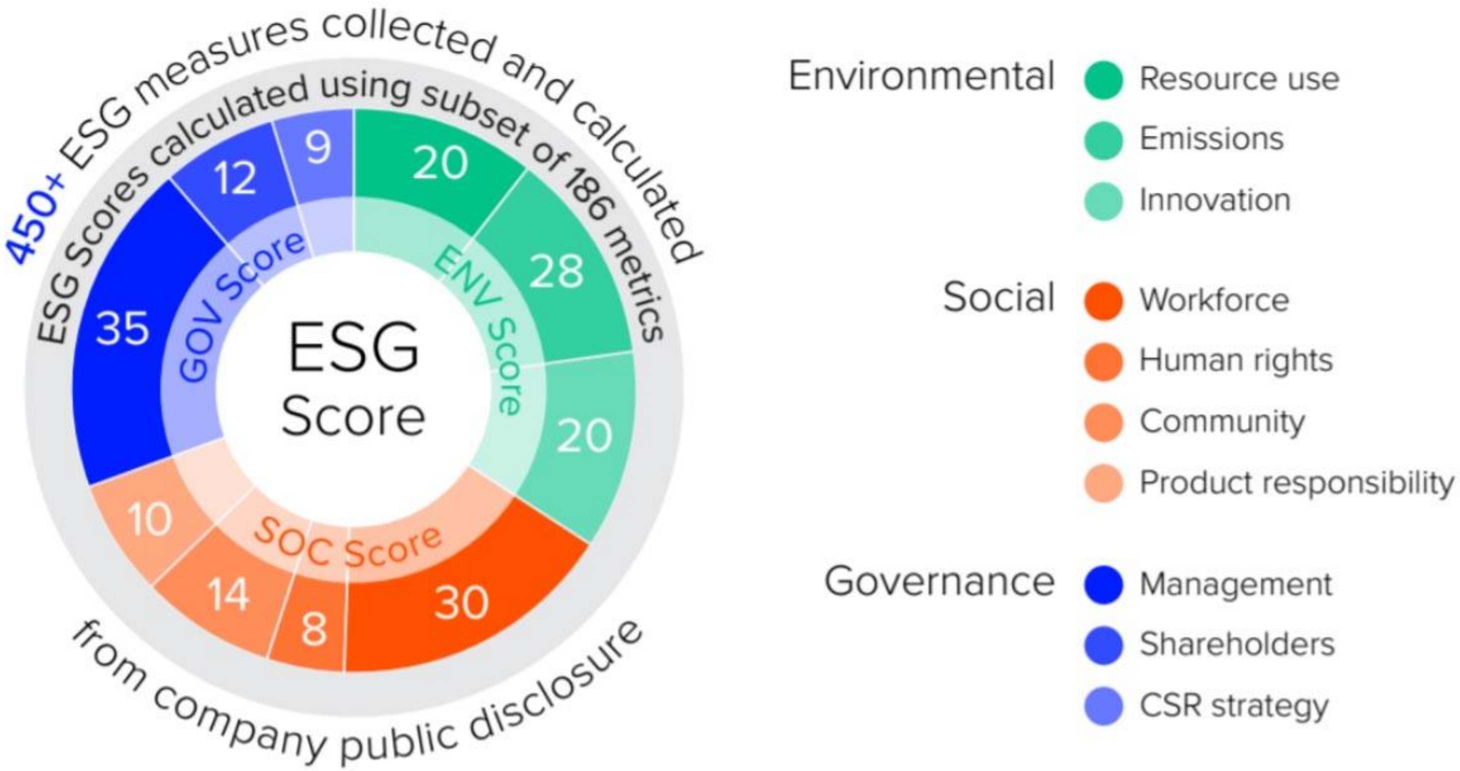
Stockholm Resilience Center/Postdam Institute

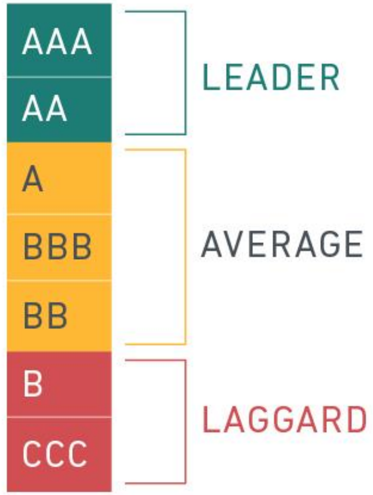
9 boundaries assessed,

6 crossed

WEAKNESSES OF ESG

- **Relying on Simplified Theoretical Models**
- **Absence of Quantifiable Metris**
- **Not unified reporting methodology**
- **Market value calculation not intrinsic value**
- **Overparameterization**
- **No Impact base evaluation**
- **ESG Sustainable System doesn’t imply good impact**
- **Extremely high model risk**
- **Doesn’t capture real world complexities**





Natural Capital Accounting Approach

What is natural Capital Accounting (World Bank Definition)

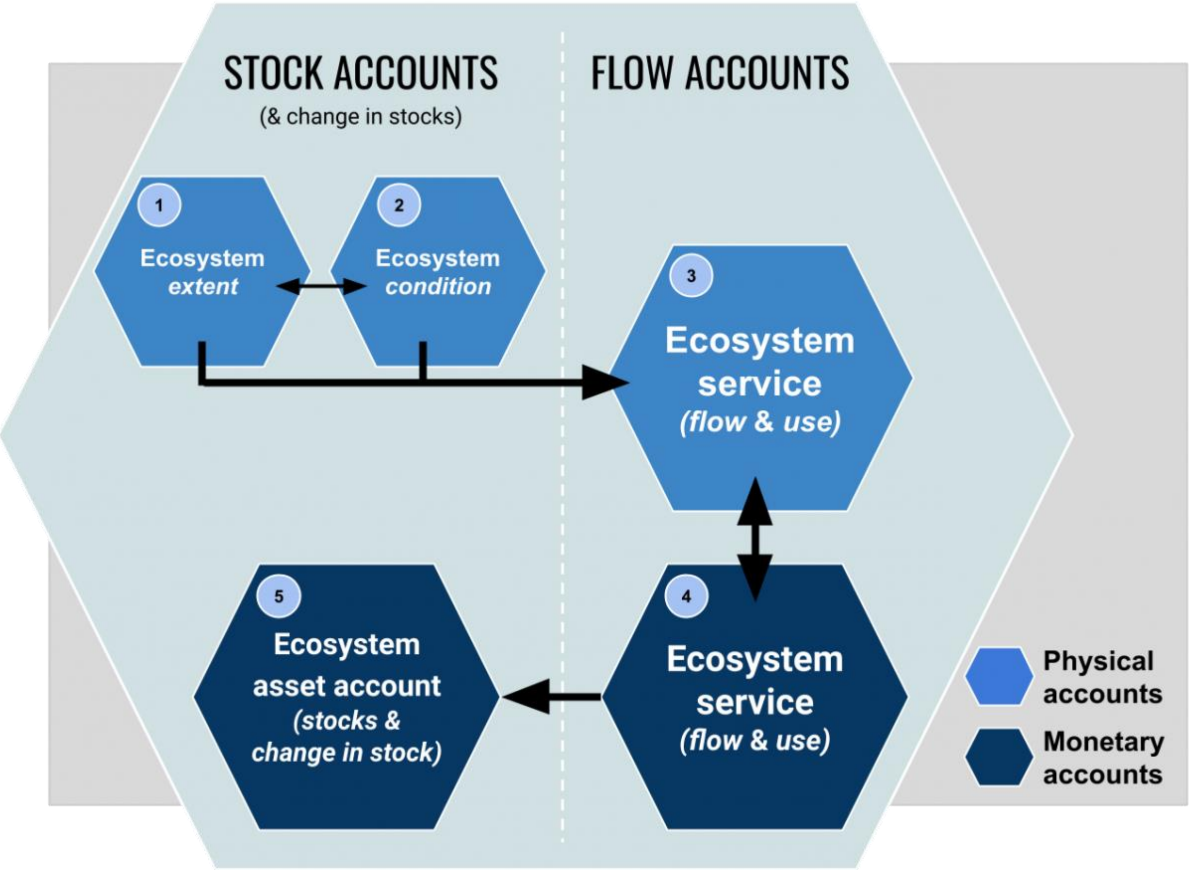
It is part of broader wealth accounting, integrates natural resources, economic valuation and analysis, providing a better understanding of development progress and its impacts on society and environment than standard measures such as Gross Domestic Product (GDP).

It provides whole picture of ecosystem.

SYSTEM OF ENVIRONMENTAL ECONOMIC ACCOUNTING(SEEA EA)

Natural Capital

- Forests **E**
- Agricultural Lands **E**
- Fisheries **E**
- Minerals **E**
- Human made/produced capital **S**
- Skills&Experince of Population **S&G**



Case Study: Integrating Capital Valuation into Türkiye's Land Degradation Neutrality Decision Supporting System (LDN DSS)

Data Set:

- Geographic Information System (GIS)
- Remote Sensing (RS)
- Environmental and Socio Economic Dataset

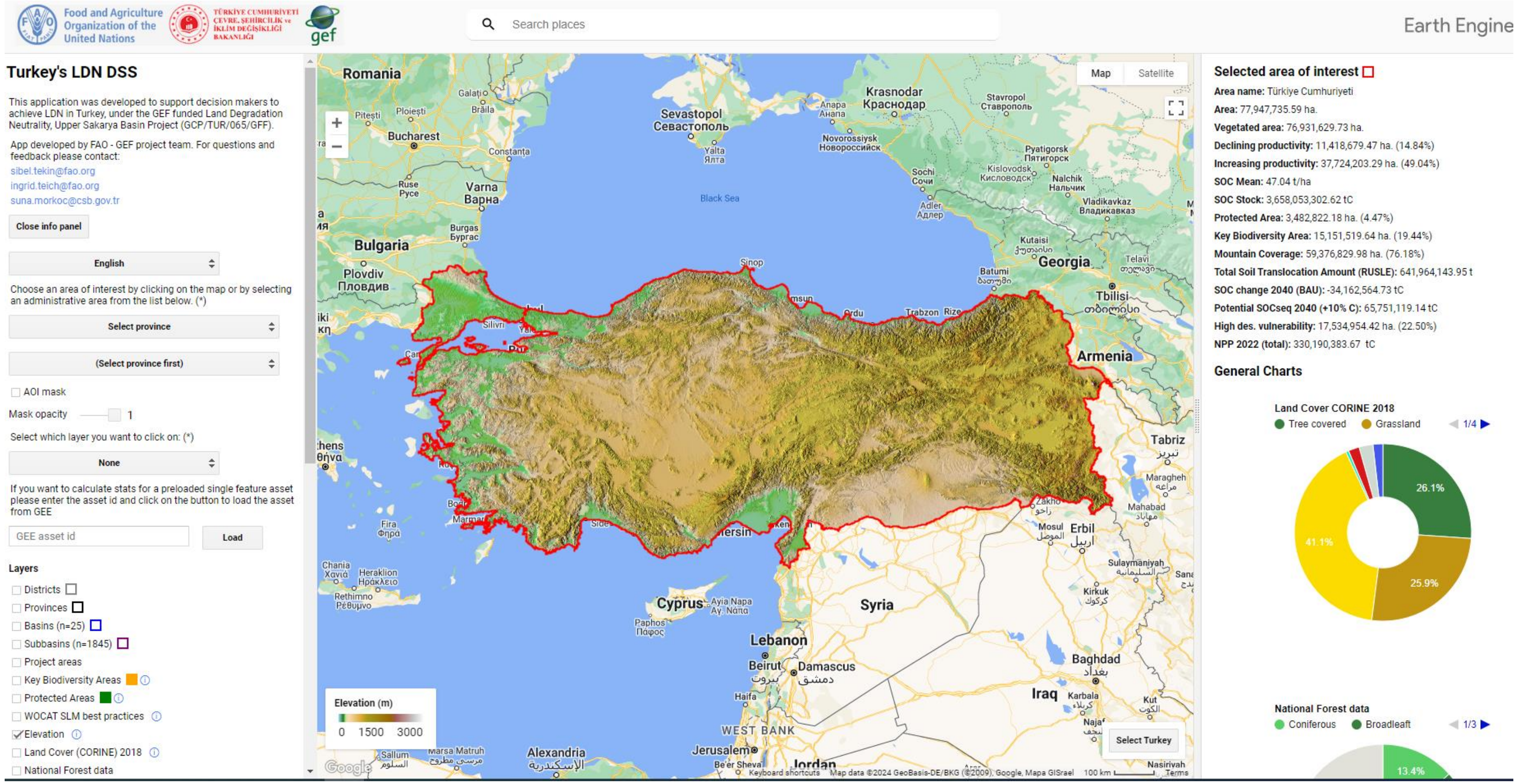
https://projectgeffao.users.earthengine.app/view/ldn-turkey

Aim:

Supports policymakers, land managers, and other stakeholders in making informed decisions that contribute to sustainable land use, restoration of degraded lands, and overall environmental conservation, aligning with Turkey's commitments to global sustainability goals and conventions.

Pilot Study: Upper Sakarya Basin Project

- Available since 2021



Turkey's LDN DSS

This application was developed to support decision makers to achieve LDN in Turkey, under the GEF funded Land Degradation Neutrality, Upper Sakarya Basin Project (GCP/TUR/065/GFF).

App developed by FAO - GEF project team. For questions and feedback please contact:
sibel.tekin@fao.org
ingrid.teich@fao.org
suna.morkoc@csb.gov.tr

Choose an area of interest by clicking on the map or by selecting an administrative area from the list below. (*)

Select which layer you want to click on: (*)

If you want to calculate stats for a preloaded single feature asset please enter the asset id and click on the button to load the asset from GEE

Layers

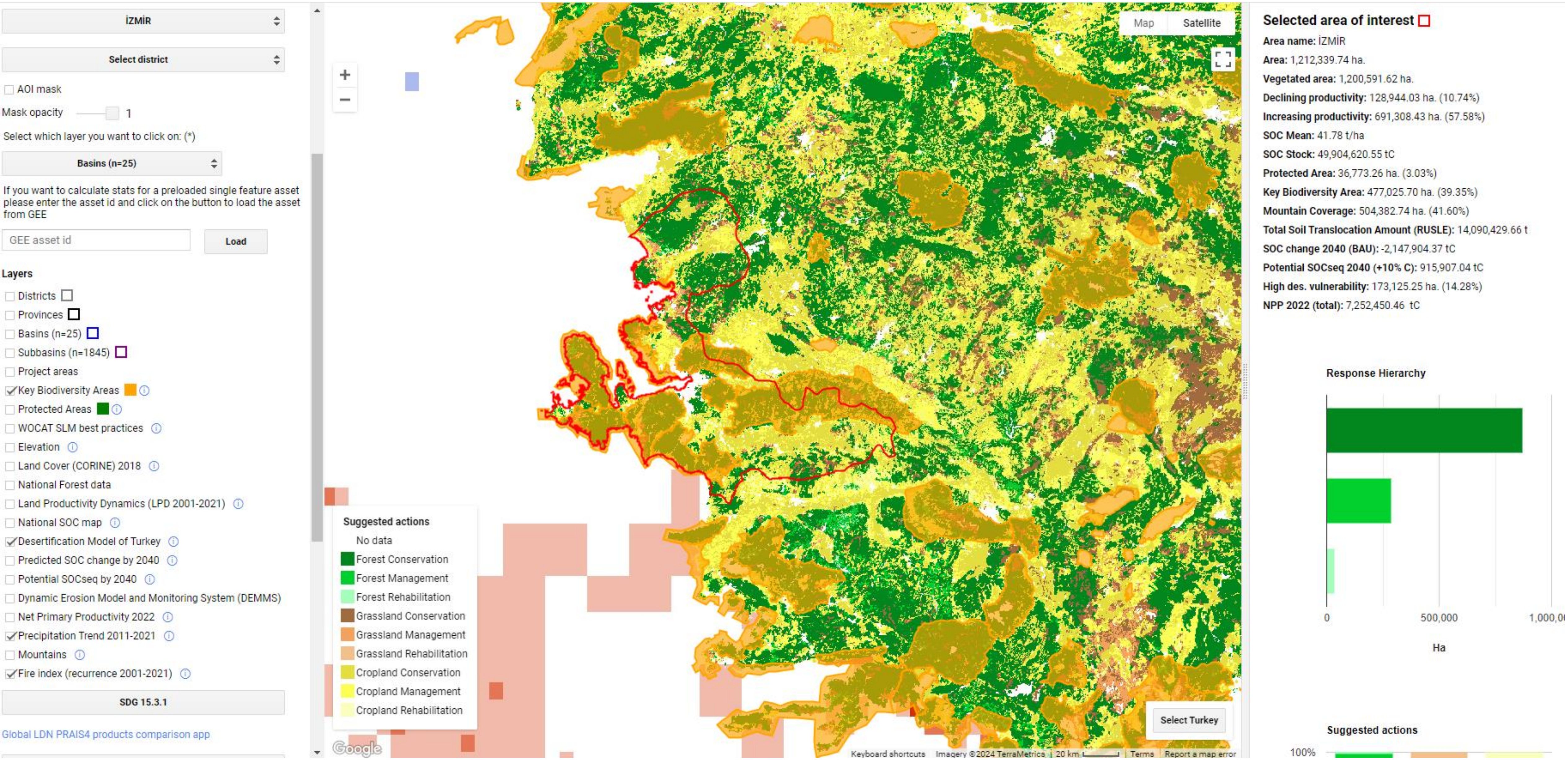
☐ Districts
☐ Provinces
☐ Basins (n=25)
☐ Subbasins (n=1845)
☐ Project areas
☐ Key Biodiversity Areas 🟧
☐ Protected Areas 🟩
☐ WOCAT SLM best practices
☑ Elevation
☐ Land Cover (CORINE) 2018
☐ National Forest data

Selected area of interest

Area name: Türkiye Cumhuriyeti
Area: 77,947,735.59 ha.
Vegetated area: 76,931,629.73 ha.
Declining productivity: 11,418,679.47 ha. (14.84%)
Increasing productivity: 37,724,203.29 ha. (49.04%)
SOC Mean: 47.04 t/ha
SOC Stock: 3,658,053,302.62 tC
Protected Area: 3,482,822.18 ha. (4.47%)
Key Biodiversity Area: 15,151,519.64 ha. (19.44%)
Mountain Coverage: 59,376,829.98 ha. (76.18%)
Total Soil Translocation Amount (RUSLE): 641,964,143.95 t
SOC change 2040 (BAU): -34,162,564.73 tC
Potential SOCseq 2040 (+10% C): 65,751,119.14 tC
High des. vulnerability: 17,534,954.42 ha. (22.50%)
NPP 2022 (total): 330,190,383.67 tC

General Charts

(LDN DSS)-İZMİR REGION



İZMİR

Select district

☐ AOI mask

Mask opacity 1

Select which layer you want to click on: (*)

Basins (n=25)

If you want to calculate stats for a preloaded single feature asset please enter the asset id and click on the button to load the asset from GEE

GEE asset id

Layers

- ☐ Districts
- ☐ Provinces
- ☐ Basins (n=25)
- ☐ Subbasins (n=1845)
- ☐ Project areas
- ☑ Key Biodiversity Areas
- ☐ Protected Areas
- ☐ WOCAT SLM best practices
- ☐ Elevation
- ☐ Land Cover (CORINE) 2018
- ☐ National Forest data
- ☐ Land Productivity Dynamics (LPD 2001-2021)
- ☐ National SOC map
- ☑ Desertification Model of Turkey
- ☐ Predicted SOC change by 2040
- ☐ Potential SOCseq by 2040
- ☐ Dynamic Erosion Model and Monitoring System (DEMMS)
- ☐ Net Primary Productivity 2022
- ☑ Precipitation Trend 2011-2021
- ☐ Mountains
- ☑ Fire index (recurrence 2001-2021)

Selected area of interest

Area name: İZMİR

Area: 1,212,339.74 ha.

Vegetated area: 1,200,591.62 ha.

Declining productivity: 128,944.03 ha. (10.74%)

Increasing productivity: 691,308.43 ha. (57.58%)

SOC Mean: 41.78 t/ha

SOC Stock: 49,904,620.55 tC

Protected Area: 36,773.26 ha. (3.03%)

Key Biodiversity Area: 477,025.70 ha. (39.35%)

Mountain Coverage: 504,382.74 ha. (41.60%)

Total Soil Translocation Amount (RUSLE): 14,090,429.66 t

SOC change 2040 (BAU): -2,147,904.37 tC

Potential SOCseq 2040 (+10% C): 915,907.04 tC

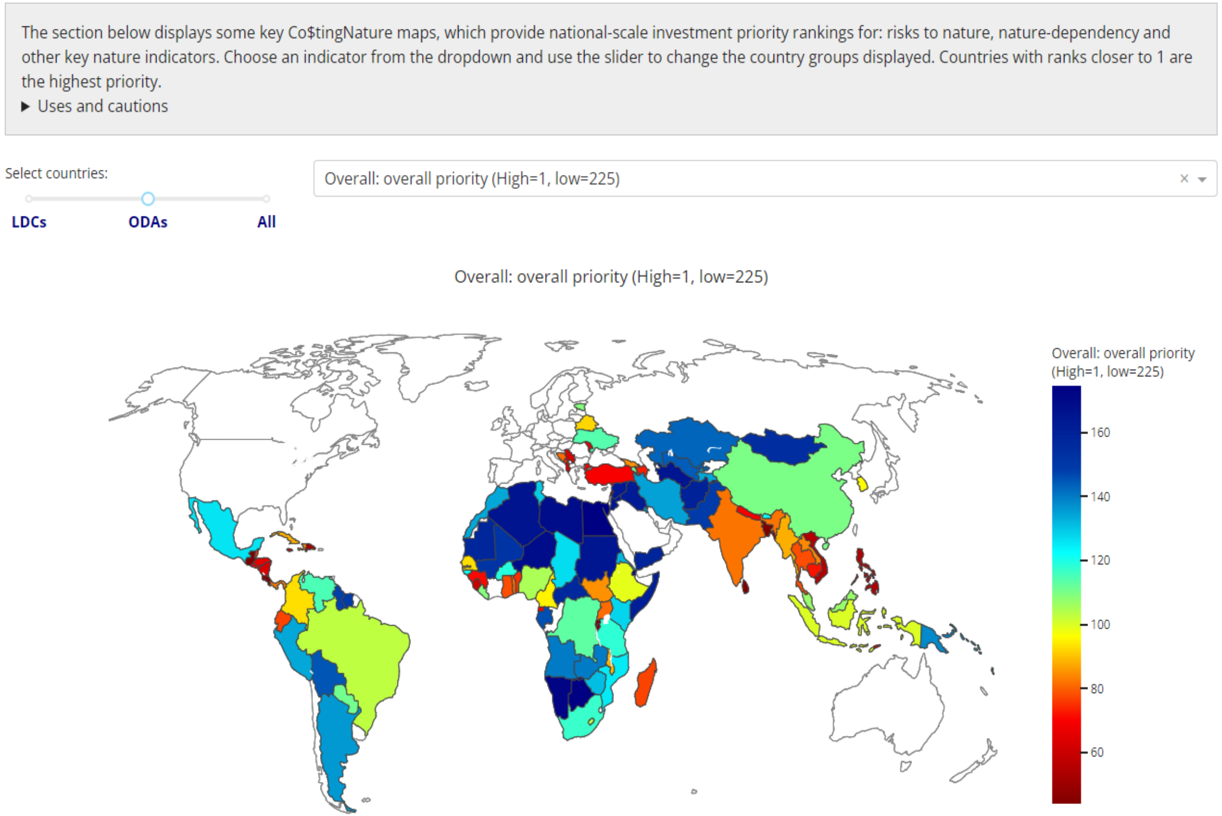
High des. vulnerability: 173,125.25 ha. (14.28%)

NPP 2022 (total): 7,252,450.46 tC

Tool to Assess Natural Capital Valuation
Co$tingNature

- Sophisticated web-based spatial policy support system (PSS) for natural capital accounting and analysing the ecosystem services provided by natural environments (i.e. nature's benefits)
- Identifying the beneficiaries of these services and assessing the impacts of human interventions.
- Adapting to ESG Models (Possible recommendation)

Module for Sustainable Development


The section below displays some key Co$tingNature maps, which provide national-scale investment priority rankings for: risks to nature, nature-dependency and other key nature indicators. Choose an indicator from the dropdown and use the slider to change the country groups displayed. Countries with ranks closer to 1 are the highest priority.

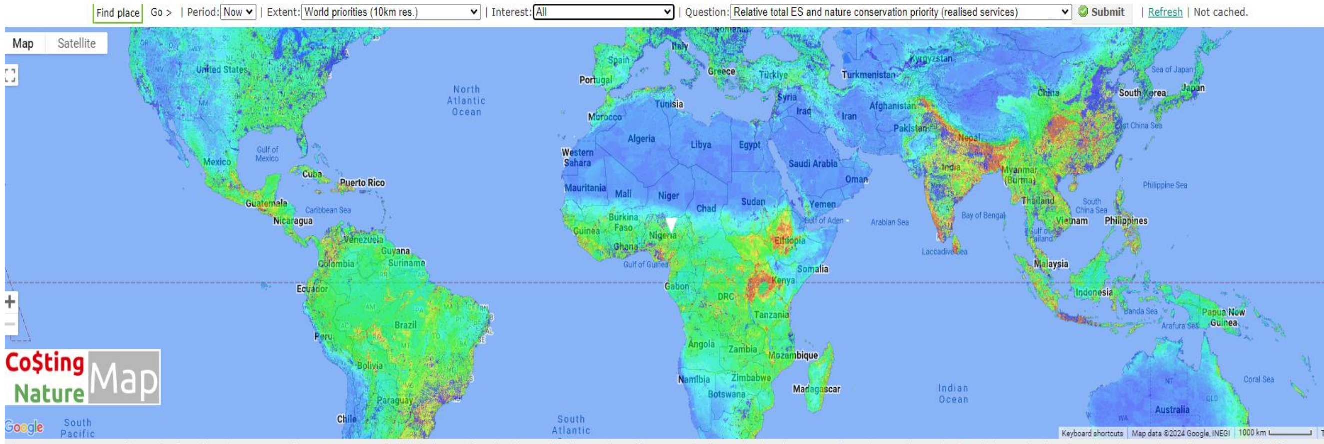
▶ Uses and cautions

Select countries: LDCs ODAs All

Overall: overall priority (High=1, low=225)

Overall: overall priority (High=1, low=225)

Module for Nature-Related financial risk disclosure


Find place | Go > | Period: Now | Extent: World priorities (10km res.) | Interest: All | Question: Relative total ES and nature conservation priority (realised services) | Submit | Refresh | Not cached.

Developers: King's College London (applications, data, models), AmbioTEK (software, data, models), UNEP WCMC (applications, data)-open source

https://www.policysupport.org/costingnature
http://www1.policysupport.org/cgi-bin/ecoengine/pssmap.cgi?project=CNMap&action=Map
https://analytics.policysupport.org/cn4sd
https://projectgeffao.users.earthengine.app/view/ldn-turkey

Co$tingNature (Methods-Assumptions and Limitations)

Co$ting Nature

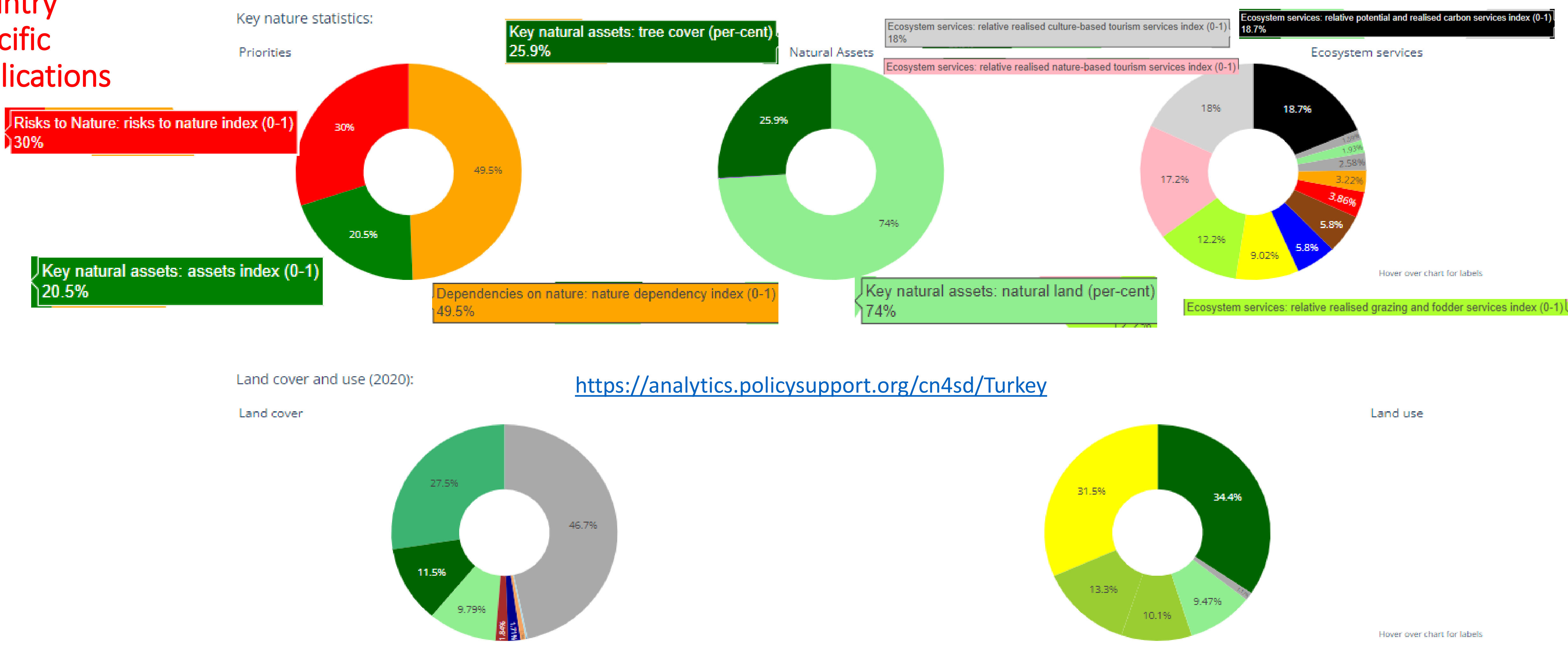
Country specific applications

Turkey: nature data

Nature overview

The section below shows some key Co$tingNature nature indicators for Turkey. These include: the contribution of each component metric to the overall nature-investment priority (left pie chart), the natural asset priorities (middle pie chart) and the nature-dependency (ecosystem service) priorities (right pie chart). For this country, the current pressure that is greatest over the most territory is: **infrastructural intensity**, the future threat that is greatest over the most territory is: **deforestation**, and the ecosystem service (nature-dependency) that is greatest over the most territory is: **water**. Nature's contribution to meeting the UN Sustainable Development Goals (SDGs) for this country is (on scale of 0-1): **0.65**. Nature's contribution is greatest over the most territory to: **SDG1: No poverty**. The overall nature-investment priority value (1=highest, 255=lowest) for this country is: **70**.

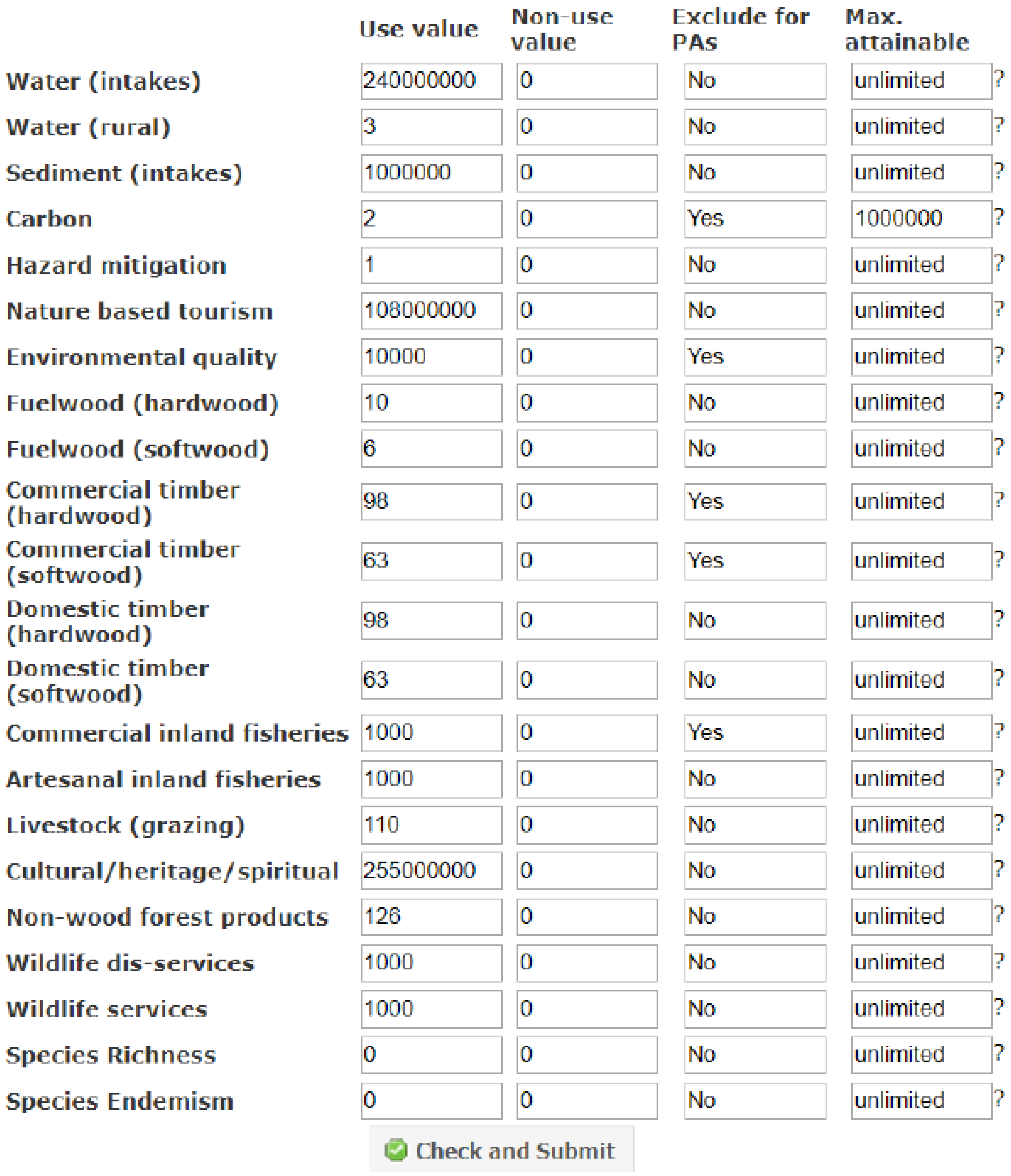
- ▶ Explanation
- ▶ Uses and cautions



https://analytics.policysupport.org/cn4sd/Turkey

Co$tingNature (Economic Units)

- Economic valuation mode the economic value of each ecosystem service is calculated, based on information available in a country's national accounts
- Suited to investment and policy applications focused on valuation of ecosystem services
- Complete a matrix of economic values for each ecosystem service to each beneficiary class.
- Future sceneario analysis
- Maps 22 potential and 22 realised ecosystem service values



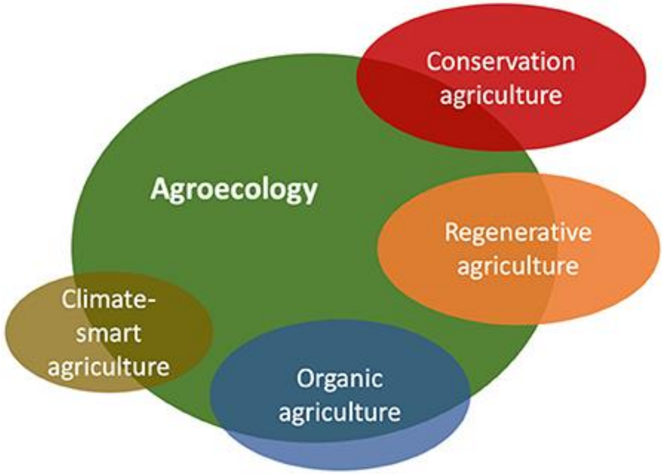
	Use value	Non-use value	Exclude for PAs	Max. attainable	
Water (intakes)	240000000	0	No	unlimited	?
Water (rural)	3	0	No	unlimited	?
Sediment (intakes)	1000000	0	No	unlimited	?
Carbon	2	0	Yes	1000000	?
Hazard mitigation	1	0	No	unlimited	?
Nature based tourism	108000000	0	No	unlimited	?
Environmental quality	10000	0	Yes	unlimited	?
Fuelwood (hardwood)	10	0	No	unlimited	?
Fuelwood (softwood)	6	0	No	unlimited	?
Commercial timber (hardwood)	98	0	Yes	unlimited	?
Commercial timber (softwood)	63	0	Yes	unlimited	?
Domestic timber (hardwood)	98	0	No	unlimited	?
Domestic timber (softwood)	63	0	No	unlimited	?
Commercial inland fisheries	1000	0	Yes	unlimited	?
Artesanal inland fisheries	1000	0	No	unlimited	?
Livestock (grazing)	110	0	No	unlimited	?
Cultural/heritage/spiritual	255000000	0	No	unlimited	?
Non-wood forest products	126	0	No	unlimited	?
Wildlife dis-services	1000	0	No	unlimited	?
Wildlife services	1000	0	No	unlimited	?
Species Richness	0	0	No	unlimited	?
Species Endemism	0	0	No	unlimited	?

Natural Capital Valuation (Sustainable Agricultural Practices)

Natural Capital Value Integrated ESG Model for Food Systems

- The integration of sustainable farming methodologies
- Agroecology,
- Permaculture,
- Regenerative agriculture
- Pivotal in mitigating environmental degradation. (Sequestor CO2)

“Environmental”

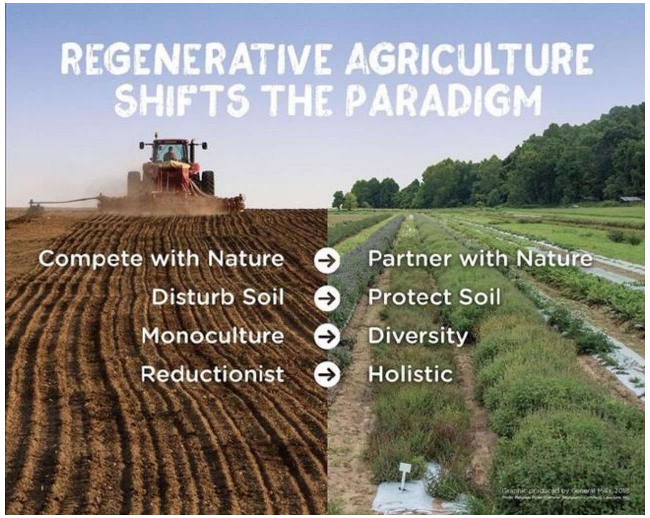


Sustainable Agricultural Methods

For local community , seasonal workers and Indigenous(not conventional agriculture practioners)

- Necessity for equitable employment conditions
- Prioritizing safe working environments
- Fair wages
- Strict adherence to labor rights.

“ Social”



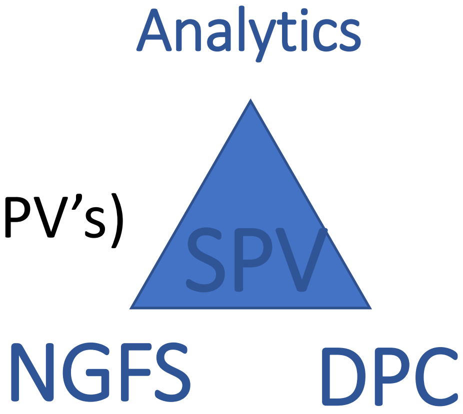
Natural Capital Valuation and ESG

- **E**
- Ensure that parameters in the E pillar directly or indirectly influence the Value of Ecosystem Services and adjust the weights accordingly.
- **S**
- Ecologists often consider humans as separate from ecological systems. While this holds some truth, it overlooks the role of local communities and seasonal workers who contribute to the ecosystem's natural capital as active participants.
- Their contributions should not be weighted the same as those of communities that have outsourced their responsibilities to the corporate sector or engaged in financial offsetting mechanisms.

Steps to Follow For Closing Data Gaps for effective Sustainability Risk Metric

- Behavior Change vs Delegation
- Respect and link your outcomes with Planetary Boundaries
- Collaboration for Data Sharing beyond market economy (Establishing SPV's)
- Adapting Natural Capital Valuation to ESG Models

(LDN DSS, Co$tingNature Modules Practices to fill data gaps)



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Irving Fisher Committee on
Central Bank Statistics

IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

Combining AI and domain expertise to assess corporate climate transition disclosures[1]

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

Combining AI and Domain Expertise to Assess Corporate Climate Transition Disclosures

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Abstract

Companies need sound planning to reduce their emissions and deal with the transition to a more sustainable economy. The disclosure of such plans is key for effective capital allocation and risk management. Transition and sustainability disclosures are a compass for market participants to guide their actions and strategies toward the net-zero target. If companies plan their transition appropriately, the negative implications of physical and transition risks for micro- and macro-financial stability can be reduced. Many frameworks have been suggested to assess transition plans' ambition, credibility, and feasibility. However, the lack of one clear reference framework paves the way for inconsistencies in transition plans and the risk of greenwashing. We propose a set of 64 common ground indicators from 28 different transition plan disclosure frameworks to comprehensively assess transition plans and develop a novel natural language processing (NLP)–based tool to automate the assessment of companies' disclosures. This can help investors and financial supervisors assess transition risks while supporting companies' disclosure efforts. Applying the tool to 143 reports from the carbon-intensive CA100+ companies, we find that companies tend to disclose more indicators related to target setting (talk) but fewer indicators related to the concrete implementation of strategies (walk). Our results demonstrate that machine learning can be used to generate a positive impact on the transition towards a more sustainable economy by identifying the elements of transition plans that require further scrutiny and/or effort. Our work will be a starting point for further leveraging new technologies in sustainable finance. For example, the assessment of the plans could be used by financial regulators in their supervisory practices or to investigate whether the risk of greenwashing is reflected in stock returns.

Keywords: Climate disclosure, RAG system, transition strategies, human evaluation, CA100+.

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Introduction

As the impacts of climate change become increasingly severe, the urgency for the global community to transition to a net-zero economy has never been more critical. This transition is essential for mitigating the negative effects of climate change and ensuring economic stability and sustainability in the long term. Corporations, as significant contributors to greenhouse gas emissions, are central to this transformation. They are tasked with adjusting their operations and strategies to align with climate goals. This requires comprehensive planning, implementation, and transparency. Furthermore, this transformation requires a large amount of financial resources. Financial institutions are pivotal in directing capital towards sustainable activities and enabling the transition of corporate business models and technologies. Yet, they need information on comprehensive corporate transition strategies to assess the future risks and opportunities associated with their investments.

Ambitious, credible, and feasible transition strategies are relevant not only for corporates-which use them to navigate the shift towards sustainable practices and ensure that they remain competitive and compliant with an evolving regulatory landscape- but also for a wide range of stakeholders. For investors, these plans gauge a company's long-term viability and alignment with increasingly stringent environmental standards, such as those set out in the Paris Agreement. Regulators rely on these plans to ensure that companies make genuine efforts to reduce their carbon footprints, which is critical to meeting national and international climate targets. Hence, the evaluation of transition strategies is key, as shown by recent contributions in this direction[1,2,3,4,5].

Despite the critical importance of corporate transition strategies, several challenges can undermine their effectiveness in supporting the achievement of the net-zero target. Reporting and credibility issues whereby companies misleadingly portray their climate and environmental efforts (greenwashing) are at the forefront. This can undermine trust and lead to a misallocation of resources in the economy, putting the climate and environmental targets at risk and coming along with negative micro- and macro- financial stability implications[6,7,8,9,10,11]. The lack of standardization in companies' disclosures reduces stakeholders' ability to compare and assess the ambition, credibility, and feasibility of the transition strategies of different companies. This poses a substantial barrier to effectively evaluating corporate contributions to climate goals and strategies to steer their business to the future. At the same time, the ongoing pressure to show progress in reducing climate impact leads companies and public institutions to release information that often results in vast amounts of unstructured data about transitioning toward net zero[12].

This paper addresses these challenges by providing a practical framework that assesses corporate climate transition disclosures. Our approach uses a natural language processing (NLP) tool to automate and enhance the analysis of sustainability disclosures and identify potential risks of greenwashing. We build on previous work that uses NLP in the field of sustainable finance and corporate climate risk analysis e.g.,[13,9,14,15,16,17] and extend the literature by providing a standardized, detailed, and expert-driven scaleable assessment process. Thus, we respond to the call for more fine-granular AI assessments in sustainability[18].

Our contribution is threefold. First, we identify the common ground of comprehensive indicators to assess transition strategies. To achieve this goal, we review 28 different transition strategy disclosure frameworks to identify common criteria for assessing corporate transition strategies and elicit experts' opinions to develop a unified framework encompassing 64 indicators. These indicators cover different key areas for a comprehensive, successful net-zero transition. In this context, the lack of disclosure of the information required by individual indicators represents a potential risk associated with the company, as it signals that it might not be well-prepared for the transition in that specific dimension.

Second, we build and validate an NLP tool for the automated analysis of transition plans based on the 64 common ground indicators. We assess the performance of the NLP tool in a pilot evaluation involving users from 26 different institutions to gain insights into practitioners' perceptions of the tool, its trustworthiness, and practical usage. The pilot involved representatives from both the private and public sectors and profit and non-profit organizations. We find that users are very satisfied with the tool's performance overall, but there is use-case specific disagreement regarding the priorities for improvement.[1]

Third, we investigate the disclosures of the Climate Action 100+[2] companies to identify potential inconsistencies in their transition strategies. We focus on these companies, as they are critical for the transition to a low-carbon economy at the global level. Our findings show that companies tend to disclose more indicators related to target setting (talk) but fewer indicators related to the concrete implementation of strategies (walk).

Our research contributes to the fields of corporate climate risk analysis, sustainable finance, and

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[1] You can try out the tool on our GitHub repository. In there, you will find the code and data of this project as well as further helpful resources.

[2] Climate Action 100+ is an investor-led initiative that aims to incentivize the world's largest corporate greenhouse gas emitters to take climate action.

corporate governance by enhancing the ability to monitor and assess the ambition, credibility, and feasibility of corporate transition plans. It offers new insights and solutions that can be adopted by policymakers, financial supervisors, corporations, and financial institutions to support a more resilient and sustainable economic and financial system.

1 Assessment indicators

We initially define a common ground of assessment indicators along which companies' disclosure related to transition strategies can be analyzed. To identify these assessment indicators, we proceed in three steps. First, we review existing transition plan disclosure frameworks and extract the most common criteria for sound transition strategies. Second, we combine quantitative and qualitative evaluations to create a structured list of the most important indicators. Third, we evaluate the importance of each indicator by collecting feedback from a group of stakeholders involved in the transition plan analysis and define the final list of indicators based on their comments.

In the first step, we review 28 existing transition plan frameworks and identify commonly suggested assessment indicators. These indicators are criteria to evaluate the ambition, credibility, and feasibility of transition plans.[3] In this study, we review frameworks that were published over the period 2021-2023 by different stakeholders and initiatives (see Table S.1 for an overview).

In the second step, we use quantitative and qualitative criteria to assess the importance of the identified indicators for ambitious, comprehensive, and credible corporate transition strategies. We first compute the frequency of indicators' appearance in the reviewed frameworks for the quantitative evaluation. In particular, we count the number of times one indicator is considered in the assessed frameworks and assign one value for each appearance. In some cases, we assign a value of 0.5 if an indicator is only partially covered by the respective framework. For example, an indicator could be a recommendation amongst others and not a core required element. This quantitative assessment helps to obtain an initial weight of the importance of an indicator. Moreover, we undertake a qualitative assessment by discussing the quantitative weights for each indicator, combining similar indicators, and verifying their suitability for assessing transition disclosures. In addition, we classify our indicators into "walk" (W) and "talk" (T). The distinction is made based on whether a specific indicator relates to future targets and/or general transition monitoring and management approaches (T) or to specific and already verifiable transition activities (W).

In the third step, we share our list of indicators with more than 50 selected experts who formed our advisory board. The advisory board included financial industry representatives, central bankers, and financial supervisors.[4] The experts were asked to provide comments, suggest amendments, and refine the indicators. We had both group meetings with the whole advisory board and individual meetings to understand the main criticalities and the importance of different indicators to different stakeholders. As a result, we obtain a common ground list of 64 indicators along which we assess transition-related disclosures.

Section S.3 lists all the indicators selected, covering the broad categories "Target", "Governance", "Strategy", and "Tracking" (as used in e.g. TCFD). In addition, we show each individual indicator's classification as primarily a walk (W) or talk (T) indicator.

With our framework, it is possible to analyze whether companies disclose information related to specific indicators or not. For each not-disclosed indicator, our approach signals that the company's transition strategy might be entirely absent or inconsistent in that specific dimension (for example, not ambitious, credible, or feasible). As such, further investigation by stakeholders and disclosure efforts by the respective company are required.

An important advantage of the proposed framework is its flexibility: While we suggest a list of indicators deemed appropriate to assess transition strategies, users can modify and extend this depending on their needs. For instance, financial institutions lending to specific sectors might want to add more details about risks that are specifically important for their assessment. Similarly, users interested in broader nature-related risks might want to include additional questions about supply chains and companies' locations.

2 NLP Model Development

We develop a natural language processing (NLP) tool to automate the analysis of company disclosures along with our indicators. Furthermore, we validate the tool in a pilot study with 26 institutions.

NLP Tool

To translate our framework into an automated analysis tool, we rely on Large Language Models (LLMs). LLMs have shown vast capabilities in reasoning, understanding, and generation of text[19,20,21,22]. However, LLMs also face two major

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[3] The literature also refers to the different dimensions of consistency as internal (ambition and feasibility) and external (feasibility).

[4] The advisory board was established to provide feedback throughout the entire project. For more details on the advisory board, see Section S.1.

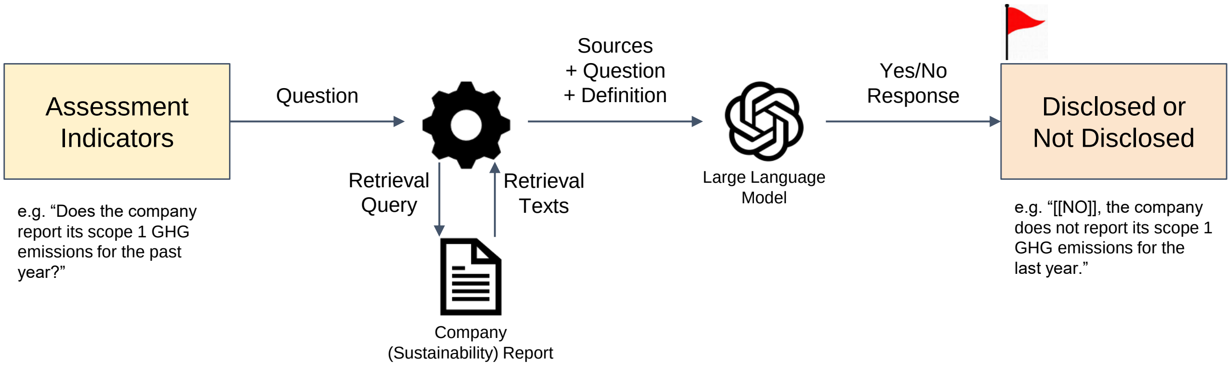

Figure 1: Retrieval Augmented Generation (RAG) pipeline for analyzing the assessment indicators.

challenges that arise from relying on internal knowledge: (1) LLMs may produce hallucinated output, that is, text that is not factual[23], and (2) the embedded knowledge base of LLMs is intransparent and truncated at a certain point in time. Against these shortcomings, practitioners and researchers rely on a technique called Retrieval Augmented Generation (RAG)[24]. RAG systems aim to include external knowledge in the prompts provided to the LLM and force the model to rely only on this information when answering a given question. Thus, RAG systems make use of the strong capabilities of LLMs to summarize and reason over the provided content and try to minimize the dependence on the internal knowledge of the LLM.

Figure 1 displays the RAG system used in this project. The starting point is given by the assessment indicators in the form of questions. Following the suggestions from our advisory board, we aim for an easy-to-use and understand approach, as well as a high-level yes/no answer for the assessment indicators. This entails a binary decision by the tool on whether the information required by the indicator is disclosed or not. For example, one indicator considered is related to the disclosure of scope 1 GHG emissions in the past year. Hence, the corresponding question reads: "Does the company report its scope 1 GHG emissions for the past year?". If the NLP tool finds information related to past year emissions in a company's disclosures, it will return a YES followed by an explanation about the decision made.

From a technical perspective, each question is embedded in a numerical representation. Accordingly, the disclosures of the investigated company are split into chunks, and every chunk is embedded in a numerical representation. Chunks with similar semantics obtain similar numerical representations. As a result, the numerical representation of the question can be used to find semantically similar, that is, question-relevant texts. These retrieved texts are included in a structured prompt format and provided to the LLM, together with specific guidelines that help pin down the exact information on which to focus when answering the question. We defined the guidelines in an iterative, expert-based process by assessing the model answers for each indicator based on the simple question and adding further information as needed until the answers were comprehensive and in line with the experts' knowledge and assessments (see Appendix for more details S.5). Furthermore, the prompt includes formal instruction and, importantly, the command that the LLM should only rely on the given sources and not on internal knowledge. This is important to ensure that the model only assesses the specific corporate document that is to be analyzed for the user and does not draw on information about the company that was available elsewhere when the model was initially trained.

Finally, the tool produces a structured answer indicating whether information as requested by the indicator under investigation, formulated as a question, is available. The output is a yes or no answer, followed by an explanation of the decision and the source references based on the answer (see Section 5 for technical details). These explanations can enable a more holistic and, importantly, transparent understanding of the evaluation made. They allow the user to understand the reasoning behind the choice and can provide starting points for more detailed investigations. The sources allow the user to cross-check whether the relevant information has been extracted by the model and whether it has been correctly summarized (see Section S.6 for more details).

Human Evaluation

We evaluate our tool in a pilot study. We choose a tool evaluation design that helps us obtain quantitative and qualitative feedback from domain experts. This adds to prior research, which has mainly addressed the quantitative evaluation of RAG systems in artificial or theoretical setups[25,26,27,28]. Only a few analyses have considered expert-based evaluations[29,30]. However, none of these prior pa-

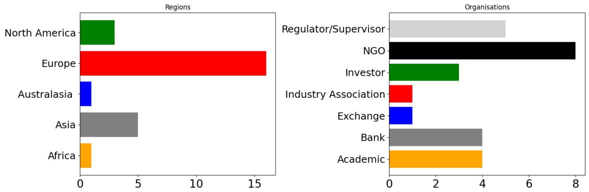

Figure 2: Overview of regions and organization types of the 26 participating organizations to the study.

pers attempted a comprehensive evaluation of quality dimensions, such as correct sourcing and answering, as well as the potential usage of such tools for stakeholders.

Our evaluation incorporates feedback from domain experts from 26 organizations. The experts include financial regulators and supervisors, investors, exchanges, NGOs and industry associations representatives, bankers, and academics. The participants are predominantly based in Europe, followed by participants from Asia, North America, Australasia, and Africa.[5] See Figure 2 for more details. One organization participated with three persons. Thus, we have 28 participants in total.

The domain experts assess the tool along the following qualitative dimensions:

System Quality, which aims at understanding if relevant information is retrieved, answers are accurate and faithful, and reasoning capabilities are solid.

Trustworthiness, which yields insights into users' perceived trustworthiness and expertise of the model.

Usage, which aims at understanding the usefulness of the tool for the respective stakeholder, as well as future possible use cases.

In the evaluation, we differentiate between feedback on the tool's assessment of individual indicators, that is, the responses and sources for specific yes / no questions (Q1-Q9), and overall feedback about the tool in general (Q10-Q15). The participants provided an answer based on a given set of options (multiple choice) and could provide additional explanations (free text). For the detailed questions and setup, see Supplementary Material S.7.

We ask the pilot participants to submit at least three reports of interest for evaluation. This ensures that the experts have prior experience in analyzing the underlying companies. We obtained a total of 93 reports from our participants (see Figure S.7 for details on the reports), which we analyzed with our NLP tool. Then, we identify a pool of 12 indicators, which we consider representative and important to get a solid understanding of the tools' performance in assessing the available information. For each of the three reports the participants submitted, we randomly assigned two of the 12 indicators to each participant to assess. This ensures that participants assess at least two answers in detail and that we obtain a reasonably large cross-section of assessments across participants for the assessed indicators. Participants are free to assess more responses in addition to the assigned ones. Finally, each participant is requested to provide a general tool assessment. As a result of this process, we obtain 28 tool assessments and 396 assessment indicator evaluations.

The results of the human evaluation offer several insights.[6] Regarding **system quality**, participants display a very high level of satisfaction. For example, 81% of the participants found that the model summarizes relevant content correctly for the indicator assessments without making up information not contained in the report, while 12% found that this is partially the case, and only 6% were not satisfied with the result in this regard (Q4). Furthermore, the majority of participants perceive that the tool captures the most relevant content for the requested indicator information (Q3) and cites it correctly without making sources up (Q6-Q9). Amongst those unsatisfied with the model output for the indicator assessed, feedback included that the model may be too judgmental or occasionally missed out on important sources for the relevant information in the report on the specific indicator. When asked what the major area of improvement for the model could be to support the usage, the responses were polarized. In particular, one part of the experts suggested a more detailed assessment, while another part highlighted that a broader overview would be desirable (Q14). The results related to the system quality dimension align with prior research that outlines that the models can achieve very satisfactory quantitative results in faithfulness[28]. However, our analysis also reveals that for specific users, adaptation to individual needs is critical. This highlights that it is very difficult to find a one-fits-all solution. Rather, users should be able to adjust the tool to their specific needs.

Regarding **trusthworthiness**, the user's first impression of the individual answers is largely positive (Q2), and the sources provided in an answer largely support the trust in the model (Q5). This is also mirrored in the general tool assessment, where only three respondents claimed that they did not

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[5] Although we have tried to achieve an acceptable level of representations in our sample, we had to rely on the self-selection of participants, which can influence the results of our pilot.

[6] We are aware that these answers might exhibit some bias. Although we ensured the anonymity of the reports submitted and the assessments provided, the responses of the self-selected participants might have been influenced by the setup of the pilot.

trust the information when using the model (Q15). Only two participants find the tool unsatisfactory (Q10). Generally, the answers of the tool were perceived as comparable with an expert with 1-2 or more years of experience in assessing companies' disclosures (Q11). However, it also becomes apparent that a large share of the participants is not sure about whether they would fully trust the information provided by the tool (11 of 28 respondents "partially" trust the model (Q15)). The optional explanations help us understand where these concerns stem from. Some participants outlined the lack of ability of the tool to handle sector-specific issues based on the current set of indicators. Others highlighted the need to compare the answers produced by the tool with third-party data.

Finally, the **usage** dimension sheds light on the ease of understanding the indicators themselves, use cases for applying the tool in practice, and improvement potentials. With respect to understanding the information requested by the indicators, the dominant feedback from the users is positive. Most of the participants would know which information they would look for if they had to answer the question themselves (Q1). Furthermore, stakeholders would utilize the tool for a wide set of use cases, ranging from corporate risk and opportunity assessment to high- and deep-level understanding of transition plans (Q13). As outlined in the System Quality dimension, enhancements reflect very individual needs (see Q14). A common qualitative feedback is that the tool can be valuable for quick assessment and understanding, but future improvements could include deeper and more actionable insights or sector-specific adjustments of the tool (Q12, Q16).

Overall, human evaluation provides valuable insight into understanding that the NLP tool represents a valuable asset for end users. However, the introduction of more user-specific adaptions of the tool could foster both trust and usage.

3 CA100+ Companies Use Case

To illustrate a use case of our tool, we apply it to analyze corporate sustainability reports of the CA100+ companies and assess the transition-related information contained in these reports along the 64 assessment indicators. CA100+ is an investor-led initiative to track the most-emitting companies in the world. Our sample covers 143 companies and the corresponding corporate sustainability reports for the fiscal year 2022. The distribution of the companies across the different sectors is shown in Figure 3. For all the reports in our sample, we assess how many indicators are disclosed in the report of the company under consideration (i.e., the tool assigned a "yes" answer to the prompt question of whether the information requested in the indicator is available in the report). Thus, for this use case, we focus on the quantitative part of the output. The qualitative answers to each indicator may provide additional information for users (see Section S.6 for a better understanding).

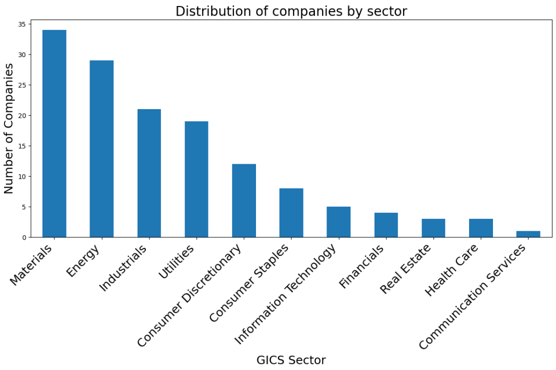

Figure 3: Distribution of companies by sector.

We find that the average count of indicators disclosed per report is 23 out of the 64 required indicators, while the best-performing report reaches a value of 43. The distribution of the average share of disclosed indicators by the company shows that a value of almost 40% is achieved by more than 35% of the companies (see Figure 4). However, it is important to understand the type of indicators for which information is available. Similarly, there might be sectoral patterns in the disclosure. Hence, we also rank the indicators according to their frequency of disclosure in the reports analyzed, and we look at sectoral disclosures.

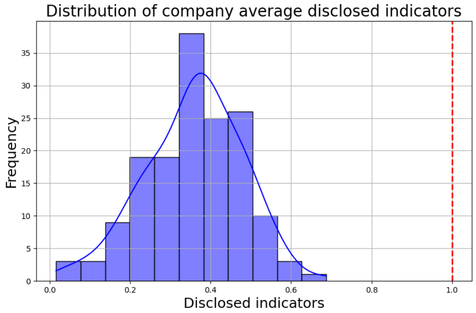

Figure 4: Distribution of the share of disclosed indicators by company.

Most and least disclosed indicators

In our analysis of corporate disclosures, we observe a clear divergence in disclosure depending on the types of indicators considered. This highlights areas where companies excel and fall short in their disclosures. The ranking of the disclosed indicators shows a pattern for the 10% most disclosed and the 10% least disclosed indicators (see Tables 1 and 2).

Identifier	Question	
9	Does the company report its GHG emission reduction interim targets for achieving the overall goal?	T
13	Does the company explain its governance structure for managing the climate transition?	T
17	Does the company report how its board oversees the climate transition plan implementation?	T
23	Does the company report quantitative or quantifiable subtargets in line with their climate targets and their climate key performance indicators?	T
26	Does the company report a renewable energy strategy and activities, covering renewable energy build out, procurement and consumption?	W
46	Does the company report its scope 1 GHG emissions for the past year?	W
50	Does the company report its annual progress of reducing GHG emissions to achieve its emission reduction or net zero targets?	W

Table 1: 10% most disclosed indicators

Identifier	Question	
12	If carbon credits and offsets are reported to be used by the company, does the company state explicitly that carbon credits and offsets will be only used when the company can ensure that the emission reduction or emission avoidance is sustained permanently?	T
19	Does the company provide a higher share of remuneration and bonuses that are linked to the successful implementation of the climate transition plan interim targets compared to the general part of variable compensation for executives and managers?	W
22	Does the company provide comprehensive evidence that it fully and completely integrates its climate strategy into its business strategy, product development, operations, financial and human resources, asset management and asset decommissioning?	W
36	Does the company report serious consequences and escalation strategies if net zero engagement is ineffective at upstream, downstream, policy maker and industry association level?	T
37	Does the company state explicitly that it stopped or will immediately stop any support or activities in new additional fossil fuel exploration and extension of fossil fuel supply?	W
38	Does the company report a strategy and activities for the decommissioning and canceling of planned or existing fossil fuel exploration and supply infrastructure?	W

Table 2: 10% least disclosed indicators

We first turn our attention to the top 10% disclosed indicators, that is, those indicators that have been disclosed the most by companies. These are related to GHG emission reduction interim targets, the structure of governance for environmental initiatives, oversight by corporate boards, and the specification of quantitative sub-targets. Moreover, companies tend to disclose assessment indicators of operational adjustments toward sustainability, including strategies related to adopting renewable energy and reporting Scope 1 GHG emissions from the past year.

In contrast, the disclosure of indicators that cover more comprehensive and ambitious implementation of transition strategies across all operations and activities is less frequent. These least disclosed indicators are related to the responsible use of carbon credits and offsets, alignment of executive remuneration with climate goals, and holistic integration of climate strategies across all business operations. The lack of disclosure suggests either a lack of fully developed strategies or a reluctance to reveal comprehensive details.

In addition, assessment indicators focusing on policy engagement transparency and ending the use of fossil fuels are less disclosed. These include examining the company's strategies for engagement in net-zero initiatives, policies on quitting the support for additional fossil fuel exploration activities, and plans to decommission fossil fuel infrastructure. The lack of disclosure in these areas could indicate a significant gap between companies' stated targets and the actual practices.

The divergence between the most and least disclosed indicators is also evident in terms of the classification of indicators into "walk" and "talk". Most of the least disclosed indicators are "walk" related, while the majority of the most disclosed indicators are "talk" related.

Sectoral analysis

Other than by the specific indicators, heterogeneity in the disclosures might also stem from sectoral characteristics. Hence, we investigate whether companies in some sectors disclose, on average, more information than others, as requested by our indicators.

Interestingly, we find that companies in sectors with the highest direct carbon emissions also have a higher amount of disclosed indicators. This could either mean that these companies are taking the transition strategy more seriously, that they are under higher pressure from investors and stakeholders to disclose their strategies, or that they are potential greenwashers.[7]

To account for potential differences in most and least disclosed indicators within sectors, we also look at the top and bottom 10% disclosed indicators in the Utilities, Energy, and Consumer Staples sectors. For these cases, we find similar results to those in the overall sample. For instance, the structure of governance for environmental initiatives and the oversight by the corporate board are always the most disclosed indicators, while the alignment of executive remuneration with climate goals and the decommissioning of fossil fuel infrastructures are the least disclosed.

The observed patterns in corporate disclosures suggest that companies may strategically prioritize reporting on areas that highlight their achievements and on communicating overall targets and less on the planned activities and changes in the business model and operations required to actually meet their future targets. This selective approach could be a form of greenwashing, as companies may highlight future promises together with easily achievable or lower impact aspects of their activities instead of stating faithfully their plans about core areas such as quitting the use of fossil fuels or their actual progress in reducing emissions across all scopes.

Again, our results hint at the fact that companies tend to disclose more indicators related to target setting (talk) but fewer indicators related to the concrete implementation of strategies (walk). This is in line with the findings of previous research and highlights the importance of calls for companies and the financial sectors to walk the talk[31,32].

4 Conclusion

Natural language processing offers unique opportunities for sustainable finance and climate-related financial risk management, including the assessment of corporate transition strategies with the aim to identify inconsistencies and potential areas of greenwashing. To the best of our knowledge, this is the first paper to show how a structured expert-centric NLP application process can help to identify a common analysis ground and assess the growing amounts of unstructured corporate climate transition information disclosed by companies.

More specifically, we first identified a common ground of assessment indicators to detect inconsistencies in transition strategies at the corporate level. We further introduce and evaluate an NLP tool to assess companies' disclosure and identify critical dimensions in the planning of the transition. Finally, we provided insights into climate transition disclosures of the world's most-emitting companies.

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[7] The higher disclosure in some sectors might also be driven by the fact that some of the indicators are not relevant for all sectors (e.g., those related to the decommissioning of fossil fuels). However, the large majority of the selected indicators are sector agnostic (only three indicators are strictly related to fossil fuels and hence might not apply to all companies in the sample).

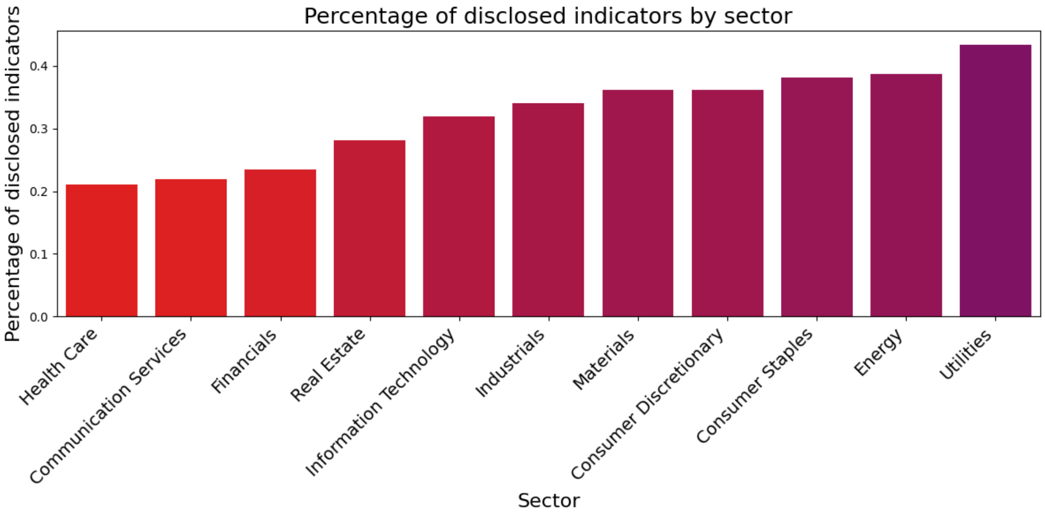

Figure 5: Average share of disclosed indicators by sector.

The examination of corporate disclosures along the climate transition strategy indicators with our NLP tool reveals that companies tend to disclose information related to target setting (talk), but less indicators related to the actual implementation of strategies (walk).

Our NLP tool aims to foster transparency in sustainability reporting and support the analysis of corporate climate transition strategies for research and practice. By obtaining detailed and verifiable disclosure assessments, stakeholders – including investors, regulators, and civil society – can more effectively evaluate the ambition, credibility, and feasibility of corporate climate transition strategies and advocate for more effective climate action in a targeted manner. Furthermore, an automated, consistent, and replicable method can assist company reporting and thereby enhance information availability and transparency for financial markets.

5 Limitations

Improving human evaluation

While the human evaluation represents a critical and valuable approach to understanding the expert-centric dimensions of NLP tools, our evaluation is not exhaustive and subjective in nature. More granular options for the answers would improve the elicitation of expert opinions. Similarly, more structured methods to elicit information could be introduced, such as Directed Acyclical Graphs. Moreover, we relied on participants' self-selection for the pilot study. Although we ensured anonymity in the responses, their choices and comments might have been influenced by having personally been in touch with the authors of this paper. The same limitation applies to the members of the advisory board.

Greenwashing

The tool cannot be used as a direct indicator of greenwashing. For instance, there might be specific company characteristics or regulatory contexts that explain the outcome. To more accurately capture greenwashing, the information disclosed should be compared with the information available in third-party datasets. This external information would allow users to properly verify whether what the company states aligns with its estimated transition and physical risk.[8]

Sector and country-specific assessments

In the current version, our tool compares the levels of ambition and the feasibility of implementing the transition strategy with global ambition goals and the internal consistency of the disclosed activities. However, for a more granular, appropriate assessment of ambition, sector-region-specific benchmarks would need to be applied. In addition, as highlighted by various researchers and think tanks currently working on credibility and feasibility assessments of transition plans,[9] Country-specific policies have a strong influence on the external feasibility drivers for corporate transition

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[8] Clearly, third-party datasets are not a perfect solution as they are often based on companies' disclosures and can contain mistakes. However, the comparison would represent an improvement relative to an assessment based on our tool only.

[9] See for example policy briefs from Shrimali, et al. 2024, and an increasing amount of sector-country specific transition plans assessments like the sector-specific assessments aligned with France's NDC (ADEME, 2024) or the guidelines for assessing transition plans by company sectors from the Transition Plan Taskforce (TPT, 2024).

strategies. As a next step, it would be desirable to ground the tool in more granular country and sector-region-specific information for a more fine-tuned analysis.

Data and Model

Our model is naturally confined by the language and the level of detail provided in the disclosures analyzed. For the present analysis, this entails two limitations. First, our study solely focuses on sustainability reports. Thus, we may miss relevant information that a company presents elsewhere. However, the tool is applicable to any textual source, and different sources could be combined to analyze one company. Second, as the human evaluation shows, the tool is very satisfactory but not perfect. This implies that our model should be used as a complement and not as a substitute for manual analysis and verification processes. This is also in line with our general expert-centric approach, where we aim to identify the most useful human-machine collaboration methods. In this regard, our tool can meaningfully support human efforts by reducing the manual workload and help focus on specific areas of interest where companies disclose least in the assessment.

Current set of indicators

Depending on the scope, users might want to include different indicators in the analysis. This might be particularly important if users want to focus on specific sectors for which only some of the identified indicators are relevant or new ones must be introduced. Similarly, more information on the supply chain might be desirable, particularly for transition strategies that go beyond climate risks and consider broader nature-related risks. While this is possible, and the tool can answer questions that are different from the pre-defined ones, the quality of answers needs to be more carefully checked as these new aspects would not have gone through our internal human evaluation process.

Methods

RAG Setup

To implement the RAG system, we use the LLama-Index software package. For the pipeline, we had to set a variety of parameters. Table 3 gives an overview of the RAG parameters.

For prompting the LLM, we rely on prior literature at the intersection of NLP and climate change[29]. The final RAG prompt requires basic information about the underlying company, which is directly retrieved with the prompt template shown in Figure 6. After retrieving the relevant information from the underlying report, the final prompt provided to the model is displayed in Figure 7 for a general question.

Parameter	Value
Chunk Size	350
Chunk Overlap	50
Top K Retrieval	8
Embedding	text-embedding-ada-002
Model	gpt-4-1106-preview
Answer Length	200

Table 3: RAG Parameters

As shown in Table 3, we prompt GPT-4 to obtain an answer as this model is the current state-of-the-art in evidence-based question-answering[28].

```
You are tasked with the role of a climate
     scientist and assigned to analyze a company's
     sustainability report. Based on the
     following extracted parts from the
     sustainability report, answer the given
     QUESTIONS.
If you don't know the answer, just say that you
     don't know by answering "NA". Don't try to
     make up an answer.

Given are the following sources:
--------------------- [BEGIN OF SOURCES]\n
{sources}\n
--------------------- [END OF SOURCES]\n

QUESTIONS:
1. What is the company of the report?
2. What sector does the company belong to?
3. Where is the company located?

Format your answers in JSON format with the
     following keys: COMPANY_NAME and
     COMPANY_SECTOR COMPANY_LOCATION.
Your FINAL_ANSWER in JSON (ensure there's no
     format error):
```

Figure 6: Prompt template to obtain basic information about the company.

```
You are a senior sustainability analyst with
     expertise in climate science evaluating a
     company's climate-related transition plan and
      strategy.

This is basic information to the company:
{basic_info}

You are presented with the following sources from
     the company's report:
--------------------- [BEGIN OF SOURCES]\n
{sources}\n
--------------------- [END OF SOURCES]\n

Given the source information and no prior
     knowledge, your main task is to respond to
     the posed question encapsulated in "||".
Question: ||{question}||

Please consider the following additional
     explanation to the question encapsulated in "
     +++++" as crucial for answering the question:
+++++ [BEGIN OF EXPLANATION]
{explanation}
+++++ [END OF EXPLANATION]

Please enforce the following guidelines in your
     answer:
1. Your response must be precise, thorough, and
     grounded on specific extracts from the report
      to verify its authenticity.
2. If you are unsure, simply acknowledge the lack
     of knowledge, rather than fabricating an
     answer.
3. Keep your ANSWER within {answer_length} words.
4. Be skeptical to the information disclosed in
     the report as there might be greenwashing (
     exaggerating the firm's environmental
     responsibility). Always answer in a critical
     tone.
5. Cheap talks are statements that are costless to
      make and may not necessarily reflect the
     true intentions or future actions of the
     company. Be critical for all cheap talks you
     discovered in the report.
6. Always acknowledge that the information
     provided is representing the company's view
     based on its report.
7. Scrutinize whether the report is grounded in
     quantifiable, concrete data or vague,
     unverifiable statements, and communicate your
      findings.
8. Start your answer with a "[[YES]]"" or ""[[NO]]
     "" depending on whether you would answer the
     question with a yes or no. Always compliment
     your judgment on yes or no with a short
     explanation that summarizes the sources in an
      informative way, i.e. provide details.

Format your answer in JSON format with the two
     keys: ANSWER (this should contain your answer
      string without sources), and SOURCES (this
     should be a list of the SOURCE numbers that
     were referenced in your answer).
Your FINAL_ANSWER in JSON (ensure there's no
     format error):
```

Figure 7: RAG prompt template enforcing structured output.

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Supplementary Information

S.1 Advisory board

For the development of the conceptual framework, the selection of the indicators and for pilot testing the tool, we rely on the knowledge of more than 50 external experts that were part of our advisory board and pilot study group. Although we cannot disclose the names of the members, the advisory board includes representatives from financial supervision, central banks, governmental organizations, NGOs, and industry practitioners.

S.2 Reviewed frameworks

The frameworks reviewed to identify the final list of indicators are displayed in Table S.1[33]. For each framework, the criteria used to assess transition disclosures were extracted and combined to identify a common ground.

Initiative	Year	Preparer	Focus	Assessment
ACT	2021	Corporates	Strategy	Ambition, credibility, feasibility
CSLN	2021	Financial institutions	Strategy	Disclosure, ambition, credibility
TCFD	2021	Corporates	Risk	Disclosure
UNEP-FI	2021	Financial institutions	Strategy	Ambition, credibility
WBA	2021	Corporates	Strategy	Feasibility
CPI	2022	Corporates	Strategy	Credibility
ESRS	2022	Corporates	Risk	Disclosure
GFANZ NZTP	2022	Financial institutions	Strategy	Disclosure, ambition, feasibility
GFANZ RETP	2022	Real economy corporates	Strategy	Disclosure
IFRS ISSB	2022	Corporates	Risk	Disclosure
NewClimate et al	2022	Corporates	Strategy	Disclosure, credibility
R2Z	2022	Corporates	Strategy	Ambition
SBTi FINZ	2022	Financial institutions	Strategy	Feasibility
TPI	2022	Corporates	Strategy	Ambition
TPT	2022	Corporates	Strategy	Disclosure
UN HLEG	2022	Corporates	Strategy	Ambition
WWF	2022	Corporates	Strategy	Credibility
CA100+	2023	High emitting corporates	Strategy	Disclosure, ambition
CBI CBS4	2023	Real economy corporates	Strategy	Disclosure, ambition, credibility
CDP	2023	Corporates	Strategy	Disclosure, ambition, credibility
IIGCC	2023	Corporates	Strategy	Credibility
NGFS	2023	Corporates, fin. institutions	Strategy, risk	Credibility
NZAOA	2023	Financial institutions	Strategy	Feasibility
OxSFG	2023	Real economy corporates	Strategy	Credibility
PwC et al	2023	Corporates	Strategy	Feasibility
RI	2023	Financial institutions	Strategy	Feasibility
SBTi Net Zero	2023	Corporates	Strategy	Ambition
WWF PtP	2023	Real economy corporates	Strategy	Ambition, feasibility

Table S.1: Transition plan frameworks assessed for the proposed credibility, ambition, and feasibility assessment framework.

S.3 Assessment indicators

Tables S.2-S.5 display the detailed indicators and their classification along two dimensions. First, we build on the widely known classification of companies' activities and merge them into Target, Governance, Strategy, and Tracking categories (building, e.g., on the initial classification by the TCFD, which has further evolved in the context of transition plan assessments). While this is of secondary importance for the underlying paper, it can help end users in their application cases. Second, we classify the indicators according to "Walk" and "Talk". Overall, we classify 34 of the 64 indicators as "Walk" and 30 as "Talk".

Identifier	Question	Walk or Talk
Target		
1	Does the company report an absolute GHG emission reduction target for the company?	T
2	If the company communicates GHG emission intensity targets, does the company show that the company's intensity targets are in line with its absolute emission targets?	T
3	Does the company report a company-wide net zero GHG emissions target?	T
4	Does the company state explicitly that it plans to achieve its net zero target until 2040 or 2050 at the latest?	T
5	Does the company state explicitly that it plans to cut its absolute GHG emissions by 50% (by half) until 2030 at the latest?	T
6	Does the company report its absolute emission target for the company's scope 1 GHG emissions?	T
7	Does the company report its absolute emission target for the company's scope 2 GHG emissions?	T
8	Does the company report its absolute emission target for the company's scope 3 GHG emissions?	T
9	Does the company report its GHG emission reduction interim targets for achieving the overall goal?	T
10	Does the company state explicitly that the interim targets are in line with specific 1.5-degree orderly sector transition pathways, which are based on front-loaded activities and no or limited emission overshoot?	T
11	If carbon credits and offsets are reported to be used by the company, does the company explicitly state that it will use them exclusively for residual unabatable emissions or beyond value chain mitigation support?	T
12	If carbon credits and offsets are reported to be used by the company, does the company state explicitly that carbon credits and offsets will be only used when the company can ensure that the emission reduction or emission avoidance is sustained permanently?	T

Table S.2: Final list of Target indicators selected and their classification.

Identifier	Question	Walk or Talk
Governance		
13	Does the company explain its governance structure for managing the climate transition?	T
14	Does the company explain how it ensures that the board members have the required skills to sign off and oversee the climate transition plan implementation?	T
15	Does the company report its available in-house skills and additional capacity needed to implement the climate transition plan?	T
16	Does the company report a strategy on how it aims to fill the additional skill and capacity needs required to implement its climate transition plan?	T
17	Does the company report how its board oversees the climate transition plan implementation?	T
18	Does the company report that it ensures that the company's board is informed at least quarterly about the progress against achieving the climate transition plan targets?	W
19	Does the company provide a higher share of remuneration and bonuses that are linked to the successful implementation of the climate transition plan interim targets compared to the general part of variable compensation for executives and managers?	W
20	Does the company report that the climate transition plan targets and information contained in the report have been subject to external assurance and validation?	T
21	Does the company state explicitly that it uses the same organizational boundaries for setting and achieving its climate targets as it does for financial accounting?	T

Table S.3: Final list of Governance indicators selected and their classification.

Identifier	Question	Walk or Talk
Strategy		
22	Does the company provide comprehensive evidence that it fully and completely integrates its climate strategy into its business strategy, product development, operations, financial and human resources, asset management, and asset decommissioning?	W
23	Does the company report quantitative or quantifiable sub-targets in line with their climate targets and their climate key performance indicators?	T
24	Does the company report the use of scenario envelopes to set targets and perform sensitivity analysis?	T
25	Has the company reported the key assumptions that form the basis of its transition plan?	T
26	Does the company report a renewable energy strategy and activities covering renewable energy build-out, procurement, and consumption?	W
27	Does the company report a strategy and activities for the expansion of and investments in climate solutions and climate solution technologies?	W
28	Does the company report its opex planning to ensure it meets its climate interim targets?	W
29	Does the company report its capex planning to ensure it meets its climate interim targets?	W
30	Does the company report its strategy and activities towards net zero aligned (or green) revenues?	W
31	Does the company report its strategy and activities to align all its Research and Development (R&D) activities with net zero targets?	W
32	Does the company report a strategy with specific activities and metrics of success for net zero engagement with its upstream value chain, i.e., with its suppliers?	T
33	Does the company report a strategy with specific activities and metrics of success for net zero engagement with its downstream value chain, i.e., with its customers or investees?	T
34	Does the company report an engagement strategy and activities with specific climate policies that it directly advocates for with policymakers?	W
35	Does the company report a strategy and activities with specific activities and engagement goals for net zero policies with industry associations?	W
36	Does the company report serious consequences and escalation strategies if net zero engagement is ineffective at upstream, downstream, policymaker, and industry association levels?	W
37	Does the company state explicitly that it stopped or will immediately stop any support or activities in new additional fossil fuel exploration and extension of fossil fuel supply?	W
38	Does the company report a strategy and activities for the decommissioning and canceling of planned or existing fossil fuel exploration and supply infrastructure?	W
39	Does the company report a strategy and activities to phase out its use and support of fossil fuel-consuming products and technologies?	W
40	Does the company report a strategy for a just transition, including monitoring and activities to mitigate adverse impacts of the net zero transition on its own workforce and indirectly affected workers and local communities?	T
41	Does the company report that it develops specific just transition plans with its own climate transition-affected workforce, local communities, and relevant stakeholders?	T
42	Does the company report a strategy and activities to mitigate adverse impacts on the natural environment and the provision of ecosystem services?	W
43	Does the company report a strategy and activities to halt and reverse deforestation by 2025?	W
44	Does the company report a strategy and activities to halt and reverse biodiversity loss by 2030?	W
45	Does the company report a strategy and activities to significantly reduce water consumption and pollution?	W

Table S.4: Final list of Strategy indicators selected and their classification.

Identifier	**Question**	**Walk or Talk**
Tracking		
46	Does the company report its scope 1 GHG emissions for the past year?	W
47	Does the company report its scope 2 GHG emissions for the past year?	W
48	Does the company report its scope 3 GHG emissions for the past year?	W
49	Does the company report the coverage of scope 3 categories included and the reasons for the exclusion of categories?	T
50	Does the company report its annual progress of reducing GHG emissions to achieve its emission reduction or net zero targets?	W
51	Does the company report its absolute scope 1 GHG emissions for the past 5 years?	W
52	Does the company report its absolute scope 2 GHG emissions for the past 5 years?	W
53	Does the company report its absolute scope 3 GHG emissions for the past 5 years?	W
54	Does the company report a decline in its scope 1 GHG emission intensity for the past 5 years?	W
55	Does the company report a decline in its scope 2 GHG intensity for the past 5 years?	W
56	Does the company report a decline in its scope 3 GHG intensity for the past 5 years?	W
57	Does the company report the specific drivers and reasons for the company's observed actual GHG emission changes?	T
58	Does the company report annual progress against its deforestation targets?	W
59	Does the company report the amount of climate-aligned capex that supports its net zero transition?	W
60	Does the company report the amount of climate transition misaligned capex?	W
61	Does the company report the amount of climate transition-aligned revenues that support the global net zero transition?	W
62	Does the company report the amount of climate transition misaligned revenues?	W
63	Does the company assess and report the alignment of its transition plan with its policy positions and its trade association's policy positions and lobbying?	T
64	Does the company report its engagement activities with the companies it invests in its own financial portfolio (including voting and proxy voting) undertaken in the relevant reporting period?	T

Table S.5: Final list of Tracking indicators selected and their classification.

S.4 Disclosed indicators

In Figures S.1-S.4, we depict the number of disclosed indicators in the four different categories (Target, Governance, Strategy, and Tracking) for the CA100+ companies. We see that indicators are disclosed across all categories and that there is a wide divergence in the coverage of indicators within each category. As highlighted in the main text, the main difference in the disclosures relates to walk and talk indicators. The most and least disclosed indicators are also described and discussed in the main text.

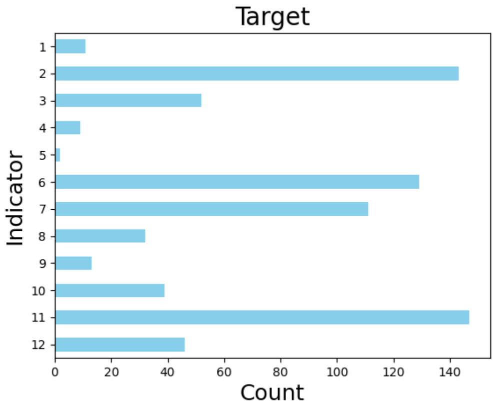

Figure S.1: Disclosed indicators in the Target group.

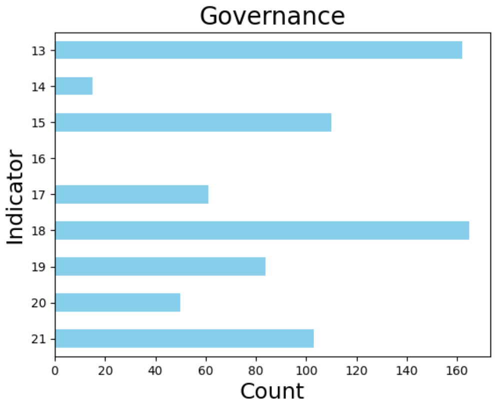

Figure S.2: Disclosed indicators in the Governance group.

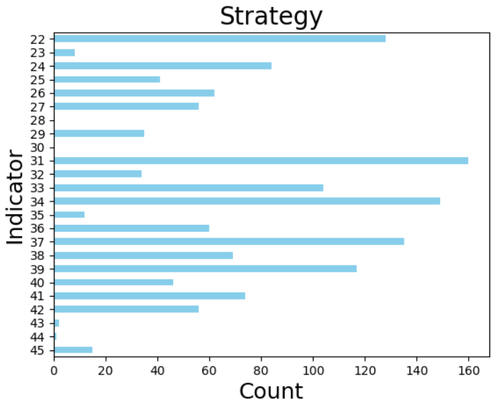

Figure S.3: Disclosed indicators in the Strategy group.

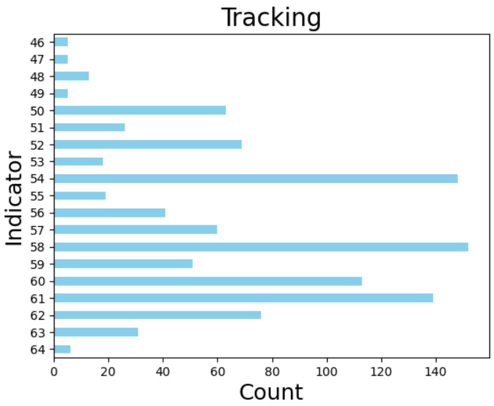

Figure S.4: Disclosed indicators in the Tracking group.

S.5 Expert-Centric Question Extension

The analysis of the answers initially provided by the tool revealed one particular disadvantage of generic RAG systems. Individual questions might be too vague, and the model's interpretation of the question might lead to an unsatisfactory outcome. Hence, we extended the prompt provided to the LLM with expert-centric knowledge and details. In essence, these extensions provide guidelines on how the model should answer the questions and the information that it should take into account when assessing the available information. They can contain restrictions, focus areas of the question, or extended explanations of some concepts. They are the result of an iterative process analyzing several responses of the model for each individual indicator. In this process, we build on the distinctive advantage of LLMs to process expert feedback and incorporate it into their answers.

Figure S.5 offers an example of such guidelines. It shows that we ask the model to follow specific restrictions. In most cases, the guidelines require the model to be more conservative or focus on specific aspects.

```
QUESTION: Does the company state explicitly that
     it plans to achieve its net zero target by
     2040 or 2050 at the latest?

QUESTION EXTENSION: Answer with "YES" if this is
     the case and "NO" otherwise. Summarize the
     timeframe for which the net zero target is to
      be achieved if this information is stated.
     Otherwise, if the company, in general, does
     not have a net zero target, state that the
     company has no net zero targets, and
     therefore, it also has no goal to achieve net
      zero by 2040 or 2050 at the latest. If the
     company has a net zero target but no
     timeframe for the achievement is reported,
     report the target and state that there is no
     year reported until the company aims to
     achieve its net zero targets. Focus on
     summarizing the relevant information, and do
     not judge the ambition, feasibility, or
     credibility of the target. Do not reference
     the sources and the chunks in the summary
     answer.
```

Figure S.5: Example of a question guideline.

The complete list of questions and extensions can be found in Tables S.6-S.9.

S.6 Answer Explanation and Sources Reported

While the dominant focus of this work lies on exploring the (non-)disclosure of the assessment indicators, the NLP tool also produces two important pieces of information: an answer explanation and the sources of the information used in the answers. The answer explanation can provide the user with a deeper understanding of the verdict. Together with the sources, it can help the user validate or investigate the underlying report further. This considerably increases the transparency of the approach. Users can check whether the NLP tool truly bases its answers on actual information available in the disclosure and accurately represents information or can use the tool to ease their search process for context and further information within the document itself.

Figure S.6 shows a typical answer. The first piece of information is the final verdict. Although the company does not disclose a target for reducing scope 3 GHG emissions, it discloses information about recycling materials or reducing their battery carbon footprint. This level of detail, combined with the sources, returns a more holistic assessment of the indicators.

```
QUESTION: Does the company report its absolute
     emission target for the company's scope 3 GHG
      emissions?

ANSWER: [[NO]] The company does not explicitly
     report its absolute emission reduction
     targets for scope 3 GHG emissions. The
     sources provided discuss various strategies
     and targets related to reducing the company's
      carbon footprint, such as reducing battery
     carbon footprint, increasing the use of
     recycled materials, and reducing emissions in
      their parts and materials supply chain.
     However, these targets are not explicitly
     categorized under Scope 3 emissions, nor is
     there a clear absolute emission reduction
     target for Scope 3 emissions. The targets
     mentioned are either related to scope 1 and 2
      emissions, such as emissions at their sites,
      or are not clearly defined in terms of scope
      categorization. Therefore, no explicit Scope
      3 absolute emission reduction target could
     be identified.

SOURCE PAGES (ordered by importance): 21, 20, 19
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Figure S.6: Example of an answer explanation and sources reported.

Question	Expert-Centric Question Extension
Target	
Does the company report an absolute GHG emission reduction target for the company?	Focus only on absolute emission reduction targets. Be aware that a net zero target or a carbon neutrality target can be counted as an absolute emission reduction target. If only a net zero target or a carbon neutrality target is reported, state that it is counted as an absolute emission reduction target in the given analysis but that the effective absolute reduction in emissions needs to be carefully assessed. Also, be aware that statements "reducing emissions to return to 2020 levels" are also absolute emission reduction targets, although they are indirectly formulated. Answer with "YES" if the company reports an absolute emission target and with "NO" otherwise. Be aware that intensity targets are not absolute emission reduction targets. Intensity targets are, for example, efficiency targets and targets that aim to reduce the amount of emissions relative to another economic or physical metric (for example dollars, or kilometers driven). If only intensity targets are mentioned in the report, add them to your answer, but state that these are not absolute emission reduction targets. Do not include past targets that have been achieved in your response. Do not provide a summarizing sentence at the end of your response, and do not speculate whether a certain target is an indicator for climate action or supportive of any other climate goals.
If the company communicates GHG emission intensity targets, does the company show that the company's intensity targets are in line with its absolute emission targets?	Focus on GHG emission intensity targets. If no intensity targets are communicated, state that you did not find GHG emission intensity targets in the document. If no intensity targets are communicated, state "N/A". If intensity targets are communicated, state "YES" if they are shown to be in line with the absolute emission intensity targets. If no absolute emission targets are reported, or if the intensity targets are not shown to be in line with the absolute emission targets, state "NO". If there are other intensity targets reported, for example, energy intensity targets or sectoral materials-related intensity targets, summarize them in your response, but do not consider them for the overall Yes/No assessment.
Does the company report a company-wide net zero GHG emissions target?	Focus on the simple presence of a net zero target for the reporting company. Do not include other targets, strategies, or activities that the company undertakes. If the company is part of a net zero alliance, you mention it but clearly state that you did not identify an own net zero target for the company and that a clear company-wide commitment to net zero is missing in the report. Do not judge the activities or the target in terms of greenwashing, climate goal alignment, or seriousness. Just summarize the information you find on net zero targets and net zero commitments. Be aware that carbon neutrality goals are also net-zero targets. If the company has net zero targets for parts of its operations or supports net zero targets in its value chain but does not have its own net zero target, summarize the targets but state that it is not a target from the company. State "YES" if a company-wide net zero or carbon neutrality target is reported. State "NO" if no net zero or carbon neutrality target is reported.
Does the company state explicitly that it plans to achieve its net zero target by 2040 or 2050 at the latest?	Answer with "YES" if this is the case, and "NO" otherwise. Summarize until which timeframe the net zero target is to be achieved if this information is stated. Otherwise, if the company in general does not have a net zero target, state that the company has no net zero target, and therefore, it also has no goal to achieve net zero by 2040 or 2050 at the latest. If the company has a net zero target, but no timeframe for the achievement is reported, report the target and state that there is no year reported until when the company aims to achieve its net zero targets. Focus on summarizing the relevant information, and do not judge the ambition, feasibility, or credibility of the target. Do not reference the sources and the chunks in the summary answer.

Question	Expert-Centric Question Extension
Target	
Does the company state explicitly that it plans to cut its absolute GHG emissions by 50% (by half) until 2030 at the latest?	No additional guidelines
Does the company report its absolute emission target for the company's scope 1 GHG emissions?	Bear in mind that scope 1 emissions are any direct GHG emissions from a company, for example emitted in its production processes, or via direct heat and energy production on site by the company. State "YES" if there are absolute emission reduction targets reported for scope 2 emissions of the company. State "NO" otherwise. If there is just a combined scope 1 and scope 2 target reported, state this in your summary, but clarify that it is a combined target, and therefore, no explicit scope 1 absolute emission reduction target could be identified.
Does the company report its absolute emission target for the company's scope 2 GHG emissions?	Bear in mind that scope 2 emissions are any indirect GHG emissions from a company's purchased energy for electricity, heating, or cooling. These emissions are usually operation-related emissions. State "YES" if there are absolute emission reduction targets reported for scope 2 emissions of the company. State "NO" otherwise. If there is just a combined scope 1 and scope 2 target reported, state this in your summary, but clarify that it is a combined target, and therefore, no explicit scope 2 absolute emission reduction target could be identified.
Does the company report its absolute emission target for the company's scope 3 GHG emissions?	Bear in mind that scope 3 emissions are any GHG emissions in a company's value chain, beyond its direct operational control. This includes upstream and downstream activities and processes. It mainly includes the use of company's products, the emissions of financed projects and businesses beyond its own operations, the emissions embodied in its purchased goods and services, the emissions from business travels, and others. State "YES" if there are absolute emission reduction targets reported for scope 3 emissions of the company. State "NO" otherwise. If there is just a combined scope 1, scope 2 and scope 3 target reported, state this in your summary, but clarify that it is a combined target, and therefore, no explicit scope 3 absolute emission reduction target could be identified. Do not judge the presence or absence of the scope 3 emissions target. Do not provide information on the sources and chunks in the written summary.
Does the company report its GHG emission reduction interim targets for achieving the overall goal?	Bear in mind that GHG emission reduction interim targets are targets that the company aims to achieve to ensure it achieves its overall emission target. Interim targets provide a way to measure and evaluate the effectiveness of mitigation efforts and can enhance the credibility of long-term goals. If interim goals are reported, state "YES". State "NO" otherwise. Do not judge the ambition or credibility of the interim goals.
Does the company state explicitly that the interim targets are in line with specific 1.5 degrees orderly sector transition pathways, which are based on frontloaded activities and no or limited emission overshoot?	No additional guidelines

Question	Expert-Centric Question Extension
Target	
If carbon credits and offsets are reported to be used by the company, does the company explicitly state that it will use them exclusively for residual unabatable emissions or beyond value chain mitigation support?	Answer with "YES" if this is the case. Answer with "NO" if the company report mentions the use of carbon offsets or carbon credits, but does not include an explicit statement that the company will use them exclusively for residual unabatable emissions or beyond value chain mitigation support. Answer with "N/A" if the company does not plan to use carbon offsets, or if the information about the use of carbon credits and carbon offsets is not available. Justify in the summary why you came to the conclusion that YES, NO or N/A are the correct answers to the question.
If carbon credits and offsets are reported to be used by the company, does the company state explicitly that carbon credits and offsets will be only used when the company can ensure that the emission reduction or emission avoidance is sustained permanently?	Answer with "YES" if this is the case. Answer with "NO" if the company report mentions the use of carbon offsets or carbon credits, but does not include an explicit statement that the company will use them only when the company can ensure that the emission reduction or emission avoidance is sustained permanently. Answer with "N/A" if the company does not plan to use carbon offsets, or if the information about the use of carbon credits and carbon offsets is not available. Justify in the summary why you came to the conclusion that YES, NO or N/A are the correct answers to the question.

Table S.6: Expert-centric question extensions for Target questions.

Question	Expert-Centric Question Extension
Governance	
Does the company explain its governance structure for managing the climate transition?	Answer with "YES" if information is available on for example board-level committees with climate responsibilities, a climate representative at/or reporting to the executive/board level, a clear team responsible for climate projects, reporting and disclosures. Answer with "NO" if there is no information about the company's governance structure for the climate transition.
Does the company explain how it ensures that the board members have the required skills to sign off and oversee the climate transition plan implementation?	No additional guidelines
Does the company report its available inhouse skills and additional capacity needs to implement the climate transition plan?	No additional guidelines
Does the company report a strategy on how it aims to fill the additional skill and capacity needs required to implement its climate transition plan?	No additional guidelines
Does the company report how its board oversees the climate transition plan implementation?	No additional guidelines
Does the company report that it ensures that the company's board is informed at least quaterly about the progress against achieving the climate transition plan targets?	No additional guidelines
Does the company provide a higher share of remuneration and bonuses that are linked to the successful implementation of the climate transition plan interim targets compared to the general part of variable compensation for executives and managers?	Provide specific examples of executive management remuneration linked to progress towards achievement of transition plan interim targets. Specify how the percentage linked to the progress towards and achievement of transition plan interim targets compares to the variable compensation in general. Answer with "YES" if the share of climate-related variable compensation compared to non-climate-related variable compensation is higher. If there is only information available about variable remuneration for climate targets in general, or if the share of climate-related variable compensation is not higher than the overall variable compensation, state this information and answer with "NO."
Does the company report that the climate transition plan targets and information contained in the report have been subject to external assurance and validation?	Provide specific examples of defined assurance and verification levels of the transition plan and statements by third parties. Focus on climate assurance and verification only. Consider Second Party Opinions (SPOs) as verification by a third party. Target validation by the Science-based targets initiative should be counted as an external validation of the transition plan targets. If a third party validation is reported, or the organisation that provides the third party valiation is stated, answer with "YES". If the report only states information about reporting initiatives like CDP, TCFD and GRI, state "NO". Do not include reporting and disclosure frameworks and voluntary initiatives in the answer.
Does the company state explicitly that it uses the same organizational boundaries for setting and achieving its climate targets as it does for financial accounting?	No additional guidelines

Table S.7: Expert-centric question extensions for Governance questions.

Question	Expert-Centric Question Extension
Strategy	
Does the company provide comprehensive evidence that it fully and completely integrates its climate strategy into its business strategy, product development, operations, financial and human resources, asset management, and asset decommissioning?	Provide specific examples of how the company's climate strategy is integrated into its business strategy, product development, operations, financial and human resources, asset management, and asset decommissioning. Focus on aspects related to the climate transition, and not on other sustainability or nature-related topics. Do not rephrase the company's climate or sustainability targets. Instead, look for information that shows how the company implements these targets into the core of the company's strategy, activities and management. If you find this information, summarize it and answer with "YES". Do not judge whether the activities are sufficient. If you find only partial information, summarize the information, answer with "NO" and highlight that additional information would be required to assess whether the company fully integrates its climate strategy across its activities.
Does the company report quantitative or quantifiable subtargets in line with their climate targets and their climate key performance indicators?	Provide information about the specific quantifiable subtargets that the company has identified to achieve their climate targets and climate key performance indicators, the time scale (if provided), and scope. State explicitly if the time scale or the application scope of the subtarget is missing. Answer "YES" if you find quantitative or quantifyable subtargets, and state the targets explicitly. Answer "NO" otherwise.
Does the company report the use of scenario envelopes to set targets and perform sensitivity analysis?	Provide specific examples of the scenarios, model ensembles and scenario envelopes used by the company to set targets and perform targets and pathways sensitivity analysis. Also include the time scale and scope of the scenario analyses. State whether the company makes reference to model constraints and whether it is aware of the limitations of modelling, and the need for resilience planning. If you find information about the use of multiple scenarios, model families or scenario envelopes directly linked to the targets and the plans to implement the targets, answer "YES". If you only find such information in terms of how the company assesses its climate risk exposure, answer "NO" and state that the company uses multiple scenarios, but it does not seem to use scenario enveloped to set its climate targets and identify a resilient strategy to achieve the targets.
Has the company reported its key assumptions that form the basis of its transition plan?	Provide specific examples of the strategic assumptions that the company reports as basis of its transition plans. These could include for instance assumptions about the development of consumer preferences, input prices, sector policies, economic development, and others. Answer "YES" if you find information about the assumptions underlying the transition plan. Answer "NO" if you do not find this information.
Does the company report a renewable energy strategy and activities, covering renewable energy build out, procurement and consumption?	Provide specific examples of how the company plans to increase renewable energy build out, procurement and consumption. If you find such examples and ideally a strategy, answer "YES". If the company does not report activities to expand renewable energies, answer "NO". Focus only on specific renewable energy activities, and do not include general net zero emission targets or further activities of the company for climate action in this answer.
Does the company report a strategy and activities for the expansion of and investments in climate solutions and climate solution technologies?	Focus on strategies that focus on forward-looking and future investment in specific climate solutions. This includes, but is not limited to, research and development (R&D), investing in early stage climate solutions, or acquisitions and substantial capital provision to scale up the climate solutions branch of the company's business. Do not repeat what the company has been doing in the past. Do not include general statements about the climate targets of the company. If you find specific information about how the company supports the expansion of climate solution technologies, answer "YES" and summarize the specific activities it undertakes, the specific technologies it focuses on, the interim targets it identifies, and the associated timeframe. If you do not find information about the specific climate solutions support by the company, answer "NO" and explain that there is no information future investmens or R&D to support the build-out of climate solutions available.
Does the company report its opex planning to ensure it meets its climate interim targets?	Focus on quantified targets and achievements, including how the company plans to shift opex to be aligned with the climate targets, the climate strategy and the specific interim targets. If you find information about how the company aligns its opex with the climate targets, reply "YES". If available, provide the quantitative information about the amount and timeframe towards full alignment of opex with the climate targets. If you do not find opex information, or if opex information is available but it is not shown to be aligned with the strategies to achieve the climate targets, answer "NO".

Question	Expert-Centric Question Extension
Strategy	
Does the company report its capex planning to ensure it meets its climate interim targets?	Focus on quantified targets and achievements, including how the company plans to shift capex to be aligned with the climate targets, the climate strategy and the specific interim targets. If you find information about how the company aligns its capex with the climate targets, reply "YES". If available, provide the quantitative information about the amount and timeframe towards full alignment of capex with the climate targets. If you do not find capex information, or if capex information is available but it is not shown to be aligned with the strategies to achieve the climate targets, answer "NO".
Does the company report its strategy and activities towards net zero aligned (or green) revenues?	Focus on quantified targets and achievements for the company's own revenues, including its products and services, and how they plan to shift away from net zero emissions misaligned sources of revenues. If you only find a collection of business activities, but not a fully developed strategy on how to align all revenues of the company with the company's climate targets, answer "NO". If the company reports a plan to align all its revenues with its climate targets, state "YES". Do not include targets to align clients' revenues with the climate goals. Focus on the company's own revenue strategy. Do not include the cost-side of the profits, for example renewable energy purchases or energy efficiency. Focus on the climate alignment of the revenues that the company generates from its products and services.
Does the company report its strategy and activities to align all its Research and Development (R&D) activties with net zero targets?	Focus on strategies specific to Research and Development, do not summarize general net zero targets or general activties. If the company does not report on R&D expenditures, if it is not active in R&D, or if the R&D expenditures are not fully or only partially aligned with net zero targets, state "NO". If the company provides information how it aligns all its R&D activties with net zero targets, state "YES".
Does the company report a strategy with specific activities and metrics of success for net zero engagement with its upstream value chain, i.e. with its suppliers?	Provide specific information about the company's supplier engagement strategy, including actual engagement activities with its suppliers and metrics for success. Do not reference general net zero targets or general scope 1 scope 2 or scope 3 targets. Do not include customer engagements, focus on the company's suppliers. State "YES" if a specific strategy with specific activities and metrics for success is reported. State "NO" if the company does not report its upstream value chain strategy, or if the value chain engagement is not associated with specific activities.
Does the company report a strategy with specific activities and metrics of success for net zero engagement with its downstream value chain, i.e. with its customers or investees?	Provide specific information about the company's customer or investee engagement strategy, including actual engagement activities with its customers or investees and metrics for success. Do not reference general net zero targets or general scope 1 scope 2 or scope 3 targets. Do not include supplier engagements, focus on the company's customers or investees. State "YES" if a specific strategy with specific activities and metrics for success is reported. State "NO" if the company does not report its upstream value chain strategy, or if the value chain engagement is not associated with specific activities.
Does the company report an engagement strategy and activities with specific climate policies that it directly advocates for with policy makers?	Provide specific activities of policy maker engagement and the policies advocated for. Do not include general activties and engagements with clients or suppliers. Focus on active engagement with policy makers and political stakeholders. Include public speaking and public positioning for the climate policies needed. Do not include event attendance and indirect support via business organisations or business initiatives. If there is information about specific climate policies that the company advocates for with policy makers, state "YES". If there is no information about policy maker engagements, or if the information lacks information about specific climate policies, state "NO".
Does the company report a strategy and activities with specific activities and engagement goals for net zero policies with industry associations?	Identify specific activities with industry associations and industry groups where the company is a member, to align the industry associations' policy positions with the net zero transition. Provide specific information on where the company leads within an industry group, for example by chairing a committee or sitting on the steering committee. Provide information about the company's activities and specific policy goals that it advocates for. Do not include the company's own climate targets. Answer "YES" if a strategy with specific engagement goals and activities is defined. Answer "NO" if there is no information about engagements within the industry associations, or if the informatiom does not include specific activities and policy goals.

Question	Expert-Centric Question Extension
Strategy	
Does the company report serious consequences and escalation strategies if net zero engagement is ineffective at upstream, downstream, policy maker and industry association level?	Do not include general climate targets or the company's overall climate goals and activities. Do not reference the company's general climate engagement. Instead, focus on whether the company defines specific and serious escalation activities for the case of ineffective engagements. Provide specific examples for each level (upstream, downstream, policy makers and industry associations). Answer "YES" if you find specific information about consequences and escalation plans or activities of the company if its engagement with suppliers, customers, policy makers or industry associations is not successful. Include information about the measurement of unsuccessful, and the timeline for engagement until when the company uses its escalation activities. Examples of consequences and escalations for unsuccessful engagements are quitting contracts, no renewal of business relations, divesting, leaving an industry organisation, and others.
Does the company state explicitly that it stopped or will immediately stop any support or activities in new additional fossil fuel exploration and extention of fossil fuel supply?	Include and summarize statements for coal, oil and gas into the answer. If you only find a committment for coal, state this, but answer with "NO", and explain that it would need to include also a statement on oil and gas. If the company states explicitly that it already stopped or will stop supporting additional fossil fuel exploration or the extention of fossil fuel supply, answer "YES".
Does the company report a strategy and activities for the decommissioning and canceling of planned or existing fossil fuel exploration and supply infrastructure?	Provide specific information where available. Do not inclue landscape restoration activities for decommissioned sites, and the general decommission process. Reply "YES" if the company commits to decommission or cancel all existing or planned fossil fuel projects. Reply "NO" if the company only states that it has decommissioned some specific sites but there is no evidence of a structural committment that applies to all planned or existing fossil fuel infrastructure of the company.
Does the company report a strategy and activities to phase out its use and support of fossil fuel consuming products and technologies?	Specify whether the company has a defined strategy and time-bound goal for their product changes. Phase out means reducing these products to zero over time, highlight how the company sets interim targets towards this goal. Focus on end consumer products like combustion engine cars, and on business to business products like manufacturing equipment and technology. If you find comprehensive information about how the company aims to phase out its own use and the support of fossil fuel consuming products and technologies, ideally including a timeframe, state "YES". If you only find information about general policies of the company to reduce or partially halt the use and support of fossil fuel-consuming products and technologies, state "NO".
Does the company report a strategy for a just transition, including monitoring and activities to mitigate adverse impacts of the net zero transition on its own workforce and indirectly affected workers and local communities?	Do not include general climate targets of the company, and general activties. Focus on specific just transition strategies that the company defines, and how it monitors the effects of the transition on possibly affected own workers and indirectly affected workers and local communities. Reply "NO" if there is only general information about the importance of the transition for local communities available. Reply "YES" if the information is specific and showcases a well developed strategy to manage the transition in a fair and equitable manner.
Does the company report that it develops specific just transition plans with its own climate transition affected workforce, local communities and relevant stakeholders?	Do not include general climate targets of the company, and general activties. Focus on specific existing plans or plans under development that the company developed explicitly together with its affected own workers and indirectly affected workers and local communities. Reply "NO" if there is only general information about the importance of the transition for local communities available. Reply "YES" if the information is specific and showcases plans that have been developed with the affected parties to manage the transition in a fair and equitable manner.
Does the company report a strategy and activities to mitigate adverse impacts on the natural environment and the provision of ecosystem services?	Ensure that you only reply "YES" if there is a specific strategy with associated activities reported on how the company deals with adverse impacts on the natural environment and the provision of ecosystem services. If there is only information available about various nature initiatives or a loose collection of some project examples, summarize these activties, but reply "NO" and explain that a comprehensive strategy is not defined. Do not include general climate or ESG strategies and actvities of the company.
Does the company report a strategy and activities to halt and reverse deforestation by 2025?	Look for time-bound, specific goals, associated activities, and metrics to measure success. If there is a strategy available, reply "YES". If the company reports only some activities without a broader strategy that covers all its businesses, reply "NO".

Question	Expert-Centric Question Extension
Strategy	
Does the company report a strategy and activities to halt and reverse biodiversity loss by 2030?	Look for time-bound, specific goals, associated activities, and metrics to measure success. If there is a strategy available, reply "YES". If the company reports only some activities without a broader strategy that covers all its businesses, reply "NO".
Does the company report a strategy and activities to significantly reduce water consumption and pollution?	Look for time-bound, specific goals, associated activities, and metrics to measure success. If there is a strategy available, reply "YES". If the company reports only some activities without a broader strategy that covers all its businesses, reply "NO".

Table S.8: Expert-centric question extensions for Strategy questions

Question	Expert-Centric Question Extension
Tracking	
Does the company report its scope 1 GHG emissions for the past year?	Do not include general emission targets or climate goals of the company. Focus on the actual scope 1 GHG emissions that the company has emitted. Include the precise figures of the emitted scope 1 GHG emissions that the company reports. Reply "YES" if the precise quantitative information for the scope 1 GHG emissions is available. Reply "NO" otherwise. If available, include the information on the calculation approach or approaches that have been applied by the company.
Does the company report its scope 2 GHG emissions for the past year?	Do not include general emission targets or climate and renewable energy goals of the company. Focus on the actual scope 2 GHG emissions that the company has emitted. Include the precise figures of the emitted scope 2 GHG emissions that the company reports. Reply "YES" if the precise quantitative information for the scope 2 GHG emissions is available. Reply "NO" otherwise. If available, include the information on the calculation approach or approaches that have been applied by the company.
Does the company report its scope 3 GHG emissions for the past year?	Do not include general emission targets or general climate goals of the company. Focus on the actual scope 3 GHG emissions that the company has emitted. Include the precise figures of the emitted scope 3 GHG emissions that the company reports. Reply "YES" if the precise quantitative information for the scope 3 GHG emissions is available. Reply "NO" otherwise. If available, include the information on the calculation approach or approaches that have been applied by the company.
Does the company report the coverage of scope 3 categories included, and reasons for the exclusion of categories?	Focus on the coverage of the scope 3 emission categories as outlined by the GHG protocol, namely purchased goods and services, capital goods, fuel- and energy-related activities, transportation and distribution, waste generated in operations, business travel, employee commuting, leased assets, processing of sold products, use of sold products, end of life treatment of sold products, franchises, and investments. State "YES" if the company explicitly explains which categories it included and which categories it did not include, as well as why. State "NO" if you only find information about some categories included, but no additional information on the reasons why the other categories have been excluded. Include information on the challenges and possible solutions that companies apply to improve the categories coverage in the future.
Does the company report its annual progress of reducing GHG emissions to achieve its emission reduction or net zero targets?	Do not summarize the general climate and emission targets of the company. Focus on the precise information about the progress of its quantified GHG emission reductions, and whether this progress is in line with its general climate, emission or net zero target. If you only find information about the general climate targets of the company, answer "NO". If you find the precise information about the emission reductions so far, and whether this is in line with how the company expects to achieve its climate, emission or net zero targets, answer "YES".
Does the company report its absolute scope 1 GHG emissions for the past 5 years?	Acknowledge the fact that this information could also be conveyed in graphs and tables which you are not able to fully analyse. Answer "YES" if you find the precise quantitative information about the company's scope 1 GHG emissions for the past 5 years. Answer "NO" if you do not find quantitative information or if the information does not cover the full 5 year period.
Does the company report its absolute scope 2 GHG emissions for the past 5 years?	Acknowledge the fact that this information could also be conveyed in graphs and tables which you are not able to fully analyse. Answer "YES" if you find the precise quantitative information about the company's scope 2 GHG emissions for the past 5 years. Answer "NO" if you do not find quantitative information or if the information does not cover the full 5 year period.
Does the company report its absolute scope 3 GHG emissions for the past 5 years?	Acknowledge the fact that this information could also be conveyed in graphs and tables which you are not able to fully analyse. Answer "YES" if you find the precise quantitative information about the company's scope 3 GHG emissions for the past 5 years. Answer "NO" if you do not find quantitative information or if the information does not cover the full 5 year period.
Does the company report a decline in its scope 1 GHG emission intensity for the past 5 years?	Acknowledge the fact that this information could also be conveyed in graphs and tables which you are not able to fully analyse. Answer "YES" if you find the precise quantitative information about the company's scope 1 GHG emission intensity declining for the past 5 years. Answer "NO" if you do not find quantitative information, if the information does not deal with emission intensity, or if the information does not cover the full 5 year period.

Question	Expert-Centric Question Extension
Tracking	
Does the company report a decline in its scope 2 GHG intensity for the past 5 years?	Acknowledge the fact that this information could also be conveyed in graphs and tables which you are not able to fully analyse. Answer "YES" if you find the precise quantitative information about the company's scope 2 GHG emission intensity declining for the past 5 years. Answer "NO" if you do not find quantitative information, if the information does not deal with emission intensity, or if the information does not cover the full 5 year period.
Does the company report a decline in its scope 3 GHG intensity for the past 5 years?	Acknowledge the fact that this information could also be conveyed in graphs and tables which you are not able to fully analyse. Answer "YES" if you find the precise quantitative information about the company's scope 3 GHG emission intensity declining for the past 5 years. Answer "NO" if you do not find quantitative information, if the information does not deal with emission intensity, or if the information does not cover the full 5 year period.
Does the company report the specific drivers and reasons for the company's observed actual GHG emission changes?	Do not include information about general climate or emission targets and activities of the company. Focus on the specific reasons spelled out by the company to explain why there has been an increase or decrease in emissions or emission intensity in the past until recently. State "NO" if you only find information about general emission reductions without linking them precisely with specific information about the relative importance to specific drivers of the change. State "YES" if such drivers and reasons for the emission change are explained, and if the information contains the quantified relative share of the drivers that is responsible for the decline or increase in the emissions.
Does the company report annual progress against its deforestation targets?	No additional guidelines
Does the company report the amount of climate aligned capex that supports its net zero transition?	No additional guidelines
Does the company report the amount of climate transition misaligned capex?	No additional guidelines
Does the company report the amount of climate transition aligned revenues that support the global net zero transition?	If you find information about the revenues from specific climate-related business branches of the company, summarize this information, but state "NO" if you do not find information about the full scale of the revenues that are climate transition aligned. State "YES" if you find specific information about the share of climate transition aligned revenues of the company in the recent past.
Does the company report the amount of climate transition misaligned revenues?	No additional guidelines
Does the company assess and report the alignment of its transition plan with its policy positions and its trade association's policy positions and lobbying?	No additional guidelines
Does the company report its engagement activities with the companies it invests in its own financial portfolio (including voting and proxy voting) undertaken in the relevant reporting period?	No additional guidelines

Table S.9: Expert-centric question extensions for Tracking questions

S.7 Human Evaluation

The human evaluation is structured to obtain insights into system quality, trustworthiness, and tool usage. This evaluation aims to collect qualitative, expert-based feedback. Thus, it does not represent an objective assessment, but it should inform users about expectations about the tool, applications, and potential improvement areas.

We designed two sets of questions. The first set of questions addresses the tool's performance on individual indicators. The tool processes items, i.e. question-answer-pairs corresponding to each indicator. As displayed in Table S.10, we ask for a range of questions about the quality of the answers provided by the tool for individual indicators (Q1-Q9). Furthermore, we ask the participants to assess the general impression and tool performance (Q10-Q15) (see Table S.11). Participants were asked to choose one option amongst the available ansers, i.e. multiple answers were not allowed. These questions can be mapped into the system quality, trustworthiness, and usage dimension as displayed in Table S.10.

As described in the text, for the pilot study we invite participants from 26 organizations spanning regulators/supervisors, banks, industry associations, NGOs, exchanges, academics, and investors. The participants stem from all over the world with a dominance in Europe. See Figure 2 for more details.

We ask every participant to submit at least three self-selected reports to the pilot study. Participants are also allowed to submit more than three reports. This aims to ensure that the experts also have prior interest and experience in analyzing the underlying companies. As a result, we obtain 93 reports from our participants. Figure S.7 shows the details of sectors and regions of the companies under investigation as well as the types and years of the report.

After submission, we analyze every report with our NLP tool. Then, we randomly assign the participants two indicators to assess from the sample of six most important indicators (see main text). Thus, the participants analyze at least two indicators for each of the three reports. Participants are allowed to assess more than the assigned indicator.

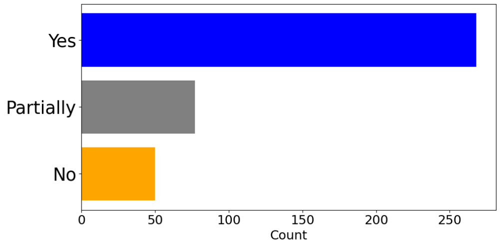
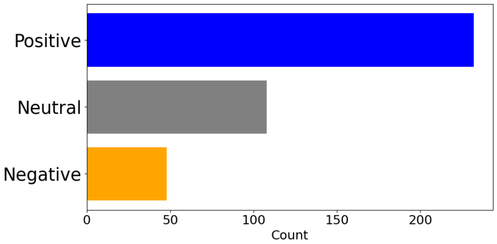
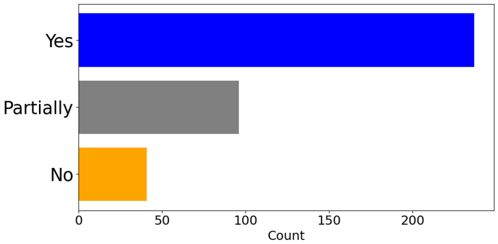
As a result of this process, we obtain 26 tool assessments and 396 indicator assessments. Table S.12 and S.13 show the detailed results. Overall, the tool reaches a very satisfactory performance. However, the participants also outline future improvement potentials.

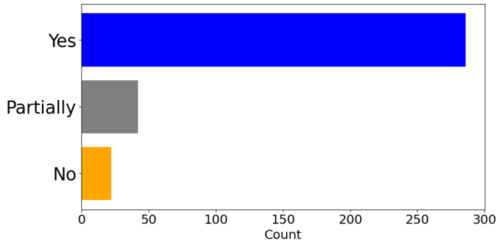
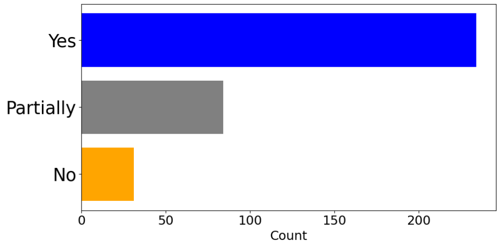
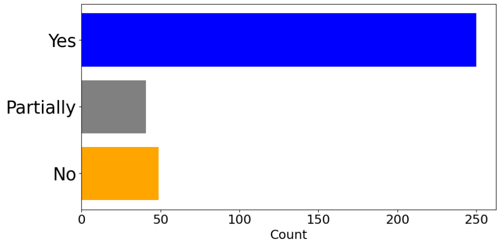
Question	Answer Options	Quality Dimension
Q1: If you had to answer the question, would you know what information to look for in a report?	- Yes - No - Partially	Usage
Q2: What is your first impression of the answer?	- Positive - Negative - Neutral	Usage, Trustworthiness
Q3: Does the model only summarize relevant content from the report to answer the question?	- Yes - No - Partially	System Quality
Q4: Does the model summarize relevant content correctly without making up information not contained in the report?	- Yes - No - Partially	System Quality
Q5: Do the sources provided support your trust in the model?	- Yes - No - Partially	Trustworthiness
Q6: Does the model cite all the information summarised from the report in the answer?	- Yes - No - Partially	System Quality
Q7: Does the model only cite pages from the report, which it uses to answer the question?	- Yes - No - Partially	System Quality
Q8: Does the model cite all the pages you think are most important to answer this question?	- Yes - No - Partially	System Quality
Q9: Does the model cite pages, which do not exist at all in the report?	- Yes - No - Partially	System Quality

Table S.10: Indicator assessment for the NLP tool answers by individual indicator.

Question	Answer Options	Quality Dimension
Q10: How do you like the tool in general?	- Very much - Somewhat - Not at all	Usage, Trustworthiness
Q11: The model provided answers which were mostly comparable to answers by…	- A person unfamiliar with the topic - A person who received a basic introduction to the topic - A person who has been working on the topic for 1-2 years - An expert in the topic with more than 2 years of analysis experience - An expert in the topic with more than 2 years of analysis experience who read the report carefully - An expert in the topic with more than 2 years of analysis experience who did not have enough time to properly read the details of the report	System Quality, Trustworthiness
Q12: I would like to use the model to…	- Be plugged into a possible risk-return analysis for an investment decision - Confirm my overall impression of how the company addresses the climate transition - Provide information on how the company addresses the climate transition - Provide the relevant information to assess the company's forward-looking business risks and opportunities - Provide the relevant information to assess the company's forward-looking business risks - Understand detailed aspects and nuances of the company's climate transition plan - Understand the broad picture of a company's transition strategy	Usage
Q13: The model answers are useful to…	- Be plugged into a possible risk-return analysis for an investment decision - Confirm my overall impression of how the company addresses the climate transition - Provide information on how the company addresses the climate transition - Provide the relevant information to assess the company's forward-looking business risks and opportunities - Provide the relevant information to assess the company's forward-looking business risks - Understand detailed aspects and nuances of the company's climate transition plan - Understand the broad picture of a company's transition strategy	Usage
Q14: The model needs to improve in the following ways to support my use case…	- Higher correctness of the answers - Less details provided in the answers - More details provided in the answers - Less irrelevant information in the answers - Always quoting the cited pages directly in the answer - Less missing out of relevant information in the report	System Quality, Usage
Q15: If I used the model, I would trust the information provided	- Yes - No - Partially	Trustworthiness
Q16: If I used the model, I would use the information provided and add the following quality checks:	(Free text only)	System Quality, Usage

Table S.11: Tool assessment for the NLP tool in general.

Question	Answers
Q1: If you had to answer the question, would you know what information to look for in a report?	 **Summary of respondent's criticism:** Most responses indicate a clear understanding of specific aspects to search for, such as ""CapEx alignment,"" ""external assurance,"" ""net zero policies,"" and ""GHG emissions reduction targets."" These responses suggest that certain participants were well-oriented towards identifying key elements of credible transition plans within reports. However, others expressed confusion or a lack of familiarity with specific terms or concepts like ""CapEx alignment"" and the general topic of transition plans, indicating a potential gap in understanding or knowledge. This variation suggests that while the tool might be helpful for those with some background or familiarity with the subject matter, it could be less accessible or intuitive for individuals lacking prior knowledge or expertise in climate transition strategies and reporting. Overall, the feedback points to a need for clearer guidance or educational components within the tool to accommodate users with varying levels of expertise and to ensure a broader understanding of how to identify and interpret the relevant information in reports.
Q2: What is your first impression of the answer?	 **Summary of respondent's criticism:** Several participants praised the tool for its accuracy and comprehensiveness, highlighting specific instances where the tool effectively connected complex pieces of information or addressed nuances in the transition plans. For example, one participant appreciated the tool's ability to connect the supervisory board's role with reduction goals as part of a transition plan, despite certain terms not being explicitly mentioned on the page. However, there were also criticisms, particularly regarding instances where the tool's answers were deemed misleading, incomplete, or failed to capture essential details. Some participants noted the tool's inability to correctly identify the presence or absence of specific elements within a company's transition plan, such as missing targets, baseline years, or the scope of GHG emissions covered. These criticisms suggest that while the tool can offer valuable insights, there is room for improvement in ensuring the accuracy and completeness of its analysis, especially in handling complex or nuanced information.
Q3: Does the model only summarize relevant content from the report to answer the question?	 **Summary of respondent's criticism:** Several participants appreciated the model's precision and conciseness in extracting relevant information, particularly in identifying specific goals, emissions data, or strategic plans directly related to the query. However, criticisms were common regarding the inclusion of irrelevant details, such as broader sustainability topics not directly answering the question, or speculative comments perceived as interpretive rather than strictly summarizing report content. Some responses highlighted the model's inconsistency, either overemphasizing certain aspects or missing crucial information, leading to partial relevancy in its summaries. This suggests a need for the tool to refine its focus on directly relevant content and reduce interpretative or supplementary information unless it directly supports the question. Overall, while the tool demonstrates capability in content summarization, there is room for improvement in ensuring relevance and limiting interpretive additions.

Question	Answers
Q4: Does the model summarize relevant content correctly without making up information not contained in the report?	 **Summary of respondent's criticism:** The participants' feedback on the AI tool's performance in summarizing relevant content without fabricating information not present in the reports shows a predominantly positive assessment, with a significant majority affirming its accuracy. However, notable exceptions were highlighted where the tool either partially met the criteria or failed. These exceptions often related to the tool's interpretation or addition of judgments not directly derived from the source material. For instance, issues were raised concerning the tool's misinterpretation or misleading representation of certain targets or achievements, such as incorrectly summarizing emission reduction targets or mischaracterizing the scope of certain corporate actions. Some participants also pointed out that the tool might go beyond summarizing to making unwarranted assessments, potentially veering into subjective analysis not supported by the report contents. This suggests that while the tool is largely effective in capturing and summarizing report contents accurately, there is room for improvement in ensuring that all interpretations and judgments are well-grounded in the source documents.
Q5: Do the sources provided support your trust in the model?	 **Summary of respondent's criticism:** Several participants highlighted specific issues with source relevance, citing examples where sources were either not provided, irrelevant, or lacked comprehensive coverage on the topic addressed by the question. Notably, some responses pointed out missed sources that could have substantiated the model's answers better, suggesting a need for the tool to encompass a wider range of relevant data. Concerns about the completeness and accuracy of the information underline a critical view on the trustworthiness of the model, with participants suggesting that while the model might identify correct pages or concepts, it often overlooks detailed verification or inclusion of all pertinent information. This feedback suggests that for the tool to enhance user trust, it must not only identify relevant sources but also ensure comprehensive coverage and contextual relevance, providing a more detailed justification for its answers.
Q6: Does the model cite all the information summarised from the report in the answer?	 **Summary of respondent's criticism:** Several responses indicate that the tool either missed citing some sources altogether or provided citations that didn't directly support the summary provided. Key observations include a lack of direct mention of sources, missing relevant page numbers, and incorrect or irrelevant citations. Some participants noted that while the tool mentioned sources, it sometimes omitted significant details or relevant pages that contained crucial information. There were also instances where the tool partially cited sources but failed to provide a comprehensive view by excluding important references. This suggests that while the tool might capture some relevant information, there's room for improvement in ensuring completeness and accuracy of citations, highlighting the importance of direct, precise, and inclusive referencing in summarizing and analyzing reports.

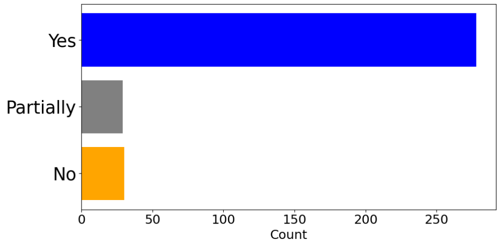
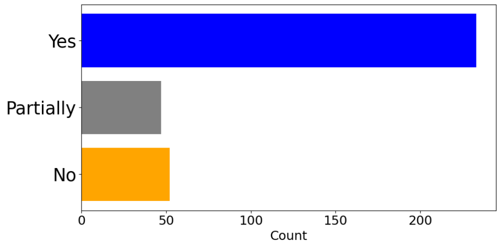
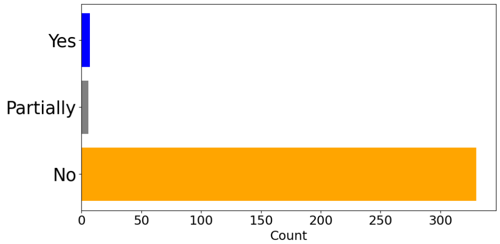
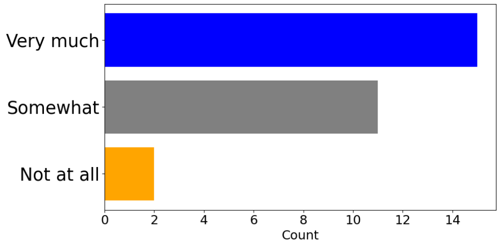
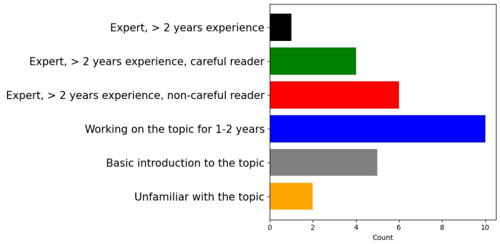
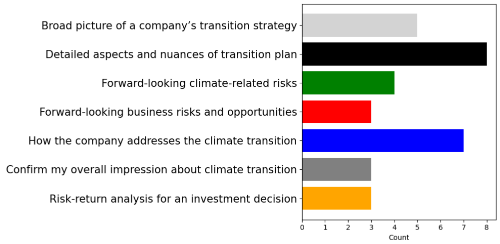
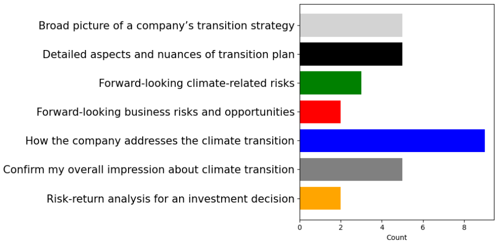
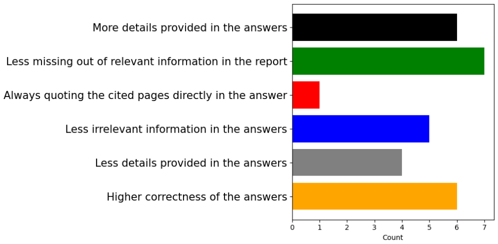
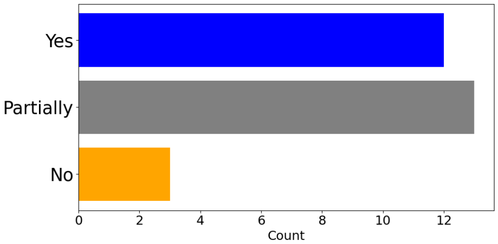
Question	Answers
Q7: Does the model only cite pages from the report, which it uses to answer the question?	 **Summary of respondent's criticism:** Several respondents indicated that the model either cited irrelevant pages or missed citing critical pages that were directly relevant to the question. Some specific feedback pointed out that certain pages mentioned by the model had no relevance to the query at hand, suggesting a mismatch between the model's citations and the actual content required to answer the question. Others noted that while the model cited pages, it either included unnecessary ones or omitted crucial information, indicating a gap in the model's understanding or retrieval capabilities. A few responses were more nuanced, acknowledging partial success but highlighting inconsistencies or the inclusion of seemingly irrelevant pages. Overall, this feedback underscores a need for improvement in the model's accuracy and relevance in citing pages from reports, ensuring it focuses only on pertinent information to address the query effectively.
Q8: Does the model cite all the pages you think are most important to answer this question?	 **Summary of respondent's criticism:** Several participants noted missing pages that contained relevant information, suggesting that the model might overlook critical content or fail to comprehensively assess the report's entirety. Concerns about missing pages indicate a need for the model to broaden its search and citation strategy to ensure it captures all pertinent information. Some feedback pointed to alternative pages that could provide more detailed or accurate information to support the model's answers better. This diversity in feedback underscores the complexity of identifying and citing the most relevant pages in extensive reports and the importance of continually refining the model's algorithms to improve its accuracy and relevance in citations.
Q9: Does the model cite pages, which do not exist at all in the report?	 **Summary of respondent's criticism:** Among the few who provided an explanation, key insights emerge. For instance, one answer highlights a lack of source material as a reason for their response, suggesting some participants might have found the assessment challenging due to insufficient information. Two answers specifically mention issues related to page citations, noting a repetitive mention of a page in a given cell, or stating no pages were cited. This indicates a perceived discrepancy in the model's citation practice or an error in the report's page numbering. Two remarks about unclear references to pages suggest confusion about whether the citations referred to physical or electronic document formats. Overall, these explanations point to a need for clearer guidelines on citations and perhaps better access to or organization of source materials for more accurate assessment by participants.

Table S.12: Item assessment result for the NLP tool

Question	Answers
Q10: How do you like the tool in general?	 **Free-text comments:** No free-text comments allowed.
Q11: The model provided answers which were mostly comparable to answers by. . .	 **Summary of respondent's criticism:** The free-text explanations suggest a generally positive, though nuanced, perception. Several respondents highlighted the tool's ability to grasp key information and offer basic analysis on climate transition plans, indicating its utility for individuals with a basic to intermediate understanding of the topic. However, criticisms emerged regarding the tool's depth of analysis, tone, relevance of commentary, and its tendency towards caution, suggesting room for improvement in delivering more expert, assertive, and concise analyses. The tool was recognized for its informed and authoritative voice, yet some felt it could benefit from a clearer stance on assessments and a refinement in distinguishing between different types of reports. This feedback points towards the tool's potential as a helpful resource, especially with enhancements in precision, expertise-level analysis, and succinctness in responses.
Q12: I would like to use the model to. . .	 **Summary of respondent's criticism:** Participants generally seek deeper insights into companies' climate transition plans, including the ability to understand nuances, access precise data, and identify discrepancies across reports. There's also an interest in the tool's potential for risk-return analysis in investment decisions and the evaluation of forward-looking climate-related and business risks. Notably, some participants express a desire for the tool to aid in broader strategic understanding, such as comparing company reports, flagging inconsistencies, and assessing the public perception of their initiatives. The feedback suggests that while the tool is seen as a potentially valuable asset for quick assessments and enhancing work processes, users also crave comprehensive analyses to feel confident in their decisions or presentations. This indicates an appetite for a tool that not only provides summaries but also deep, actionable insights.

Question	Answers
Q13: The model answers are useful to. . .	 **Free-text comments:** Few participants offered specific insights that reveal areas for potential improvement and trust concerns. One response highlighted the need for the tool to address climate transition credibility more explicitly, suggesting a desire for a deeper analysis of how companies' actions align with their stated commitments. Another response pointed to a need for gap analysis towards identifying greenwashing, indicating an interest in more nuanced evaluations of companies' sustainability claims. A critical note was also made about the current trustworthiness of the tool's answers, with one participant stating they would still feel the need to verify disclosures independently. Lastly, there was a constructive suggestion about using the tool to analyze how external parties view a company's publicized sustainability efforts, which could help in refining and improving communication strategies.
Q14: The model needs to improve in the following ways to support my use case. . .	 **Summary of respondent's criticism:** Participants noted issues with the tool either omitting crucial information or incorporating irrelevant details, particularly in regards to interpreting data in tables and understanding implications of financial allocations. There's a desire for clearer delineation between direct quotations, summaries, and analytical judgments, as well as for more targeted questioning to reduce the risk of "greenwashing" by accepting weak disclosures as sufficient. Suggestions for enhancements include more granular questioning, breaking down information for ease of understanding, and ensuring that answers directly cite sources to facilitate verification.
Q15: If I used the model, I would trust the information provided	 **Summary of respondent's criticism:** Concerns were raised about the tool's ability to handle complex, sector-specific issues and in-depth qualitative analysis, suggesting it performs better with general information and broader overviews. Some responses highlighted inaccuracies in model interpretations and a desire for a more comprehensive assessment beyond climate and environmental aspects. Additionally, the trustworthiness of the tool's outputs seems to be contingent on their alignment with established players in the field, like DJSI and CDP.

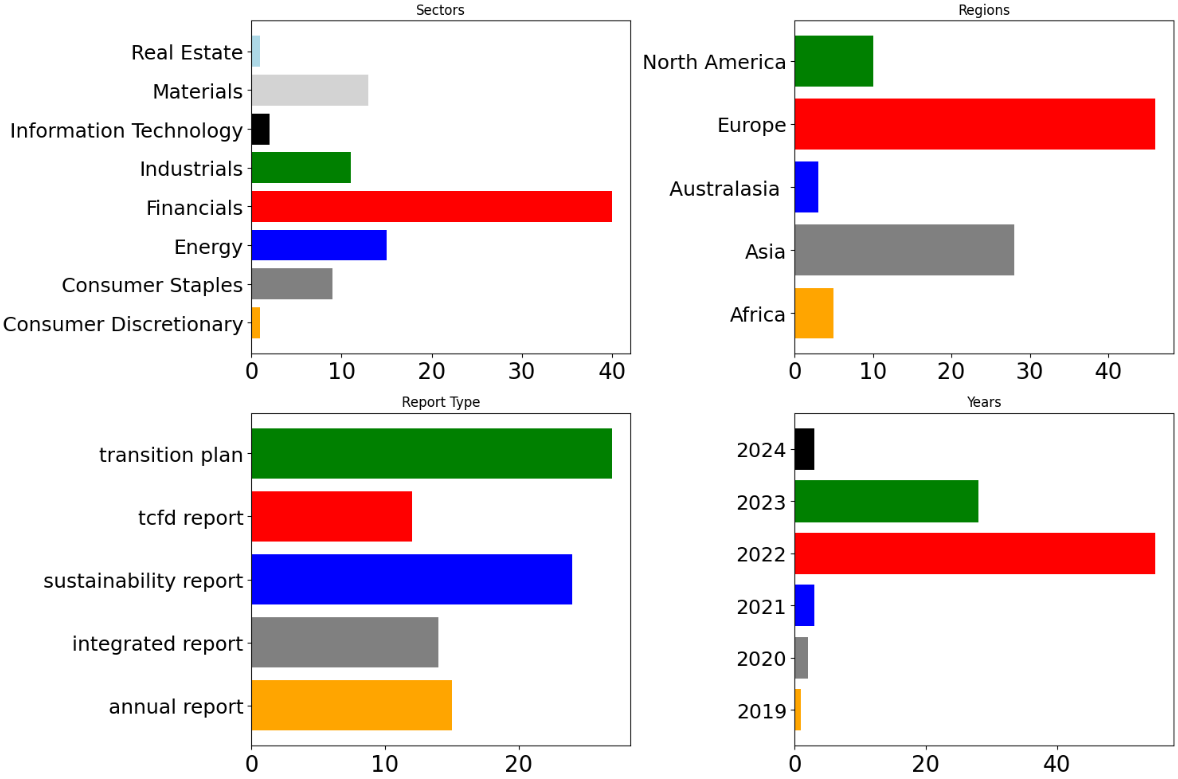


Figure S.7: Overview of the 93 reports in the evaluation.

Question	Answers
Q16: If I used the model, I would use the information provided and add the following quality checks:	**Free-text comments:** Participants highlighted a range of additional quality checks they would implement to enhance the trustworthiness and utility of the AI tool's outputs. Common themes include the necessity for cross-checking information across companies, sectors, and countries to ensure fairness and consistency in analysis. There's a clear demand for the model to accurately identify and compare specific elements, such as carbon offsetting practices between different companies. Users expressed the need for detailed verification of negative responses and alternatives considered, suggesting a deeper dive into qualitative analysis and materiality specific to each industry. Moreover, the feedback indicates a desire for more accessible, digestible summaries and targeted information to address specific inquiries. Participants also suggested integrating checks on the accuracy of numerical data and the relevance of cited sources, alongside cross-referencing indicators for a comprehensive assessment of transition plans' credibility. This feedback underscores a cautious approach, valuing accuracy, comprehensiveness, and user-friendliness in the tool's application.

Table S.13: Tool assessment results for the NLP tool.

S.8 Word clouds

To provide additional insights into the main topics covered in the most and least disclosed indicators, we display word clouds based on the frequency of terms used in the corresponding questions. Figure S.8 confirms our interpretation of the factors driving the divergence in performance between indicators. While companies are more likely to report a target for emission reduction, they tend to not disclose information related to offsets and fossil fuels.

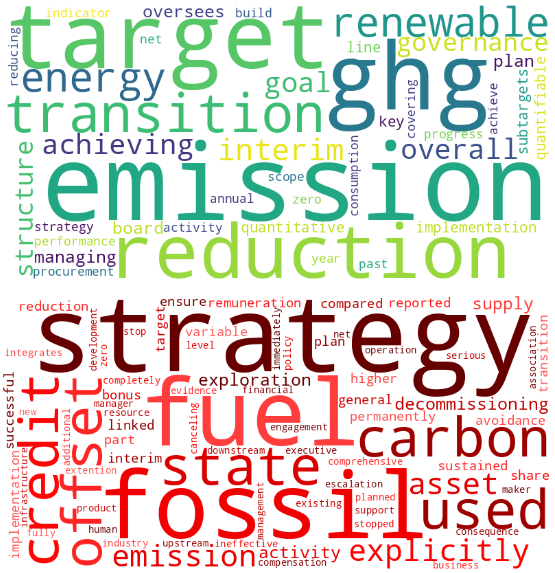


Figure S.8: Word clouds for the 10% best (green) and worst (red) performing questions.

Net Zero Transition Plans: Red Flag Indicators to Assess Inconsistencies and Greenwashing

Tobias Schimanski, Julia Bingler, Chiara Colesanti Senni, Jingwei Ni, Markus Leippold

University of Zurich, ETH Zurich, University of Oxford

Problem Set and Solution Approach

Current Set of Problems

- Companies need to transition towards a low carbon economy
- Vast amounts of recommendations, principles, guidelines for disclosure
- ? Companies disclose, but no one exactly knows how good or bad

Vast amounts of data, information asymmetry

Solution Approach

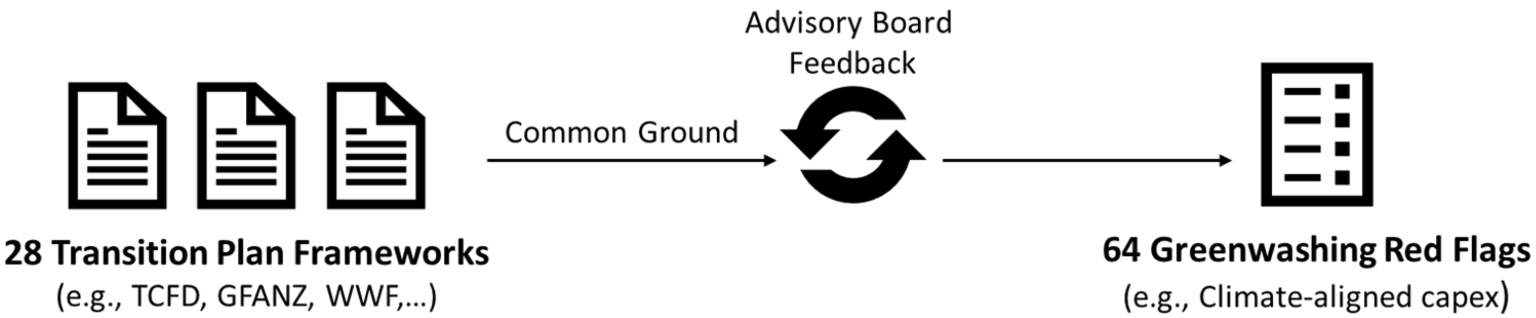
- ✓ 1. Create common ground between disclosure frameworks
- ✓ 2. Create and validate AI tool that assesses company disclosures
- ✓ 3. Apply AI tool on company disclosures to assess patterns

Automatic approach of assessing companies on scale

1. Assessment Indicators

Identify indicators to assess transition disclosures based on

- External consistency: ambition and feasibility of transition plans
- Internal consistency: credibility of transition plans toward achieving a net-zero business strategy



Advisory Board Feedback

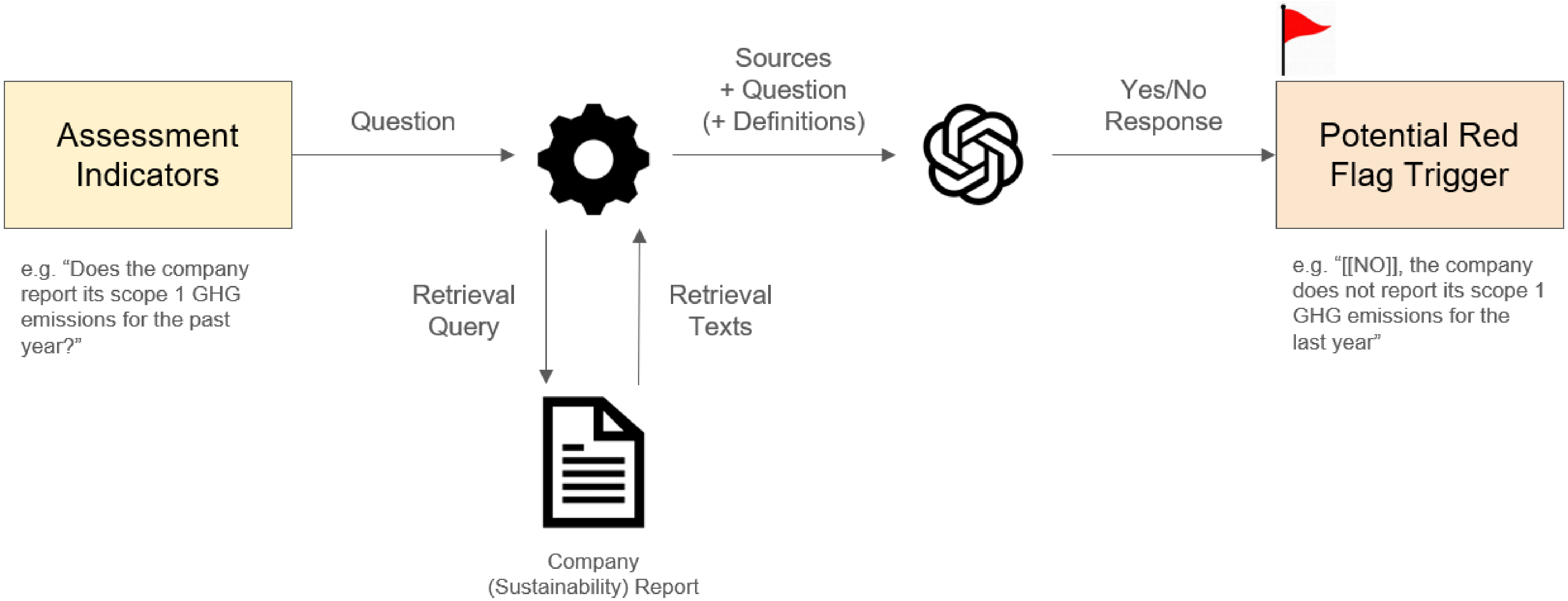
Common Ground

28 Transition Plan Frameworks
(e.g., TCFD, GFANZ, WWF,...)

64 Greenwashing Red Flags
(e.g., Climate-aligned capex)

Red flags to signal that transition plans underperform against some of the selected criteria and the risk of greenwashing

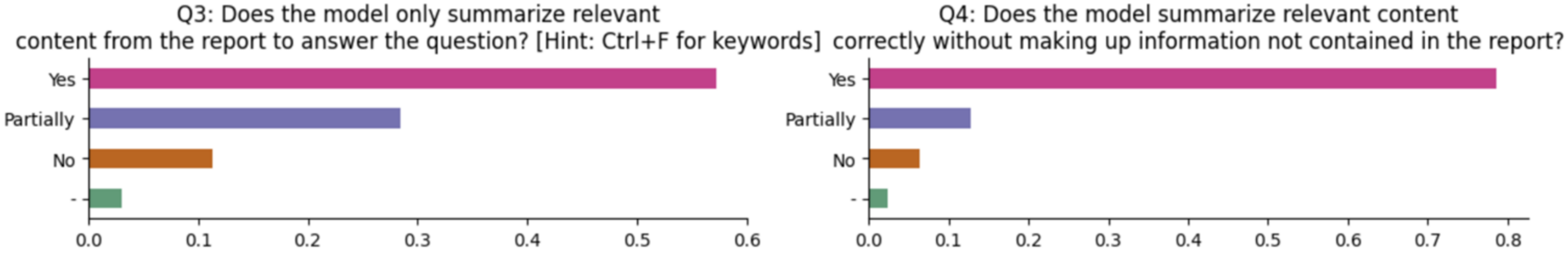
2. Retrieval Augmented Generation



Focus on traceability, verifiability and transparency

2. Expert-Centric Validation Approach

Pilot Study: 26 institutions spanning central banks, NGOs, investors, exchanges, regulators/supervisors, etc.: Quantitative and Qualitative Validation



Key Insights:

- Very Satisfactory level of system quality: source quality, citing, very limited hallucination
- Trustworthiness of the system depends on external verifiability and user needs
- Usage potentials are vast, improvement through sector- or investor-specialisations of the tool

3. CA100+ Study

Climate Action 100+

Companies
Analyse reports of the highest emitters in the world

Key Insight

- Indicators relating to “talk” are most often fulfilled (commitments, plans)
- Indicators related to “walk” are least often fulfilled (achievements, details on execution)

=> Huge amount of reporting but selective communication (?)

Outlook and Limitations

Data

- Reliance on “solely” sustainability reports
- Availability of reports

Model and Indicators

- Technical improvements will enable huge advancements
- Flexibility of the Indicators

Greenwashing

- Indicators show self-reported perspective and deliver “indication”
- Third-party and human verification

Thank you for your attention!

Working Paper to be out soon

Feel free to follow on LinkedIn

Tobias Schimanski

IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

Introducing the work programme of the BIS Innovation Hub Singapore Centre on green finance and climate risk data[1]

P Hoffmann and M El Dimachki,
BIS Innovation Hub Singapore Centre,

K Gay,
Monetary Authority of Singapore,

L Grisey,
NGFS Secretariat,

Z Bossert,
De Nederlandsche Bank

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

Introducing the work programme of the BIS Innovation Hub Singapore Centre on green finance and climate risk data

Dr Patrick Hoffmann,[1] Maha El Dimachki,[2] Kenneth Gay,[3] Léa Grisey,[4] Zooey Bossert[5]

Abstract

Central banks and financial authorities have an important role to play in alleviating the implications of climate risks on the financial system. They need to carefully monitor and mitigate climate risks and must make sure that they get the adequate and reliable data they need to do so. However, climate change and its impacts are complex, and central banks and financial authorities have only just started building the foundations for working with climate risk data, bridging data gaps and experimenting with suptech tools to visualise data for predicting and forecasting. In response to these challenges, the Bank for International Settlements Innovation Hub (BISIH) Singapore Centre has built collaboration on green finance and climate risk data into its work programme since the centre was established in 2019. In this paper, we describe our climate risk- and data-related work by introducing our work programme and by explaining how we collaborate with our partners. We highlight how we teamed up with the Monetary Authority of Singapore (MAS) to lay the foundations for working with climate risk data in Projects Ellipse and Viridis. Then, we describe how we have worked together with the Network for Greening the Financial System (NGFS), the MAS and Banque de France (BdF) to bridge data gaps by offering a data directory (Project NGFS DD 2.0). We also provide information on how the BISIH Singapore Centre facilitates a collaboration community to work on climate risks topics, such as the digital twin use case of the De Nederlandsche Bank (DNB).

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[5] Data scientist, De Nederlandsche Bank

1. Introduction

Relative to other risks facing financial services, climate risk is relatively new, but it has received more and more attention over the last few years (Grippa et al (2019), Huang et al (2018)). It is worth noting that the concept of risk due to weather or seasons is not new, and hedging against weather patterns, namely through weather derivatives and insurance, has been a common practice in financial institutions for a long time. In fact, it started in 1997 when the first transaction in weather derivatives took place (Perez-Gonzalez and Yun (2013)). However, this approach is only short-term and transactional in nature. It involves a payout from the seller of the derivative to the buyer if adverse weather has affected the buyer's output; for example, and quite simplistically, weather causing damage to crops or flooding closing down a factory. In contrast to these short-term perspectives, dealing with climate risks is much more complex and long-term in nature. Climate change has the potential to cause structural change and its impact goes beyond one organisation to affect society as a whole. This is a key reason why the topic is on government agendas and a universal, coordinated approach is required (Grisey (2022)).

One of the issues facing a universal and coordinated approach is the lack of data, the lack of consistency in approaching how to assess and measure risks, and the retrospective rather than future-looking data that are considered when assessing climate risks (Schmieder and Tissot (2022)). These are issues that supervisors and regulatory authorities face now that most of them have an added responsibility to assess climate risk in discharging their supervisory duties. In response to these challenges, the BISIH Singapore Centre has built collaboration on green finance and climate risk data into its work programme since the centre was established in 2019 (BIS 2019b). In this paper, we describe this climate risk- and data-related work. In Section 2, we introduce the work programme of the BISIH Singapore Centre and explain how we collaborate with our partners to address climate risk. In Section 3, we explain how the MAS, the BISIH Singapore Centre and others teamed up to lay the foundations for working with climate risk data in Projects Ellipse and Viridis. Then, we explain how the NGFS, the MAS, the BdF and the BISIH Singapore Centre have started to bridge data gaps by offering a data directory (with Project NGFS DD 2.0). In Section 4, we provide information on how the BISIH Singapore Centre facilitates the Ellipse Data and Knowledge Platform (EDKP) collaboration community to work on climate risk topics such as the digital twin use case of the

DNB. This collaboration community offers horizon scanning for future projects that might be added to the BISIH Singapore Centre's future work programme. We conclude in Section 5 by offering an outlook on the work programme of the BISIH Singapore Centre on green finance and climate risk data.

2. Work programme of the BISIH Singapore Centre on green finance and climate risk data

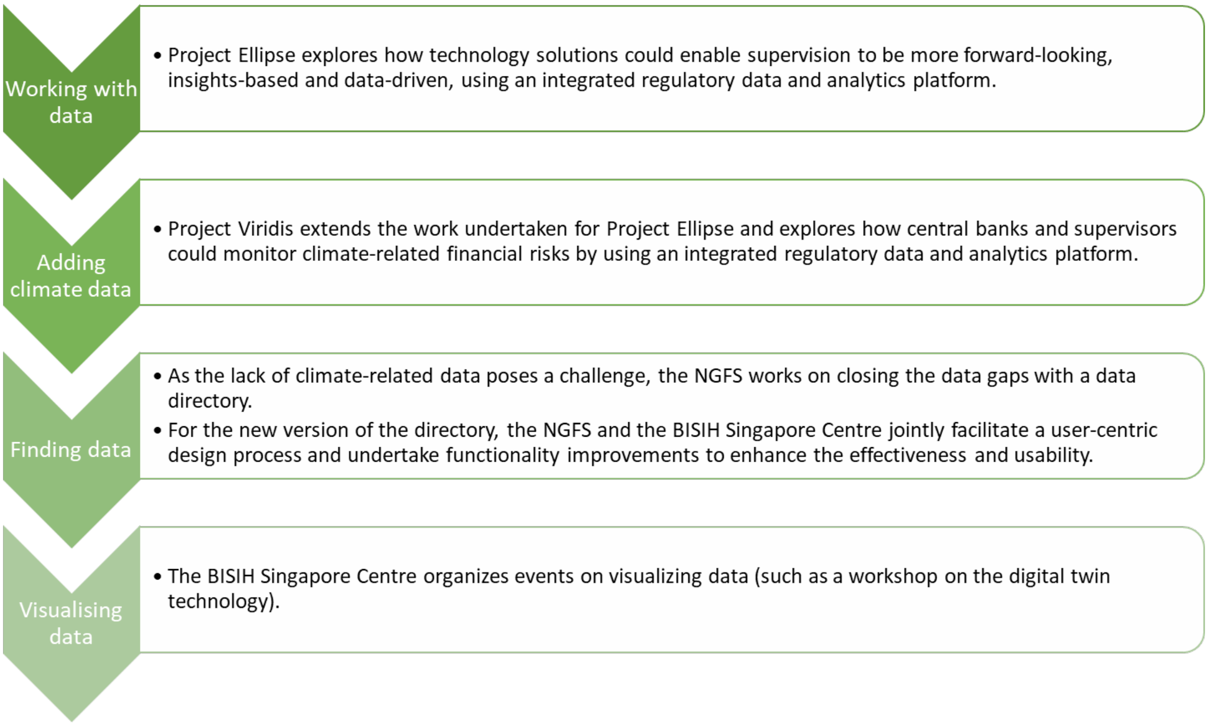
The BISIH Singapore Centre is part of the BIS Innovation Hub, a growing network of BISIH Centres around the world (BIS (2019a)). The BISIH aims to foster innovation and collaboration amongst central banks and financial authorities. Its work is structured around six core themes:

i. suptech, regtech and monetary policy tech
ii. next-generation FMIs
iii. central bank digital currency
iv. open finance
v. cyber security
vi. green finance (BIS (2024a))

As regards the latter, the BISIH is particularly interested in climate risk data, green bonds/loans/listed equity, sustainability-linked products, standardisation of ESG (environmental, social and governance) disclosures, measurement of environmental liabilities and impact, stress testing of portfolios and exposures, and carbon trading (BIS (2021)).

Over the last years, the BISIH Singapore Centre's work programme in the green finance space has focused on climate risk data by running three projects (Ellipse, Viridis and NGFS DD 2.0) and by facilitating the EDKP collaboration community to foster exchange on current topics such as climate risk data. When the BISIH Singapore Centre started its work in 2019, the transformational shift in the volume, velocity and variety of data had already been ongoing for quite some time (Borio (2011)). However, even today banking supervisors still rely heavily on template-based data, which are often outdated and difficult to compare. Therefore, the MAS and the BISIH Singapore Centre launched Project Ellipse (BIS (2022)), supported by the Bank of England, the International Swaps and Derivatives Association, Financial Network Analytics and Accenture. The objective of Project Ellipse was to enable supervisors to become more forward-looking by using technology solutions to work with granular data and to combine structured and unstructured sources of data. Supported by advanced analytics, the EDKP platform offers early warning indicators, analytics and prudential metrics. Next, the MAS and the BISIH Singapore Centre took into account the challenges of climate risk and launched Project Viridis (Wright and Nyberg (2017), von Kalckreuth (2022), BIS (2024b)). Project Viridis has been built on the platform from Project Ellipse and has climate risk data integrated into it. These data were initially drawn from available data sources in order to show that supervisors can already get first insights on which entities are more exposed to climate-related financial risks as well as any potential systemic exposure in sectors and geographies. As a modular platform, Viridis allows for further advancements and international alignment on climate risk data and metrics to be integrated into it in the future, providing richer insights. However, one of the key lessons for the BISIH Singapore Centre from Project Viridis was that the lack of decent quality and readily accessible climate-related data remains a challenge. Therefore, the centre teamed up with the NGFS, MAS and BdF to create a new version of the NGFS Data Directory (BIS (2024a)). This collaborative website will enable users to check out where to find specific climate risk data sources. At the start of the project, the partners went through a user-centric design process to undertake functionality improvements and to enhance the effectiveness and usability of the NGFS Data Directory. We also explored the latest technology tools to better search and browse on the data directory. In the next few months, we will continue working on this project together with the support of an industry partner.

In parallel to its projects, one of the objectives of the BISIH Singapore Centre is to foster central bank collaboration on climate risk topics. Its Project Ellipse is a prototype that authorities can test in their own environments and which may help them to explore new solutions (BIS (2023b)). It also presents an opportunity for the global regulatory community to further consider, explore and collaborate on common solutions to future-proof the data and analytical capabilities of supervisors. Therefore, the centre facilitates the EDKP collaboration community, consisting of 18 central banks and financial authorities. In addition to fostering collaboration, another objective of the collaboration community is horizon scanning for the BISIH Singapore Centre in the climate risk space The work programme of the BISIH Singapore Centre on green finance is summarised in Figure 1.



- Project Ellipse explores how technology solutions could enable supervision to be more forward-looking, insights-based and data-driven, using an integrated regulatory data and analytics platform.

- Project Viridis extends the work undertaken for Project Ellipse and explores how central banks and supervisors could monitor climate-related financial risks by using an integrated regulatory data and analytics platform.

- As the lack of climate-related data poses a challenge, the NGFS works on closing the data gaps with a data directory.
- For the new version of the directory, the NGFS and the BISIH Singapore Centre jointly facilitate a user-centric design process and undertake functionality improvements to enhance the effectiveness and usability.

- The BISIH Singapore Centre organizes events on visualizing data (such as a workshop on the digital twin technology).

Figure 1: Green finance work of the BISIH Singapore Centre

3. Projects of the BISIH Singapore Centre on green finance and climate risk data

Projects Ellipse and Viridis: Laying the foundations for working with climate risk data

In 2021, the BISIH Singapore Centre and the MAS launched Project Ellipse (BIS (2022)). A collaboration with the Bank of England, the International Swaps and Derivatives Association, Financial Network Analytics and Accenture, this project aimed to transform supervision into a forward-looking, insight-driven and data-driven approach. This was achieved by developing an integrated regulatory data and analytics platform. A key feature of the Ellipse prototype is its ability to amalgamate both structured and unstructured data sources, which are pertinent to real-time current events. Subsequently, advanced analytics are employed on these consolidated data sources, yielding early warning indicators, analytics and prudential measures for supervisors. Specifically, the project refined existing regulatory data on large exposures and combined them with unstructured data. Innovative analytics methods, including machine learning and natural language processing, were utilised to identify risk correlations and analyse sentiment. Real-time alerts were generated for supervisors to investigate potential issues. Network analytics were also employed to illustrate exposure connections, highlighting potential systemic risks to the banking system. The result was the Ellipse platform prototype, capable of extracting valuable insights from the collected data and presenting them through dashboards as early warnings for supervisory focus. This phase of Project Ellipse showcased the development of a unified platform, enabling authorities to promptly access integrated data sources, supporting and enhancing their supervisory evaluations.

Subsequently, the BISIH Singapore Centre and the MAS addressed the challenges of climate risk with the initiation of Project Viridis (BIS (2024b)). Project Viridis expands on the work conducted for Project Ellipse, examining how central banks and supervisors can monitor climate-related financial risks via an integrated regulatory data and analytics platform. The project operates under the assumption that initial insights on climate risks can be derived from existing data sources. These insights can aid supervisors in identifying financial entities with significant exposure to climate-related risks, as well as potential systemic exposure in sectors and geographies.

The Viridis platform offers authorities a comprehensive perspective of climate-related risks affecting financial institutions and the financial system as a whole, constructed from individual entity risks. At the institutional level, supervisors can view the top entities to which each bank is exposed, with the portfolio of borrowers categorised by industry sector and country in order to easily spot risk concentrations. For each entity to which the financial system has exposures, reported and modelled data on Scope 1, 2 and 3 absolute emissions and emission intensities are provided, if available. Entities' emissions are compared with those of the data-available entity universe to spot firms with a relatively higher carbon footprint. A transition risk measure is the anticipated impact of expected carbon prices or taxation in jurisdictions where entities operate. When entities have disclosed transition strategies, such plans can be combined with carbon pricing trajectory information to evaluate the monetary impact on the entity under various scenarios. When financial institutions possess comprehensive data on the portion of their counterparties' emissions that is linked to financing supplied to those counterparties, a view of financed emissions (by scope) can be aggregated and displayed. Banks can also total up the emissions trajectory (taking into account transition plans) of their counterparties to outline their own financed emission trajectories under various scenarios.

Financial institutions may have their own transition strategies, which could involve phasing out existing non-green exposures or strategically repositioning their business away from specific entities. These transition plans can be overlaid to present authorities with a clear view of financed emission trajectories and evaluate the relative impact of the assumptions made by a bank in formulating these projections. Accessing such detailed data would likely necessitate an in-depth collaboration between supervisor and supervisee. In instances where data on entities' assets (eg factories, production centres etc) are accessible, the Viridis climate risk platform can offer a more detailed perspective of the physical risks such entities face. Such information can be extracted from entity disclosures, which could cover key operational centres or break down operational costs by geographical location where production facilities are present. Data on the occurrence of various physical hazards (eg floods, erosion etc) by geographical location can provide a rudimentary view. Where available, this view can be combined with existing risk mitigation measures implemented by different jurisdictions (eg stricter building code expectations in high wind zones) to estimate an entity's sensitivity to different physical hazards.

Project NGFS Data Directory 2.0: Creating a platform to find climate risk data

As the lack of good quality and readily accessible climate-related data has posed a challenge for central banks, supervisors and the financial sector alike, the NGFS worked on assessing and systematically mapping climate-related data needs and availability in order to identify gaps. In this process, the NGFS gathered a unique data set of 1,200 climate-related raw data items and 750 climate-related relevant data sources – catering to the specific use cases of financial sector stakeholders – in a directory, as outlined in NGFS (2021). One key – and initially unexpected – conclusion of this work was that a significant number of gaps were in reality perceived gaps, as the data existed but the user was unaware of it. Against this backdrop, the NGFS published in 2022 the *Final report on bridging data gaps* (NGFS (2022)) and made the NGFS Data Directory (DD)[6] – a curated version of its directory – publicly available to facilitate the dissemination of climate-related relevant information and to highlight the actual data gaps that needed to be bridged, as opposed to perceived gaps.

The DD was built to systematically identify and map climate-related data gaps and provide evidence-based conclusions about the main gaps and key challenges to closing them in order to finally enable the NGFS to propose policy recommendations and solutions. To do

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[6] See ngfs.dev.masdkp.io/.

this, the NGFS applied a user-centric approach which classifies climate-related data sources into seven main stakeholder categories[7] and eight main use cases,[8] and built up the DD from both ends: identifying available climate-related data sources that are actually used within and beyond the NGFS community, but also metrics foreseen in some use cases and the associated aspirational data points. This consisted of a very tedious manual process of reviewing and classifying data.

Slightly derived from its intended initial use (see above), the DD can be thought of – and used – as a catalogue of available climate-related metrics and data sources based on specific stakeholder use cases. In directing users to the raw data items for which the sources are known/available, the DD can help financial sector stakeholders identify important and relevant climate-related data sources in order to meet their needs, facilitate access to data and improve the broader dissemination of existing climate-related data, thus closing perceived gaps. Similarly, by linking climate-related data needs to available sources, the DD can improve broader knowledge of missing climate-related data items by pointing to potential actual gaps that have not been identified so far and creating incentives to bridge them.

The NGFS sees the DD as a public good, a living tool aimed at fostering better dissemination of climate-related metrics, raw data items and sources and offering a practical solution to bridge the gaps. As the perception of climate data gaps remains entrenched and new data sets are becoming available, the need for a directory of climate-related relevant information is not going away. Meanwhile, the current DD, which has significant drawbacks, can be improved. Indeed, despite being a rich repository, it remains significantly underutilised and the information is static, leading to progressive obsolescence.

To ensure that the DD remains relevant, the NGFS is looking to establish it as a collaborative website where information (new data sources and metrics, as well as additional content on existing data sources and metrics) can be crowdsourced and curated by a community of interested professionals (including but not limited to those from NGFS members and observers), while maintaining the credibility and reliability of the information. The NGFS Secretariat thus approached the BISIH Singapore Centre to jointly facilitate a user-centric

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[7] Central banks, supervisors, credit institutions, insurers, pension funds, other buy-side entities and asset managers.

[8] Exposure quantification, investment and lending decisions, macroeconomic modelling, economic growth analysis, financial stability monitoring, climate-related disclosures, scenario analysis and stress testing.

design process and to undertake functionality improvements to enhance the effectiveness and usability of its DD.

At the start of the project, the BISIH Singapore Centre set up a series of design thinking workshops to map out the desired user journeys. Overall, there was broad consensus that the DD should be a current (ie regularly updated) and trusted reference on climate-relevant data for financial services stakeholders. It was also clear that the process of updating and maintaining it should be easy. Regarding governance, it was agreed that, in order to maintain the quality of information in the DD, any changes would only be made by accredited users such as staff from central banks and regulatory authorities, while non-accredited users would only be able to browse the DD. Features would also be introduced to enable accredited users to provide access to data (where available) and rate the quality of data items, sources and metrics. Finally, it was deemed crucial that greater filtering features be introduced in order to enhance searchability. The user journey, in terms of navigating through the DD, would also need to be further simplified to cater to a broader base of users. The outcomes of these workshops have been integrated into a wireframe for the new version of the DD (the DD 2.0), which fed into a detailed report on this design thinking process.

Overall, the project received good support both at the design thinking workshops, with participants[9] of various backgrounds recognising the usefulness of the product, and via several other channels. The DD has a clear value added and could serve as a solid basis upon which various national directories could be built.

In preparation for the development phase, the project manager (BISIH Singapore Centre), product owners (BdF and MAS) and NGFS Secretariat organised a 1.5-day in-person workshop in Paris on 29 February and 1 March. The workshop facilitated the exchange of ideas among participants, who also attended presentations by potential vendors which could be engaged during the development phase. These presentations allowed the project team to further improve and crystallise the design features from the wireframe. The workshop was also the occasion to discuss important points for the post-development phase, such as the soft

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[9] The workshop participants included potential public sector users, ie central bankers and financial supervisors/regulators, and potential private sector users, ie financial institutions.

launch of the DD 2.0, the handover to a permanent host and key enablers for the DD 2.0's success.

With the completion of both the design thinking phase and the preparatory work for the development phase, and with key enablers already identified for ensuring success in the post-development phase, the project team has proceeded to the development phase. The BISIH Singapore will stay engaged until the soft launch (foreseen for the COP29) and handover to the permanent host, while the NGFS is also looking to partner with interested stakeholders (professional associations, data providers etc) to deliver the DD 2.0 as a public good and unlock the full potential of the wealth of already existing climate-related data.

4. Horizon scanning of the BISIH Singapore Centre on green finance and climate risk data

As outlined above, one of the objectives of the BISIH Singapore Centre is to foster the collaboration of central banks and financial authorities on climate risk topics by facilitating the EDKP collaboration community. The community meets on a regular basis to exchange views on upcoming topics and projects in the suptech space, with a particular focus on climate change and artificial intelligence. The community also gets together for workshops and hackathons. For example, at the beginning of June 2024 the MAS and the BISIH Singapore Centre ran an in-person hackathon for the EDKP collaboration community, focusing on suptech tools for climate risk, amongst other topics. The last virtual workshop was held in November 2023, when the BISIH Singapore Centre and DNB facilitated an exchange on visualising climate risk data for the community. The topic of the virtual workshop, the digital twin technology, was inspired by the Digital Twin project of the DNB, BdF and Hong Kong Monetary Authority (HKMA). The project first started as a pilot of a workstream, led by DNB, under the Working Group on Green Finance of the BIS Innovation Network. The workstream was tasked with exploring ways to increase the amount of sustainability-related data using innovation. To explore this, the members of the workstream adopted a "learning by doing" approach to obtain insights into specific barriers and possibilities via experimentation. Specifically, the members of the workstream created a minimum viable product of a digital twin solution for physical climate-related risks (BIS (2023a)).

Physical climate risks can have a sudden and significant impact on the financial system or an individual institution. Climate change is exacerbating those risks by making natural disasters more common and increasing their intensity. However, the data for quantifying these risks in a timely manner are often lacking. This makes it hard to account for these risks in decision-making by central banks and supervisors when natural catastrophes occur or when changing circumstances affect forward-looking estimates of risk. Digital twin technology can increase the visibility of those risks. A digital twin is a digital representation of a real-world entity, event or system. It allows for the real-time monitoring of an asset or system, or a simulation of its performance, under different conditions. The technology has various applications, ranging from manufacturing to healthcare services and urban planning. If applied to the financial sector, digital twins could be replicas of financial institutions, infrastructures, assets, systems, processes etc. In this case, a digital twin could form the linking pin that connects financial and environmental data.

In the first phase of the Digital Twin project, a general theoretical framework and open source IT solution were developed. The project incorporated three case studies: one in the Netherlands on flood risk, one in France on flood risk and one in Hong Kong SAR on cyclone risks. The IT solution consists of a framework that extracts, combines and models various internal and external data sources into digital twin architecture, making it possible to conduct interactive analyses. By making a digital replica of financial institutions (or parts thereof), the effect of climate-related events can be immediately viewed or modelled in a digital environment. The difference with existing dashboards is that a digital twin offers an interactive environment that is also suitable for scenario analyses. Moreover, and in contrast to existing scenario analyses, the analysis is always performed on the latest available data, such as real-time satellite data. This allows the supervisor to engage more interactively with physical climate risk. Overall, the case studies demonstrated the value of a shared theoretical basis and the technical feasibility of such a digital twin solution. After the minimal viable product was delivered, DNB, BdF and HMKA opted to advance the project to further refine the framework and IT solution by incorporating financial and real-time data.

International collaboration has played a crucial role in bringing the project to its current stage, and the EDKP community has offered many opportunities, such as the above-mentioned virtual workshop and hackathon. The virtual workshop aimed to inspire and enthuse other participants in the community about the topic. It has led several members to also participate with the topic in the EDKP hackathon. The goal during the hackathon was to implement other use cases of climate risks and further generalise the framework to make it more accessible to other jurisdictions. As the Digital Twin initiative progresses, rather than solely visualising and analysing the effect of physical climate risks, it can eventually be utilised for real-time operations.

5. Conclusions

In our paper, we have shown how the work programme of the BISIH Singapore Centre and its collaboration partners on green finance and climate risk data contributes to global discussions and initiatives to address climate change data needs. Our work started with Project Ellipse and Project Viridis to lay the foundations for working with climate risk data. Next, we have been working on closing existing data gaps with our Project NGFS Data Directory 2.0. In the coming months, we will further elaborate on suptech tools to visualise climate risk data in order to enable supervisors to become more data-driven and forward-looking in their day-to-day work on climate risk. As a result, the work programme of the BISIH Singapore Centre and its collaboration partners will further add to the ongoing discussion of central banks and financial authorities on the intersection between technology, sustainability and finance.

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BIS Innovation Hub

Introducing the Work Program of the BISIH Singapore Centre on Green Finance and Climate Risk Data

Dr. Patrick Hoffmann, Maha El Dimachki, Kenneth Gay, Léa Grisey, and Zooey Bossert

May 2024

Work program of the BISIH Singapore Centre on Green Finance and Climate Risk Data

Working with data

- Project Ellipse explored how technology solutions could enable supervision to be more forward-looking, insights-based and data-driven, using an integrated regulatory data and analytics platform.

Adding climate data

- Project Viridis extends the work undertaken for Project Ellipse and explores how central banks and supervisors could monitor climate-related financial risks by using an integrated regulatory data and analytics platform.

Finding data

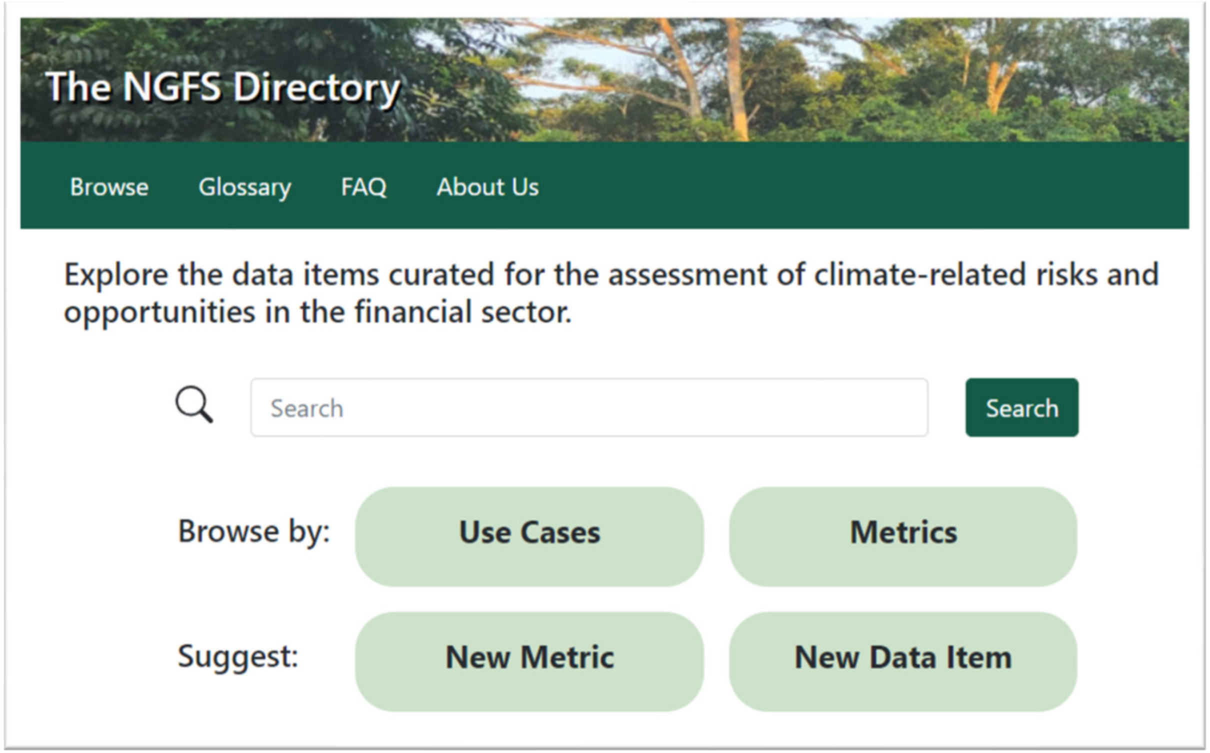
- As the lack of climate-related data has posed a challenge, the NGFS worked on closing the data gaps with a Data Directory.
- For the new version of the DD, the NGFS and the BISIH Singapore Centre will jointly facilitate a user-centric design process and will undertake functionality improvements to enhance the effectiveness and usability.

Visualizing data

- BISIH Singapore Centre organised a virtual workshop on the digital twin concept for the EDKP community in November 2023.
- In a next step, use cases around the digital twin concept will be part of the MAS/BISIH hackathon in June 2024.

Project NGFS DD 2.0 - Overview

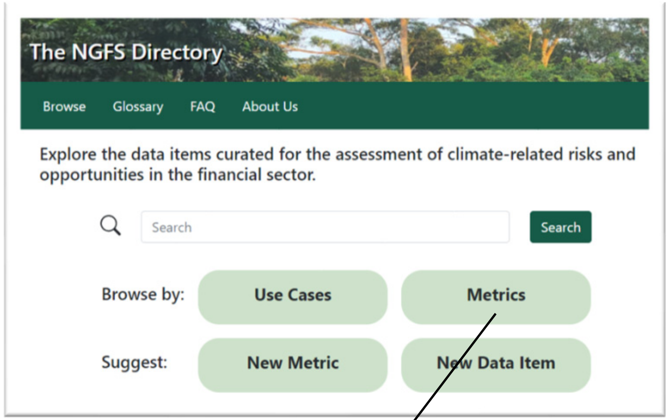
- The first version of the NGFS Data Directory was built to identify, map and plug climate-related data gaps.
  - However, was largely manually collated by the NGFS's Expert Network on Data working group.
- The NGFS Secretariat has approached the BIS Innovation Hub Singapore Centre to explore a user-centric re-design and re-build of the Data Directory (i.e., to build a version 2.0).
- The aim is to **incorporate functionality improvements** to **enhance the effectiveness** and **usability** of the NGFS Data Directory through a user-informed approach.



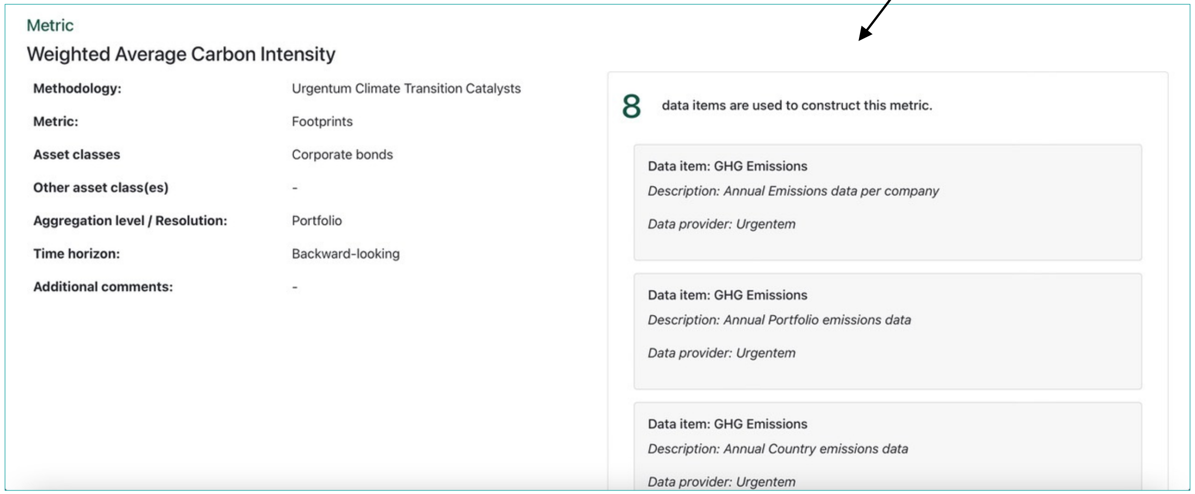
Explore the data items curated for the assessment of climate-related risks and opportunities in the financial sector.

Project NGFS DD 2.0 - Problem statement

- The design of the current Directory needs to be improved and re-designed to facilitate searching and browsing through data sources.
    - The Directory is currently not well utilised and does not function as a useful public repository of green and climate-related data
- Directory lacks the functionalities or features that support crowd-sourcing new data sources to help with the updating of the available information (i.e., information is static).



Explore the data items curated for the assessment of climate-related risks and opportunities in the financial sector.



Weighted Average Carbon Intensity

Methodology:	Urgentum Climate Transition Catalysts
Metric:	Footprints
Asset classes	Corporate bonds
Other asset class(es)	-
Aggregation level / Resolution:	Portfolio
Time horizon:	Backward-looking
Additional comments:	-

8 data items are used to construct this metric.

Data item: GHG Emissions
Description: Annual Emissions data per company
Data provider: Urgentem

Data item: GHG Emissions
Description: Annual Portfolio emissions data
Data provider: Urgentem

Data item: GHG Emissions
Description: Annual Country emissions data
Data provider: Urgentem

Project NGFS DD 2.0 - Proposed solution

- To ensure that the Directory remains relevant, the NGFS is looking to establish the Directory as a **collaborative website** where information (new data sources and metrics, additional content on existing data sources and metrics) can be crowd-sourced.

- This would be an opportunity for the BISIH to explore **latest public communication tools**, **data generation tools** and **design methods** to better communicate and disseminate public resources and verified data in the green finance space. It would also allow us to explore how to promote and facilitate more effective two-way interactions and communications between the "experts"/expert sources and the public.

Project NGFS DD 2.0 - Examples of types of functionality improvements we hope to explore

- Broaden the search possibilities by adding further browsing functionalities (e.g., by data item, data provider, or full text search)

- Allow for more detailed searches for existing functionalities (e.g., by increasing the possibilities to filter use cases, metrics, risk types, data source types)

- Implement web analytics tools to monitor critical web usage metrics

- Exploratory study of the usefulness and appropriateness of other innovative tools and models to supplement NGFS and crowd-sourced data

Project NGFS DD 2.0 - What would success look like?

- Provide collaborative website as a public resource
- Greater and more consistent data for green and climate finance reporting
- Information on the website can be crowd-sourced / dynamically updated and populated (e.g., in a next step the website could be updated with data on biodiversity)
- Code sharing to promote collaboration over competition

Are you interested in collaborating with us?

The BIS Innovation Hub invites central banks and regulatory authorities to form a collaboration community where authorities can work together to further build the platform and create new applications to serve common use cases and priorities.

The Ellipse collaboration community will operate in a private repository at least until 30 Jun 2026 and will make available the Data and Knowledge Platform in its repository for all community members. The community intends to enable participation, usage and contributions in much the same way as a fully open-source environment.

- *18 CBs or regulatory authorities have already joined the EDKP community – e.g. Bank Indonesia, BNM, BoJ, Bundesbank, DNB, ECB, FINMA…*
- *Many have started to test EDKP, some have installed EDKP already*
- *First Hackathon conducted in March 2023 resulting to 4 new use-cases from the 8 CBs/reg. auth. participating*
- *Next Hackathon planned for June 2024*

***Next steps** for the EDKP:*

***Expanding the circle of members** and **introduce further use-cases** to make the EDKP even more interesting for members. **Use-cases should come more and more from member commits;** however, we plan to **host furthers Hackathons** to get the members engaged in the initiative.*

BIS Innovation Hub

Thank you very much for your attention!
Do you have any questions?

IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

Advancing climate action through enhanced data governance: a case of Indonesia[1]

S Juhro, I Robinson, H Rahadyan and C Lim,
Bank Indonesia

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[1] This contribution was prepared for the workshop. The views expressed are those of the authors and do not necessarily reflect the views of the Central Bank of the Republic of Türkiye, the BIS, the IFC or the other central banks and institutions represented at the event, including Bank Indonesia.

Advancing Climate Action Through Enhanced Data Governance: A Case of Indonesia

Solikin M. Juhro[1], Irman Robinson, Heru Rahadyan, Charvin Lim

Abstract

This paper explores the critical role of climate-related data in supporting robust policy decisions, driving sustainable investments, and facilitating climate action, with a specific focus on Indonesia. Through an examination of global climate data initiatives and Indonesia's efforts to strengthen its climate data landscape, the paper highlights the importance of data transparency, accountability, and credibility in addressing the climate-related data gap. Key strategies identified include harmonizing sustainability reporting standards, implementing mandatory reporting requirements, and providing assurance for sustainability reports. This paper highlights the importance of mandatory structured data reporting, as well as tools to help banks and firms meet reporting requirements. Through collaborative efforts among main stakeholders, Indonesia is advancing sustainability reporting and climate data collection to support informed decision-making and mitigate climate-related financial risks, ultimately contributing to a financial system stability and sustainable economic development.

Keywords: Climate risks, Climate data initiatives, Indonesia.

1. Introduction

The current global discourse on climate change underscores its multifaceted nature, emphasizing not only its adverse impacts but also the possibilities for sustainable development and innovation. The discussion acknowledges that human activities have caused significant changes in the climate, with far-reaching consequences for ecological systems, socioeconomic structures, and geopolitical dynamics. The Intergovernmental Panel on Climate Change (IPCC) has unequivocally affirmed the escalation of climate-related hazards, including extreme weather events, sea-level rise, biodiversity loss, and disruptions to food and water systems (IPCC, 2021).

At the same time as these urgent challenges, lies a spectrum of opportunities to recalibrate our economic systems toward sustainability and resilience. The transition towards renewable energy sources, sustainable land management practices, and circular economy models embodies a trajectory that not only mitigates greenhouse gas emissions but also fosters inclusive growth and technological innovation (UNEP, 2020). Moreover, investments in climate

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adaptation and mitigation measures can catalyze job creation, enhance energy security, and bolster community resilience in the face of climatic uncertainties.

However, taking advantage of these opportunities requires concerted efforts across the public and private sectors. Policymakers are tasked with formulating robust regulatory frameworks that incentivize sustainable practices while safeguarding vulnerable populations from climate vulnerabilities (UNFCCC, 2015). Businesses are called upon to embrace sustainable business models, integrate climate considerations into their operations, and disclose relevant environmental, social, and governance (ESG) metrics to investors and stakeholders (TCFD, 2017).

Amidst the urgency to address climate change, the availability and accessibility of high-quality climate-related data becomes crucial. Climate-related data includes various types of information, such as weather observations, greenhouse gas emissions inventories, climate models, and economic indicators (WMO, 2020). These data sources serve as critical inputs for assessing the current state of the climate, projecting future climate scenarios, and identifying vulnerabilities and adaptation needs across various sectors and regions (IPCC, 2021).

Climate-related data serves as a fundamental prerequisite for effective policy formulation and informed decision-making. Governments rely on climate data to develop and implement mitigation and adaptation measures, set emissions reduction targets, and track progress towards climate goals, such as those outlined in the Paris Agreement (UNFCCC, 2015). Similarly, businesses and investors use climate-related data to assess climate risks and opportunities, integrate climate considerations into their decision-making processes, and disclose relevant information to stakeholders (TCFD, 2017).

However, the availability and quality of climate-related data remain uneven and fragmented, particularly in developing countries and vulnerable regions. Data gaps and inconsistencies hinder efforts to accurately assess climate risks, allocate resources efficiently, and design targeted interventions to build resilience toward climate change (UNEP, 2019). Moreover, the complex and interdisciplinary nature of climate data poses challenges in terms of data collection, management, and interpretation, further exacerbating existing disparities in data availability and accessibility (WMO, 2020).

Addressing the climate-related data gap requires concerted efforts to enhance data collection, sharing, and interoperability, as well as investments in data infrastructure and capacity building (UNEP, 2019). Moreover, promoting transparency, standardization, and harmonization of climate-related data across sectors and jurisdictions is essential for facilitating cross-sectoral collaboration and enabling evidence-based decision-making (WMO, 2020).

This paper endeavors to propose a comprehensive strategy aimed at addressing the pervasive climate-related data gap, with a specific focus on Indonesia. As a nation highly vulnerable to the impacts of climate change, Indonesia stands to benefit immensely from a robust framework for collecting, analyzing, and disseminating climate-related data. The overarching objective of this paper is to delineate actionable steps and recommendations to bridge existing data gaps, enhance data infrastructure, and foster a culture of data-driven decision-making in the context of climate change mitigation and adaptation efforts in Indonesia.

Central to the proposed strategy is the establishment of a robust institutional framework to coordinate and oversee climate-related data initiatives at the national level. This involves collaboration among governmental bodies, private sector organizations, civil society groups, and other involved parties to create specialized committees or mechanisms responsible for coordinating data collection, standardizing data formats, and promoting data sharing among relevant stakeholders. Moreover, the strategy emphasizes the importance of investing in data infrastructure, including data centers, standards and certifications, and capacity-building initiatives, to enhance the quality, accessibility, and interoperability of climate-related data.

The remainder of the paper is structured as follows. Section II delves into a discussion of global trends and policies aimed at enhancing the data environment. Section III examines climate data initiatives specifically in Indonesia. Finally, Section IV summarizes our study's findings and conclusions.

2. Global climate data environment

2.1. The roles of central banks in climate transition

The issue of welfare and economic sustainability are inseparable from the role of the central bank in discharging its duties to achieve and maintain price stability, such as economic growth, full employment and income equality, as well as environmental/climate change issues. The influence of the central bank is even stronger, especially in emerging markets and developing economies (Juhro, 2023). Central banks, which have traditionally focused on managing monetary policy and ensuring financial stability, are now recognizing the importance of addressing risks associated with climate change and supporting the shift towards a more sustainable economy. The recognition of climate change as a systemic risk to financial stability has prompted central banks worldwide to reassess their mandates and operational frameworks. The Bank for International Settlements (BIS) has emphasized the imperative for central banks to integrate climate considerations into their risk management practices, stress testing frameworks, and asset purchase programs to mitigate the financial repercussions of climate-related shocks (BIS, 2021).

Moreover, central banks are assuming a proactive stance in fostering green finance initiatives and sustainable investment practices. Through their regulatory and supervisory functions, central banks are incentivizing financial institutions to integrate climate risk assessments into their lending decisions, disclose climate-related financial information, and adopt sustainable investment strategies. The Network for Greening the Financial System (NGFS), comprising central banks and supervisory authorities from across the globe, has emerged as a pivotal platform for facilitating knowledge exchange and collaboration on climate-related financial risks and opportunities (NGFS, 2019).

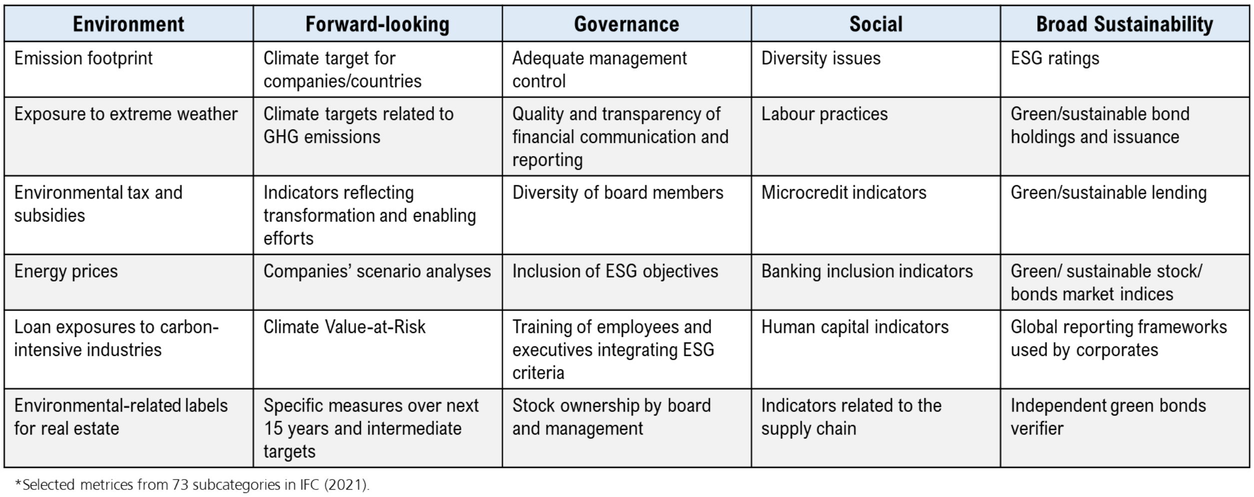
Furthermore, central banks are leveraging their influence as institutional investors to promote sustainable finance practices within capital markets. By incorporating environmental, social, and governance (ESG) criteria into their investment portfolios, central banks are signaling their commitment to supporting the transition towards a low-carbon economy.

The International Monetary Fund (IMF) has underscored the role of central banks in aligning their investment strategies with the objectives of the Paris Agreement and the United Nations Sustainable Development Goals (IMF, 2020).

2.2. Global Climate Data Initiatives

The global landscape of climate data initiatives represents a collaborative endeavor among international organizations, governments, and non-state actors to bolster the availability, accessibility, and quality of climate-related data worldwide. These initiatives encompass a diverse range of frameworks, standards, and platforms geared toward facilitating data collection, analysis, and dissemination, thus supporting informed decision-making and action on climate change mitigation and adaptation.

International Finance Corporation (IFC) (2021) conducted a survey focusing on sustainable finance data for central banks, providing valuable insights into the purpose and challenges associated with gathering data while also identifying relevant metrics for central banks' sustainable finance initiatives. The survey which resulted from 63 country responses has shown that statistics on sustainable finance show growing demand for central banks to pursue their mandate, particularly in addressing the risk of climate change including formulating macroprudential policies and microprudential supervision, asset and reserve management, financial inclusion, and other mandate. The survey also identified a comprehensive list of relevant metrics for central banks' initiatives and cataloged them in 73 subcategories across five broad areas, encompassing environment, forward-looking assessments, governance, social considerations, and broader sustainability indicators.



Environment	Forward-looking	Governance	Social	Broad Sustainability
Emission footprint	Climate target for companies/countries	Adequate management control	Diversity issues	ESG ratings
Exposure to extreme weather	Climate targets related to GHG emissions	Quality and transparency of financial communication and reporting	Labour practices	Green/sustainable bond holdings and issuance
Environmental tax and subsidies	Indicators reflecting transformation and enabling efforts	Diversity of board members	Microcredit indicators	Green/sustainable lending
Energy prices	Companies' scenario analyses	Inclusion of ESG objectives	Banking inclusion indicators	Green/ sustainable stock/ bonds market indices
Loan exposures to carbon-intensive industries	Climate Value-at-Risk	Training of employees and executives integrating ESG criteria	Human capital indicators	Global reporting frameworks used by corporates
Environmental-related labels for real estate	Specific measures over next 15 years and intermediate targets	Stock ownership by board and management	Indicators related to the supply chain	Independent green bonds verifier

*Selected metrices from 73 subcategories in IFC (2021).

Table 1. Climate-Related Metrics for Central Bank, adapted from IFC (2021)

Several noteworthy initiatives have been established on the global stage to address the critical need for consistent climate-related data across different countries. Two leading examples include the IMF's global dashboard on climate change indicators and the NGFS data repository for climate data. The IMF dashboard provides a centralized and user-friendly platform for key climate metrics, including greenhouse gas emissions, mitigation and adaptation policies, transition pathways, climate finance, and climate and weather data on a global level and across a range of countries. In contrast, the NGFS repository serves as a comprehensive archive of diverse climate-related datasets, providing information regarding climate data sources and fostering informed decision-making among researchers and policymakers. The NGFS extends its value by providing data on transition pathways.

CATEGORY	INDICATOR(S)	SPECIFICATION
Green House Gas Emissions	GHG Emissions	• Annual • Quarterly (for Experimental SEEA Based Air Emissions Accounts) • Global and country-level • Sectoral • firm ownership
Mitigation	• Environmental taxes • Govt. expenditure on environmental protection • Fossil fuel subsidies • Renewable energy • Trade in low carbon technology • Forest and carbon	• Annual • Country-level
Adaptation	• Climate disaster frequency • Climate-driven INFORM risk	• Annual (for climate disaster frequency) • For the year 2022 (for climate-driven INFORM risk) • Global and country-level
Transition to a Low-Carbon Economy	• Forward looking risks (carbon cost, revenues at risk) • Trade in low carbon technology • Renewable energy	• Annual • Country level • Type of emission • Sectoral
Climate Finance	• Green Debt (issuance and outstanding) • Carbon footprint of bank loasn	• Annual • Country level
Climate and Weather	• Annual surface temperature change • World Monthly Atmospheric Carbon Dioxide Concentrations • Change in Mean Sea Levels	• Annual • Country level / Sea region
NGFS Indicators	• Transition Pathways (energy mix, fossil fuel prices, emissions and CCS, shadow carbon price, mean surface temperature) • GDP losses and benefits	• Annual • Country level • 7 (seven) scenario options

Table 2. Country-level Climate Change Indicators, Adapted from IMF Global Dashboard of Climate Change (2023)

The NGFS Working Group on Scenario Analysis is also actively developing methodologies and tools to develop diverse climate scenarios to better understand the potential impact of climate-related risks. This initiative aims to empower financial institutions and regulators to enhance their comprehension and management of climate-related risks (NGFS, 2020). This additional resource empowers researchers and policymakers to conduct forward-looking analyses, enabling a more comprehensive assessment of climate change risks and potential mitigation strategies. These initiatives underscore the mounting acknowledgment of the significance of climate-related data in informing financial decision-making and propelling the transition toward a low-carbon, climate-resilient economy.

A prominent initiative within the disclosure sphere is the Task Force on Climate-related Financial Disclosures (TCFD), established to formulate voluntary, consistent climate-related financial risk disclosures. These disclosures aid companies in providing information to investors, lenders, insurers, and other stakeholders (TCFD, 2017). The TCFD framework delineates climate-related risks and opportunities across four thematic areas: governance, strategy, risk management, and metrics and targets, thereby enabling investors and financial institutions to assess and manage climate-related risks in their portfolios more effectively.

Furthermore, the International Financial Reporting Standards (IFRS) Foundation has introduced a comprehensive set of sustainability reporting standards, known as the IFRS Sustainability Disclosure Standard, aimed at harmonizing sustainability reporting practices and bolstering the comparability, consistency, and reliability of sustainability-related disclosures (IFRS Foundation, 2023). These standards complement existing financial reporting standards, providing investors and stakeholders with a more holistic understanding of companies' environmental, social, and governance (ESG) performance and risks.

In addition, initiatives such as the G20 Data Gaps Initiative (DGI) and NGFS are pivotal in addressing data gaps and fortifying the resilience of financial systems against climate-related risks (G20, 2020; NGFS, 2019). The DGI targets the identification and rectification of data gaps in crucial areas of economic and financial statistics, including those pertaining to climate change. Meanwhile, the NGFS focuses on advancing sustainable finance and integrating climate-related risks into financial supervision and regulation.

3. Climate data initiatives in Indonesia

Climate-related data is crucial for the Indonesian financial regulators to assess financial institutions' exposure to climate risks and formulate initiatives for sustainable finance. Global initiatives have established benchmarks for sustainable finance metrics pertinent to financial authorities. However, there remains a necessity at the national level to address data deficiencies in a more detailed manner. This granular approach is important to enable the central bank identifying its exposure accurately and to support the central bank and other financial sector authorities devising tailored policies aimed at mitigating and adapting to climate-related financial risks, thereby safeguarding the stability of the financial system.

Indonesia's unique geographical location and diverse ecosystems render it particularly vulnerable to the impacts of climate change, ranging from sea-level rise and extreme weather events to biodiversity loss and ecosystem degradation. In response to these challenges, Indonesia has embarked on a series of initiatives aimed at strengthening its climate data infrastructure, enhancing data governance mechanisms, and promoting data-driven decision-making in the context of climate change mitigation and adaptation efforts. These initiatives reflect a multi-dimensional approach involving governmental agencies, financial institutions, private sector entities, and non-profit as well as civil society organizations to address the complex challenges posed by climate change and to facilitate sustainable development.

3.1. The Central Bank mandate on sustainable finance

In the Indonesian context, the enactment of the Financial Sector Omnibus Law (FSOL) has introduced significant regulatory mandates for Bank Indonesia. The legislative reforms aimed at strengthening and developing Indonesia financial sector and introduced by the law extend to amendments in the Central Bank Law, empowering Bank Indonesia with regulatory authority to oversee and foster sustainable finance. The mandate on sustainable finance for Bank Indonesia is integrated into the central bank's policy mix strategy[2], including macroprudential policy. By the law, the goal of macroprudential policy is to contribute in maintaining financial system stability that is achieved through promoting balanced and sustainable intermediation, mitigating and managing systemic risk, and enhancing inclusive and sustainable finance. The amendments to the Banking Law also entail collaborative efforts between Bank Indonesia and the Financial Services Authority (OJK) to ensure that financial institutions provide lending to support sustainable initiatives.

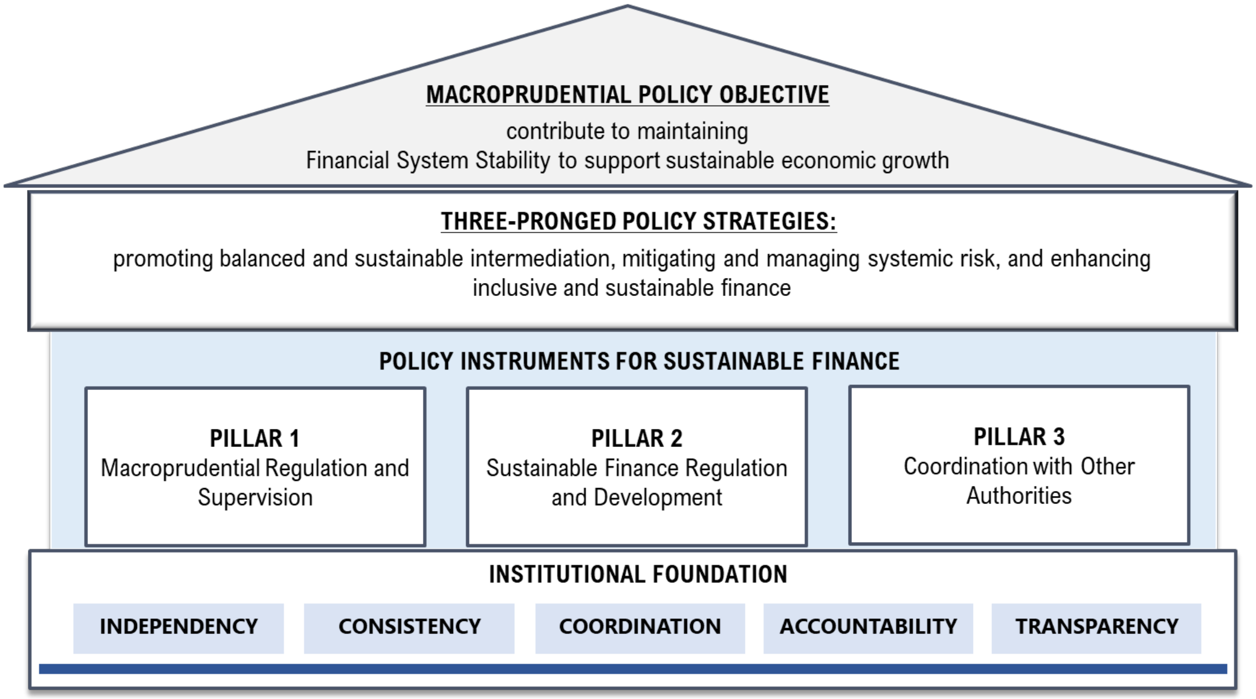


Figure 1. Sustainable Finance under the Macroprudential Policy Framework of the Central Bank

FSOL strengthens the role of financial sector regulators[3], namely the Ministry of Finance (MoF), Bank Indonesia (BI), and OJK, in promoting sustainable finance. Within the legal framework, sustainable finance is conceptualized as an ecosystem characterized by robust

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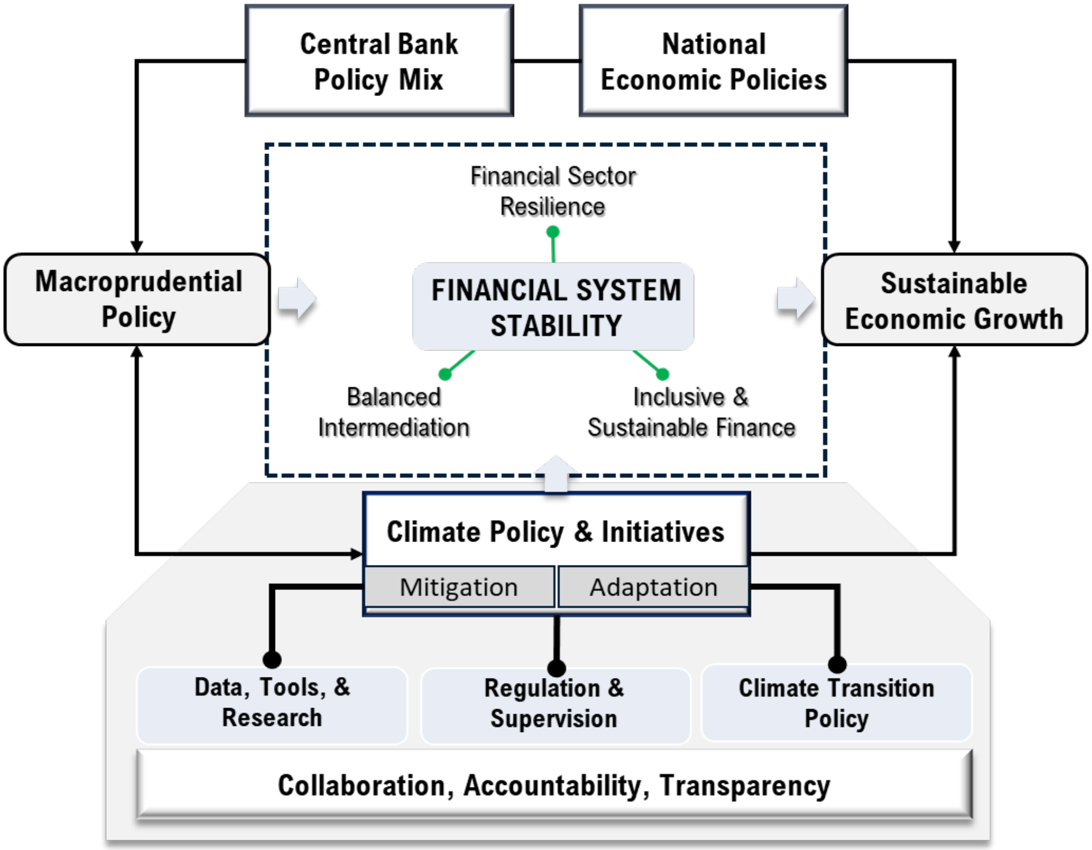
[2] Bank Indonesia employs policy mix strategy in alignment with its mandate to achieving Rupiah stability, maintain payment system stability, and contribute to overall financial system stability to bolster sustainable economic growth as mandated in the FSOL. The policy mix focuses on three pivotal aspects namely growth, stability, and inclusion. The adoption of this approach is necessitated by the interlinkages between the three main mandates, aligned with the evolving strategic environment characterized by increased complexity, globalization, and digitalization of the economy.

[3] Financial regulators in Indonesia have established the Financial System Stability Committee (KSSK) through the enactment of the Law of Republic of Indonesia No. 9 of 2016, which is further fortified by the FSOL. The committee is composed of four ministries/institutions: the MoF, BI, OJK, and the Indonesia Deposit Insurance Corporation (LPS). The primary mission of the Financial System Stability Committee is to oversee the prevention and resolution of Financial System Crises, ultimately safeguarding the economic interests and resilience of the state. Noting the importance of mitigating and adapting climate risk for ensuring financial system stability, the MoF, BI, and OJK are mandated to establish Sustainable Finance Committee.

support across various domains including policy, regulation, norms, standards, products, transactions, and financial services. This comprehensive framework aims to harmoniously integrate economic, environmental, and social imperatives, fostering both sustainable finance practices and the transition towards ecologically sound economic growth. Furthermore, to support sustainable finance, the financial sector regulators are entrusted with the mandate to:

a) Coordinating efforts in the formulation and the establishment of strategies, policies, and programs pertinent to Sustainable Finance.
b) Optimizing the utilization of fiscal, microprudential, monetary, payment system, and macroprudential policies to support sustainable finance.
c) Facilitating the development of sustainable finance databases and requisite infrastructure.
d) Collaborating in the formulation of a sustainable taxonomy framework.

The Ministry of Finance, Bank Indonesia, and OJK are additionally entrusted with the responsibility of establishing a Sustainable Finance Committee, intended to bolster their efforts in advancing sustainable finance initiatives. While the roles of the Sustainable Finance Committee are mainly to coordinate and optimize sustainable finance policies, Bank Indonesia and OJK are specifically given additional power in regulating the financial sector. While Bank Indonesia is authorized to regulate and develop sustainable finance, OJK is authorized to regulate and supervise carbon exchange. In addition, the law also authorizes OJK and Bank Indonesia to promote banks providing lending to sustainable activities.



Source: Juhro et al (2024).

Figure 2. Integrated Climate Policy framework to Support Sustainable Economic Growth

Recognizing the critical role of the financial sector in advancing sustainable finance and supporting sustainable economic growth, it is imperative for central banks to align financial sector policies to facilitate a just transition. This alignment involves harmonizing financial sector policies with national economic strategies aimed at transitioning to a low-carbon economy. Such national strategies establish commitments and targets for achieving sustainability in key sectors, thereby guiding the financial sector to support the financing of mitigation and adaptation initiatives. To ensure financial system stability and contribute to sustainable economic growth, macroprudential policies will be reinforced with climate policies and initiatives. These efforts encompass three main pillars: enhancing data, tools, and research capabilities; strengthening regulation and supervision of the financial sector; and supporting climate transition policies. Transformations in these areas will provide enabling environment for financial institutions to promote green finance by encouraging debtors to adopt low-carbon technologies or business processes, and by allocating more financing toward sustainable activities. These initiatives will be undertaken through collaboration, strong accountability, and reliable transparency principles, ensuring that each policy is prudently based to promote financial system stability and supporting sustainable economic growth.

3.2. Sustainability report

Firm-level sustainability reporting serves as a fundamental component of climate data management, offering stakeholders transparent insights into companies' environmental, social, and governance (ESG) performance. This section delineates key strategies for bolstering firm-level sustainability reporting, with a focus on adopting national sustainability reporting standards, enforcing mandatory reporting requirements, and advocating for robust data assurance mechanisms.

The adoption of national sustainability reporting standards in alignment with global benchmarks constitutes a pivotal stride towards standardizing sustainability reporting practices and enhancing data comparability, consistency, and reliability. By adhering to global best practices, companies can ensure that their sustainability disclosures meet international standards, enabling investors, regulators, and other stakeholders to make well-informed decisions and consistently evaluate companies' ESG performance. For instance, in response to the publication of the new IFRS sustainability disclosure standards (IFRS, 2023), Indonesia has established the Sustainability Standards Board to harmonize sustainability reporting with international benchmarks (IAI, 2023). The Sustainability Standards Board will undertake the task of adapting and instituting national sustainability disclosure standards which will outline firms' disclosure requirements encompassing climate strategy, risk management, governance, and metrics and targets. This endeavor aims to aid both firms and financial institutions in aligning their operational activities and portfolio management with sustainability considerations.

However, the effectiveness of such standards may be limited if not mandated. Implementing mandatory sustainability reporting requirements compels companies to divulge material ESG information in their financial reports, annual statements, or dedicated sustainability reports. Mandatory reporting fosters transparency, accountability, and stakeholder trust by ensuring companies disclose pertinent environmental and social risks and opportunities. Additionally, it standardizes sustainability disclosure practices across industries and sectors, facilitating benchmarking, peer comparison, and trend analysis. In alignment with this principle, the Financial Services Authority (OJK) in Indonesia, through regulation no. 51/POJK.03/2017, mandates financial institutions, public firms, and issuers to produce mandatory sustainability reports encompassing environmental impacts, social responsibilities, and governance practices (OJK, 2020).

Despite the increasing interest in publishing sustainability reports, challenges persist in ensuring the completeness and reliability of such reports. Assuring sustainability reports involves independent verification and validation of companies' sustainability disclosures by qualified auditors or assurance providers. Assurance bolsters the credibility and reliability of sustainability information, instilling confidence in stakeholders regarding the accuracy and completeness of reported data. Moreover, it assists companies in identifying gaps, inconsistencies, and areas for improvement in their sustainability reporting processes, thereby fostering continuous improvement and transparency.

Furthermore, it's imperative to note that the current sustainability reporting practices may not fully align with the new IFRS sustainability disclosure standards. Therefore, updating the existing reporting requirements to conform to the IFRS-aligned sustainability disclosure standard is essential. This update will enhance the comparability, consistency, and reliability of sustainability-related disclosures, empowering investors and stakeholders to make well-informed decisions and assess companies' environmental and social performance accurately.

3.3. Structured reporting

Sustainability reports serve as crucial components of climate data; however, their unstructured nature poses challenges. To address this issue, there is a growing recognition of the necessity for more structured reporting frameworks. In response, Bank Indonesia has undertaken initiatives to collect structured data concerning various aspects of sustainable finance. This includes data on mortgages for eco-friendly houses, loans for electric vehicle ownership, and ownership of sustainable bonds by banks. Additionally, the Financial Services Authority (OJK) has initiated pilot projects focused on bank loan reporting grounded in the Taxonomy for Sustainable Finance.

These endeavors in climate data collection aim to evaluate the feasibility and efficacy of incorporating sustainability criteria into bank lending decisions. By promoting the integration of environmental and social considerations into lending practices, these initiatives support the transition toward a more sustainable and resilient economy. Bank Indonesia has also mandated banks to report loan data based on project locations, collateral locations, and economic sectors, further enhancing the structured nature of climate finance reporting.

Complementing these efforts, the Ministry of Environment and Forestry (MEF) has compiled greenhouse gas (GHG) inventories based on nationally determined contributions (NDCs) sectors. Additionally, the National Agency for Disaster Countermeasures publishes a list of natural disaster events categorized by location. These datasets provide foundational information for conducting climate risk assessments and formulating effective policies to address climate change impacts.

Looking ahead, there is a forthcoming initiative aimed at enhancing transparency regarding carbon emissions associated with banking operations and financing activities (Scope 3 emissions). To calculate their financed emissions, banks need to require their debtors to disclose their emissions in sustainability reports. Given that firms seeking financing from banks are incentivized to publish comprehensive sustainability reports, this initiative is expected to encourage broader adoption of sustainability disclosure practices across industries.

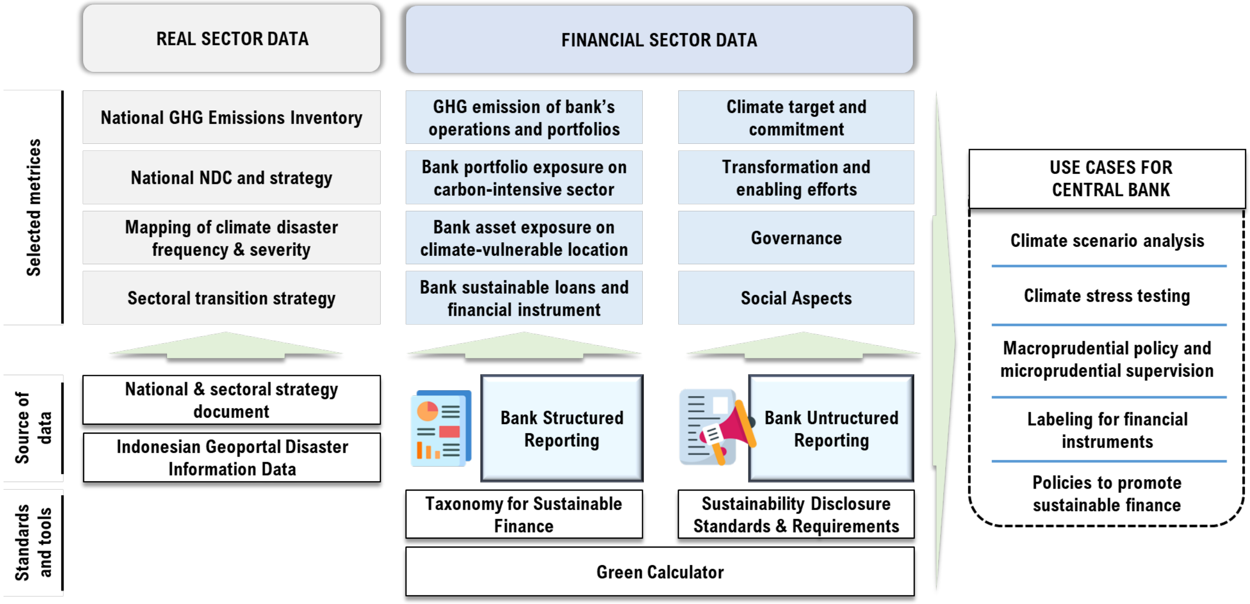


Figure 3. National Sustainability Data Landscape and Required Standards and Tools

3.4. Tools and infrastructure

Indonesia has embarked on a significant initiative to bolster sustainability reporting and climate data collection through the development of a Taxonomy for Sustainable Finance. This framework is designed to classify and standardize investments based on their environmental and social impacts, offering clarity and transparency to investors, financial institutions, and other stakeholders (OJK, 2020). Indonesia's Taxonomy for Sustainable Finance also builds upon the regional taxonomy (ASEAN Taxonomy for Sustainable Finance v2.0) to harmonize and foster interoperability between the national taxonomy and those of neighbouring regions. By providing a standardized classification system, the taxonomy facilitates the integration of sustainability considerations into investment decisions and capital allocation processes, thereby promoting investments that align with sustainability goals.

In addition to the Taxonomy for Sustainable Finance, the OJK has introduced climate risk stress test guidance and climate risk management and analysis tools. These resources serve as powerful instruments to help banks enhance their resilience to climate risks. By conducting stress tests and analyzing climate-related risks, banks can better understand and mitigate potential vulnerabilities in their operations and portfolios, thus safeguarding financial stability in the face of climate-related challenges.

Recognizing the pivotal role of firm-level sustainability in the successful implementation of transition agendas, financial regulators in Indonesia have launched several initiatives aimed at supporting firm-level disclosure. Bank Indonesia and OJK, with other members of the Indonesian Sustainability Standards Board, are preparing the adoption of the IFRS Sustainability Disclosure Standards into Indonesian standards. Multiple focus group discussions involving firms, academics, regulators, NGOs, consultants, financial institutions, and various stakeholders were conducted to examine the challenges and opportunities associated with the implementation of the IFRS sustainability disclosure standard. Key challenges identified include the establishment of infrastructure to ensure comparability of GHG emission calculations, the necessity for capacity building in calculating, reporting, and verifying GHG statements, as well as approach concerning the inclusion of scope 2 and scope 3 emissions.

Furthermore, Bank Indonesia is on progress to develop a carbon calculator aimed at assisting banks and their debtors in calculating and disclosing their carbon emissions in sustainability reports. This carbon calculator represents a standardized approach to quantifying carbon emissions, thereby enabling banks to align their financing portfolios with climate objectives. By providing stakeholders with insights into the carbon intensity of their operations and investments, the carbon calculator facilitates informed decision-making and identifies opportunities for emissions reductions. Ultimately, this initiative supports the transition towards a low-carbon economy by encouraging greater transparency and accountability in carbon emissions reporting and management across the banking sector.

Collectively, these initiatives across the financial authorities underscore Indonesia's commitment to advancing sustainability reporting and climate data collection. By providing stakeholders with the necessary tools and frameworks to assess and address climate-related risks and opportunities, Indonesia is fostering a financial sector that is better equipped to support the transition towards a sustainable and resilient future.

3.5. Regulation and Supervision

Bank Indonesia is taking significant strides toward promoting sustainable banking practices through a comprehensive set of initiatives aimed at incentivizing banks to finance green housing, electric vehicle (EV) ownership, and other sustainable projects. These efforts underscore Indonesia's commitment to fostering a sustainable and resilient financial sector.

One of the key initiatives undertaken by Bank Indonesia is the facilitation of green financing for eco-friendly housing and electric vehicle ownership. Banks are encouraged to provide mortgages for eco-friendly housing and loans for EV ownership with attractive terms, including up to 0% down payment and a 100% loan-to-value ratio. By making it easier for individuals to access financing for environmentally friendly initiatives, Bank Indonesia aims to accelerate the transition towards a greener economy.

To further incentivize banks to finance green projects, Indonesia has introduced macroprudential liquidity incentives. Banks that allocate funds towards green housing and EV ownership are eligible for liquidity incentives of up to around Rp35 trillion per December 2023.

These incentives are provided through the loosening of reserve requirements by up to 50 basis points, thereby freeing up capital for sustainable investments while ensuring financial stability.

In line with the Macroprudential Inclusive Financing Ratio requirements, banks are empowered to invest in green and sustainable bonds aimed at funding environmentally friendly projects. By incorporating green investments into their portfolios, banks not only contribute to sustainability objectives but also fulfill regulatory requirements, promoting a more inclusive and environmentally conscious financial sector. Furthermore, Bank Indonesia further incentivizes banks to align with inclusive financing requirements by participating in a blended finance platform focused on financing green projects. Through this platform, banks can leverage public and private funds to support sustainable initiatives, maximizing the impact of their investments while diversifying risk.

In addition to advocating for policies that accelerate the growth of sustainable finance, Bank Indonesia (BI) is taking initiatives to assess how climate risks may affect the financial sector in order to formulate policies that can safeguard financial system stability with regard to climate risk. Climate change introduces a novel dimension of risk to the financial landscape, primarily through physical and transition risks. Exposure to these risks can deteriorate the economy by destroying capital stock, reducing productivity, and diminishing wealth effects due to declining asset valuations, which may hinder borrowers' repayment capacity and, consequently, impact the financial sector. BI is developing a climate stress test framework that will provide the analytical foundation needed to formulate macroprudential policies addressing climate-related financial risks. Conducting scenario analyses and stress tests is anticipated to offer crucial insights for policy-making and financial sector surveillance. These efforts are expected to not only facilitate the transition towards economic and financial sector sustainability but also to mitigate the systemic risks associated with climate change.

In addition to domestic initiatives, Bank Indonesia is adopting a Sustainable and Responsible Investment framework in managing its international reserves. The country has allocated approximately USD 7 billion to invest in global sustainable bonds, thereby supporting sustainable development efforts beyond its borders.

4. Conclusion

The urgency to address climate change and its associated challenges has never been more pressing. As nations worldwide endeavor to mitigate greenhouse gas emissions, fortify resilience against climate impacts, and transition towards sustainability, the pivotal role of robust climate data infrastructure and governance mechanisms cannot be overstated. This paper has scrutinized the significance of climate-related data in shaping policy decisions, driving sustainable investments, and facilitating climate action, with a focused examination of Indonesia.

Indonesia has embarked on a substantial initiative to bolster sustainability reporting and climate data collection. Initiatives such as the development of a taxonomy for sustainable finance, climate risk stress test guidance, climate risk management, and analysis tools, as well as the introduction of a carbon calculator to aid banks in preparing sustainable reports, underscore the nation's commitment to advancing sustainability practices.

In terms of regulation and supervision, Bank Indonesia is also taking significant strides toward promoting sustainable banking practices through a comprehensive array of initiatives aimed at incentivizing banks to finance green housing, electric vehicle ownership, and other sustainable projects. These endeavors underscore Indonesia’s dedication to fostering a sustainable and resilient financial sector.

Looking ahead, stakeholders spanning from policy authorities, business, academia, and civil society must sustain collaborative efforts and innovative approaches to further fortify Indonesia's climate data infrastructure and governance mechanisms. Essential strategies include harmonizing sustainability reporting standards, mandating reporting requirements, and ensuring assurance for sustainability reports to bolster data transparency, accountability, and credibility.

By harnessing climate-related data effectively, Indonesia can enhance its understanding of climate risks, identify opportunities for sustainable growth, and mobilize resources towards climate-resilient and low-carbon pathways. Moreover, fortified climate data infrastructure and governance will enable Indonesia to fulfill its obligations under international agreements like the Paris Agreement and contribute meaningfully to global endeavors to combat climate change.

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IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

Enhancing climate resilience through geospatial analysis for use cases of JC3 climate data catalogue by Bank Negara Malaysia[1]

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

Enhancing Climate Resilience through Geospatial Analysis for Use Cases of JC3 Climate Data Catalogue by BNM[1]

Muhammad Nadzif Bin Ramlan

Abstract

Climate change threatens agriculture, water supply, health, and public infrastructure. Therefore, this paper discusses the creation of a resource by Bank Negara Malaysia (BNM) to mitigate these risks: the JC3 Climate Data Catalogue. Designed to address data gaps and support increased climate resilience in the Malaysian financial sector, the catalogue is developed in collaboration with the Securities Commission Malaysia. It supports scenario planning, product development, macroeconomic modelling, and stress testing. The paper describes the research and development around the catalogue's functionality and enhancements in the 2023 version, as well as the use cases pertinent to Malaysia including the socioeconomic impact of floods and the urban heat island (UHI) effect linked to deforestation. Using GeoTranslator and QGIS, the author created maps of affected areas, documenting socioeconomic impacts and highlighting regional disparities in flood damage, underscoring the need for tailored mitigation strategies. Google Earth Engine was utilised to analyse Land Surface Temperature (LST) data illustrating the UHI effect, emphasising the importance of effective urban planning and reforestation efforts.

The paper also addresses challenges in data availability, reliabiliyu, and comparability to provide suggestions for further developing the ICT infrastructure and maintaining stakeholder engagement. In a world where climate risks are becoming immediate concerns, financial institutions need the JC3 Climate Data Catalogue to support strategic and operational risk management processes while identifying opportunities in the transition to sustainable, low-carbon economies. This research demonstrates how comprehensive climate data can build resilience in Malaysia's financial sector and supports continued action to address the challenges posed by climate change.

Keywords: data gaps, data catalogue, geospatial analysis, socioeconomic impact, urban heat island, deforestation

JEL classification: G18, Q01, Q50, Q54, Q56

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This paper was originally titled "The Use Cases of JC3 Climate Data Catalogue by BNM In Bridging Data Gaps and Building Climate Resilience" at the CBRT-IFC Workshop on 6-7 May 2024.

Contents

1. Introduction

Climate change is a global issue and the challenges surrounding it take place over long periods of time, involving interactions between environmental, economic, political and institutional factors, facilitated by society or technology. It is anticipated to have strong impacts on the climate-sensitive sectors of agriculture, water, coast and health that manifests into significant international and intergenerational adverse effects (Ibrahim *et al.*, 2016). The Network for Greening the Financial System (NGFS) serves as an international platform to combat global warming. This voluntary grouping of central bankers and supervisors are the leaders in their efforts to help guide sustainability within financial systems.

In their report dating back to April 2019 entitled "A call for action: Climate change as a source of financial risk", they have released several recommendations in which Recommendation No. 3 is Bridging the Data Gaps. NGFS reckoned that public authorities share relevant data for Climate Risk Assessment (CRA) and make it publicly available. They also suggested setting up a joint working group to bridge existing data gaps, resulting in a detailed list of data items needed by authorities and financial institutions (FIs) to enhance the assessment of climate-related risks and opportunities. Currently, available data covers brief period, and risk-weighted assets are calculated on a one-year forward-looking basis. The NGFS is ready to initiate work with interested parties to establish a detailed list of currently lacking data items, allowing data providers to mine relevant data and progressively bridge gaps. This initiative aims to move from observation to action and improve the assessment of climate-related risks and opportunities.

Considering the general global call to act upon climate efforts, in September 2019, the Joint Committee on Climate Change (JC3) rose as a platform of collaboration within the Malaysian financial sector. This platform forged by Bank Negara Malaysia (BNM) and the Securities Commission Malaysia (SC) embodies the crucial role of regulatory cooperation in building climate resilience. The interconnectedness of financial and environmental strategies is further underscored by integrating climate data into national development plans, recognising both sectors as pillars of sustainable development. The fifth sub-committee, Bridging Data Gaps on Climate Change (Subcommittee), has been entrusted with facilitating the prioritisation of the initial use cases, which included scenario analysis, product development, macroeconomic modelling, and stress testing in addition to data to support investment and lending decisions. The Subcommittee collaborates with key public and private sector partners to identify and map critical data requirements to pertinent data sources for the use cases. The financial sector now has access to a catalogue of climate data compiled by the Subcommittee in 2022, followed by the enhanced version in 2023 entitled "JC3 Climate Data Catalogue".

In order to provide a local perspective, this paper analyses Bank Negara Malaysia's policies and actions via two research objectives:

i. Delves into the functionality and usage of JC3 Climate Data Catalogue

In this part, we examine how the Subcommittee strategically identifies climate-related issues and promotes comprehensive data availability, providing a full understanding of its multidimensional approach as we explore the functionality of the data catalogue.

ii. Use cases of JC3 Climate Data Catalogue

We will investigate two pertinent case studies relevant to the Malaysian context: Flood (Natural Disasters) and linking deforestation with urban heat island (UHI) as well as to consider any other risk related (e.g. transition risk).

2. The Highlight: JC3 Data Catalogue

The JC3 Climate Data Catalogue, inaugurated in December 2022, serves as a crucial reference point for climate and environmental data relevant to the financial sector.

As shown in Table 1, the Subcommittee has identified eight use cases along with their brief descriptions. This is based on the use cases identified by NGFS and consultations with five key stakeholder groups comprising financial sector regulators (BNM, SC, Bursa Malaysia), pension and provident funds, asset managers, banking institutions, insurers and takaful operators, and asset managers. Product development is an additional use case in comparison to the NGFS' use cases, given the critical role that FIs play in financing transitions via the expansion and upscaling of green financial solutions.

Use Cases Identified by the Subcommittee on Bridging Data Gaps Table 1

Use Case	Description
Climate-related disclosures	Reports by corporations on climate-related factors, used for analysis and monitoring. Global frameworks like TCFD facilitate consistent disclosure. Malaysia's Bursa Malaysia has enhanced its Sustainability Reporting Framework, requiring Main Market listed issuers to provide TCFD-aligned disclosures by 2025.
Exposure quantification	Potential loss on financial instruments, assessing physical risk and transition risk, and assessing portfolio adjustments towards low-carbon economies.
Financial stability monitoring	Assessment of financial system vulnerabilities, recognising systemic risks and climate change-related impacts. Malaysia's regulators – BNM and SC – assess climate-related risks' potential impact on the financial system and capital market.
Investment and lending decisions	The decision-making process involves both demand-side and supply-side factors such as footprint, vulnerability, mobilisation, and alignment when deciding on funds for investment opportunities or loans, focusing on low carbon activities.
Macroeconomic modelling	Analyses of climate-related impacts on GDP, employment, and inflation in Malaysia, focusing on transition risk and physical risk/vulnerability associated with extreme weather conditions.
Product development	The development of new financial products and solutions to support green growth and industry alignment with climate agendas, exploration of intermediation structures, and increased financing and protection solutions.
Scenario analysis	The NGFS has designed six scenarios to assess climate change risks, while BNM issued the Policy Document on Climate Risk Management and Scenario Analysis in December 2022, aiming to enhance financial institutions' resilience and facilitate a low-carbon economy transition.

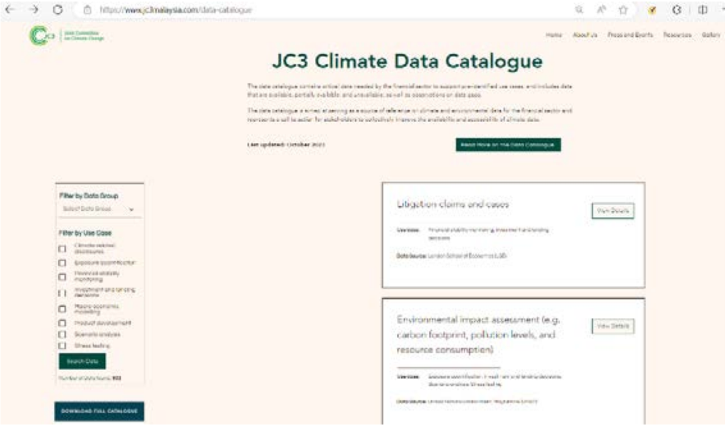
Stress testing	BNM proposes a risk framework method focusing on climate change's impact on exposures' actual risk, with industry-wide Climate Risk Stress Testing (CRST) exercise set to be implemented in 2024.

Finally in October 2023, The Joint Committee on Climate Change (JC3)’s Subcommittee on Bridging Data Gaps released an enhanced JC3 Climate Data Catalogue (DC), tackling critical data gaps in climate and environmental information for the financial sector. This part dives into the upgraded DC, highlighting its newest structure, accessibility, and functionality.

The new Relational Spreadsheet Structure (RSS) streamlines search and updates, making the DC user-friendly and intuitive in discovering 128 unique environmental and climate-related data items with 249 granular data, categorised into 14 data groups, and mapped to relevant NGFS use cases. This data catalogue with a 68% availability rate, empowers users to conduct in-depth analyses and make informed decisions.

With improved navigation, filtering, and even potential API integration, users can access and analyse data with ease. Its structured format allows for future expansion and seamless integration with diverse platforms, paving the way for a robust, fully relational database. This ensures the DC stays relevant and adaptable, serving the evolving needs of users and the financial sector. New data inputs are readily accommodated, integrated into the existing framework without compromising coherence. This ensures a consistently high-quality dataset that users can trust to inform vital decisions.

Homepage of the JC3 Climate Data Catalogue Diagram 1



Source: https://www.jc3malaysia.com/data-catalogue. Accessed on 19 April 2024.

The 2023 JC3 Climate Data Catalogue (DC) improves in terms of data availability, marking a major step forward in supporting the Malaysian financial sector's climate resilience endeavours. Referring to Chart 1, compared to the 2022 edition, available data items increase from 49% to 68%, representing a 19% increase in overall accessibility.

Even when accounting for the expanded scope of data items in 2023, the availability of existing items from the 2022 DC showed a 6% improvement, rising from

49% to 55%. This positive trend owes credit to broader data dissemination by government agencies, such as flood-related information from the Department of Irrigation and Drainage (DID) and the Department of Statistics Malaysia (DOSM).

The DC now also features:

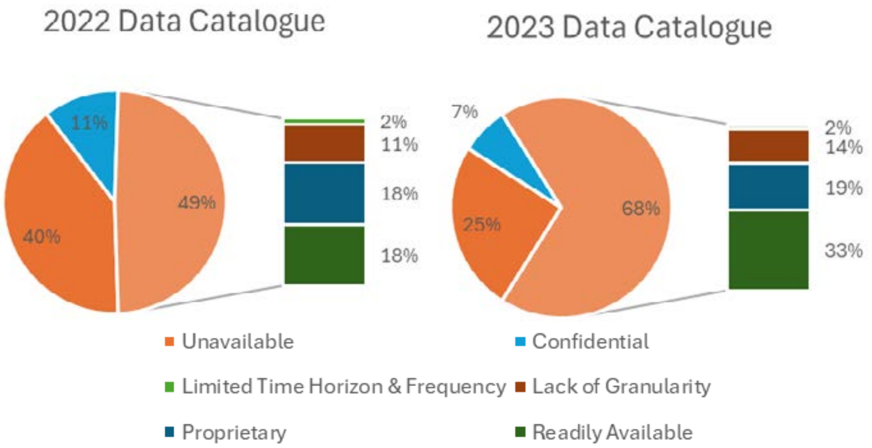
i. A richer data ecosystem with 399 data sources across 135 providers, spanning diverse institutions like the World Bank, the International Energy Agency, and domestic players like the Department of Statistics Malaysia (DOSM) and the Energy Commission.

ii. A 56% increase in data items, offering 46 new data points for exploration, primarily focusing on critical areas like energy, water, physical risk exposure, and GHG emissions aligned with TNFD and ISSB requirements.

iii. Enhanced existing data: 43 items from the 2022 DC have been updated with improved standards, methodology, time series coverage, and additional data sources, ensuring greater accuracy and depth.

Comparison of DC Content Between 2022-2023

Chart 1



Source: JC3 Climate Data Catalogue, as of April 2024.

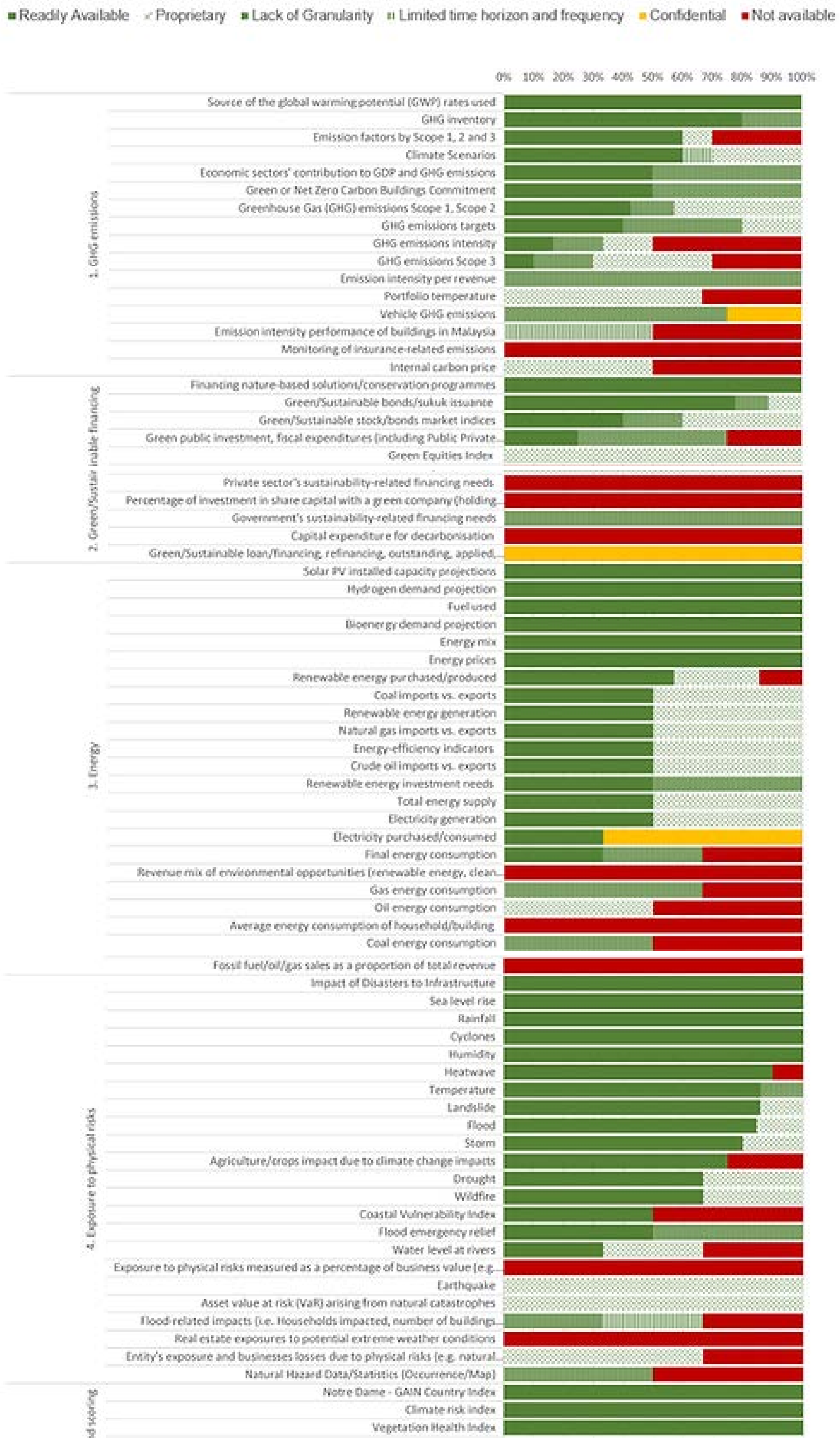
While the 68% availability mark is plausible, further work remains. Within this category: 33% of data is readily available, offering direct access without barriers; 19% remains proprietary, requiring subscription or other forms of access limitation; 16% faces gaps due to granularity and time horizon limitations, particularly in areas like government sustainability-related financing needs and flood-related impacts.

The DC's progress underscores the increasing commitment to filling critical data gaps and equipping the financial sector with the tools needed to navigate climate change challenges. Continued collaboration between data providers, regulators, and users is crucial for unlocking the full potential of this valuable resource and building a robust climate-resilient future for Malaysia.

Diagram 2 shows the summary for Data Groups, Data Items and Status of Availability in the Climate Data Catalogue scrutinising the composition of data availability within the data groups.

Data Groups, Data Items and Status of Availability of JC3 Climate Data Catalogue

Diagram 2



Source: Data Groups, Data Items and Status of Availability from Appendix A (https://www.jc3malaysia.com/about-data-catalogue), as of April 2024.

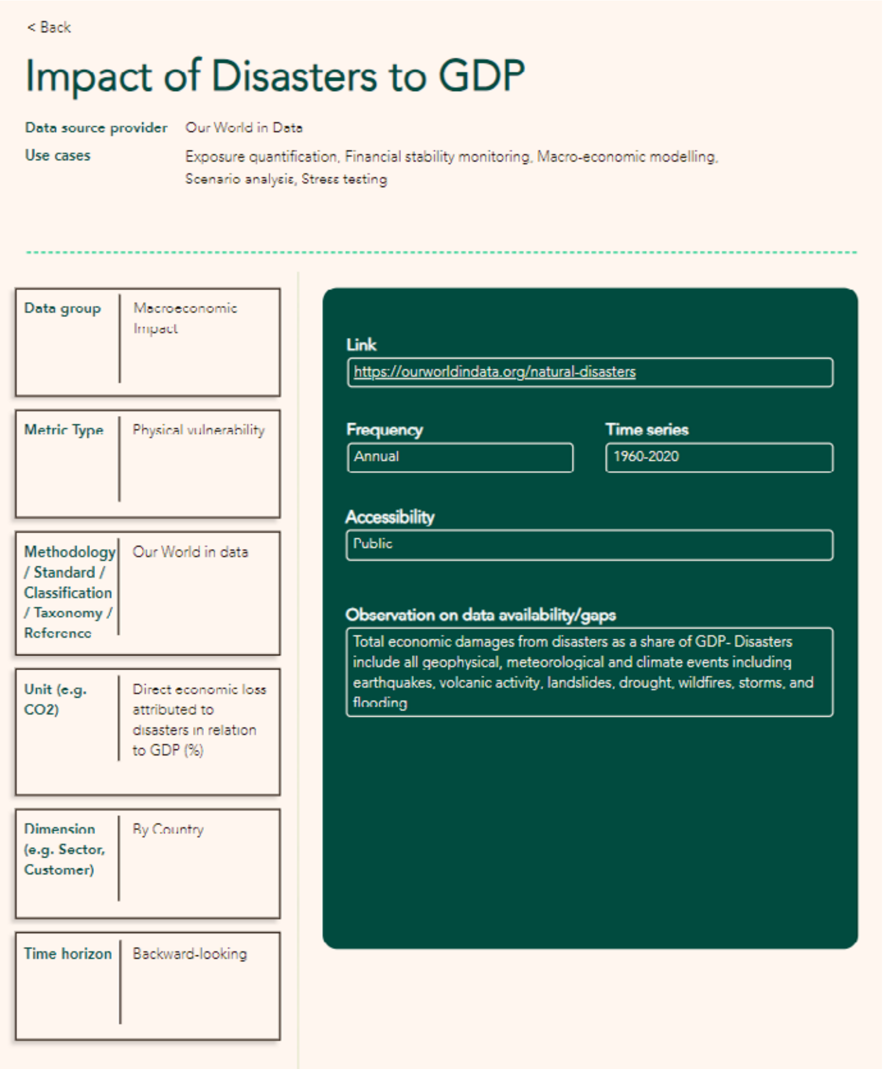
The DC is more than just a reference point. It actively promotes awareness of data gaps, urging data providers to improve accessibility and fill critical knowledge voids. This collaborative approach fosters a robust climate data ecosystem that benefits everyone. The DC prioritises Malaysian climate and environmental data, aligning with the Network for Greening the Financial System (NGFS) protocols. However, its reach extends beyond borders, incorporating relevant global data sources for a comprehensive view. It lays the groundwork for a national-level climate data catalogue, empowering all stakeholders across Malaysia to address climate challenges effectively.

3. Use Cases of JC3 Climate Data Catalogue

Socioeconomic Impact of Flood

Utilising the data catalogue, a reference to comprehend the effect of flood upon Malaysia would be *Our World in Data* (Natural Disasters - Our World in Data) as shown from the data catalogue interface below.

Impact of Disasters to GDP in JC3 Climate Data Catalogue Finding Diagram 3



Impact of Disasters to GDP

Data source provider Our World in Data

Use cases Exposure quantification, Financial stability monitoring, Macro-economic modelling, Scenario analysis, Stress testing

Data group Macroeconomic Impact

Metric Type Physical vulnerability

Methodology / Standard / Classification / Taxonomy / Reference Our World in data

Unit (e.g. CO2) Direct economic loss attributed to disasters in relation to GDP (%)

Dimension (e.g. Sector, Customer) By Country

Time horizon Backward-looking

Link https://ourworldindata.org/natural-disasters

Frequency Annual

Time series 1960-2020

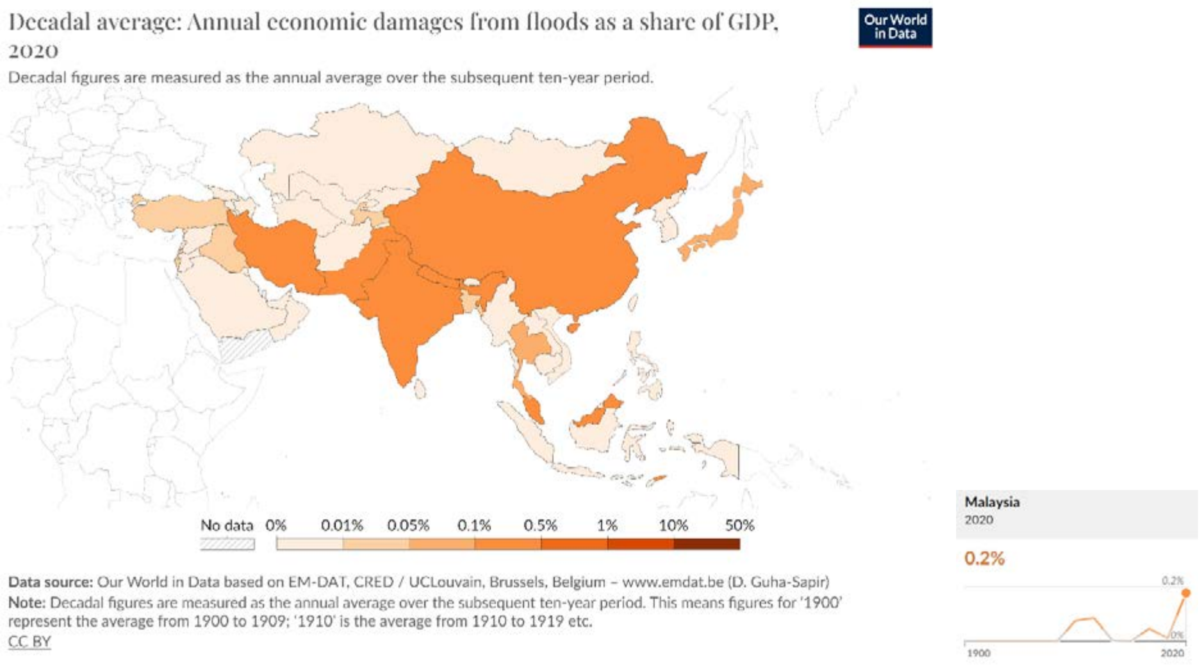
Accessibility Public

Observation on data availability/gaps Total economic damages from disasters as a share of GDP- Disasters include all geophysical, meteorological and climate events including earthquakes, volcanic activity, landslides, drought, wildfires, storms, and flooding

Source: https://www.jc3malaysia.com/data-catalogue/impact-of-disasters-to-gdp/424. Accessed in April 2024.

The preliminary information about the website is already provided such as the data group, metric type (in terms of measurement dimension), reference or taxonomy, the subject of measurement, dimension and the time horizon associated. This would aid researchers in getting prior insights into such data and thus facilitate more time-efficient research endeavours.

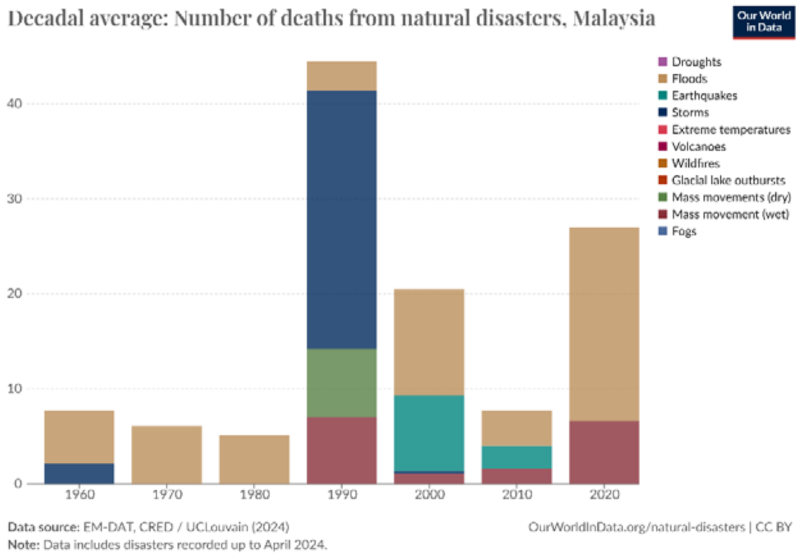
Decadal Average of Economic Damages from Floods Upon GDP (%), 2020 Diagram 4



Data source: Our World in Data based on EM-DAT, CRED / UCLouvain, Brussels, Belgium – www.emdat.be (D. Guha-Sapir)
Note: Decadal figures are measured as the annual average over the subsequent ten-year period. This means figures for '1900' represent the average from 1900 to 1909; '1910' is the average from 1910 to 1919 etc.
CC BY

Source: Ritchie and Rosado (2022) - "Natural Disasters". Data adapted from EM-DAT, CRED / UCLouvain

Decadal Average of Number of Deaths from Natural Disasters in Malaysia Chart 2



Data source: EM-DAT, CRED / UCLouvain (2024)
Note: Data includes disasters recorded up to April 2024.

Source: Ritchie and Rosado (2022) - "Natural Disasters". Data adapted from EM-DAT, CRED / UCLouvain.

Diagram 4 shows the decadal average for the yearly economic impact of flood upon GDP in the Asian region for the 2011-2020 period and Malaysia records the 5th highest figure at 0.2% from GDP after Iran (0.33%), India (0.27%), Pakistan (0.25%), and Timor-Leste (0.23%). Chart 2 meanwhile ascertains the severity of flood in

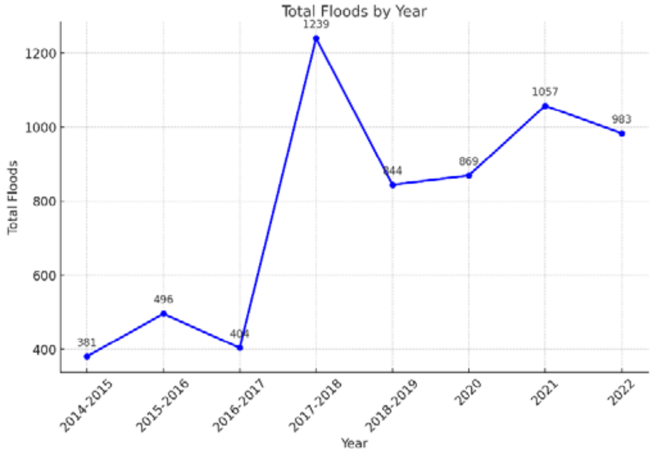
Malaysia as it is prevalent among the major cause of deaths from natural disasters from 1960-2020. Malaysia will likely experience significant consequences from climate change, as demonstrated by a predicted average annual surface temperature increase of 1.9 to 2.1°C by the end of the century and a sea level rise of roughly 0.7m by the end of the twenty-first century. This might have an impact on the country's economy, agriculture, industry, tourism, and energy, disproportionately affecting the population.

Malaysia is using both structural and non-structural solutions to adapt to and mitigate floods. These encompass the adoption of nature-based solutions, the development of plans for sub-national implementation, and the periodic maintenance of flood mitigation infrastructures and early warning and forecasting systems. Effective CEPA and regulatory intervention are required to promote sustainable and future-proof water management. Malaysia is implementing a comprehensive strategy to address identified critical and vulnerable areas, which includes subnational cooperation and routine river basin maintenance. The financial provisions designated for flood mitigation initiatives have been augmented by RM19 billion and RM5 billion, respectively, in the Eleventh and Twelfth Malaysia plans. Incorporating nature-based solutions, integrating water resources management, integrating river basin management, and implementing integrated flood management are all components of non-structural flood mitigation.

Therefore, the methodology to be utilised would be via i) geocoding via the Malaysian government's application GeoTranslator to specifically locate the affected or risky locations pertaining to flood across the country, based on the government information such as Public Info Banjir (Public Flood Info) and also data extraction from Annual Data Reporting by the Department of Irrigation and Drainage (DID) from 2014-2022; followed by ii) utilising the QGIS software for the geomapping of the specific locations involved to evaluate the socioeconomic impact upon the residents and the specific policy recommendations for this situation.

Annual Flood Occurrences by Year

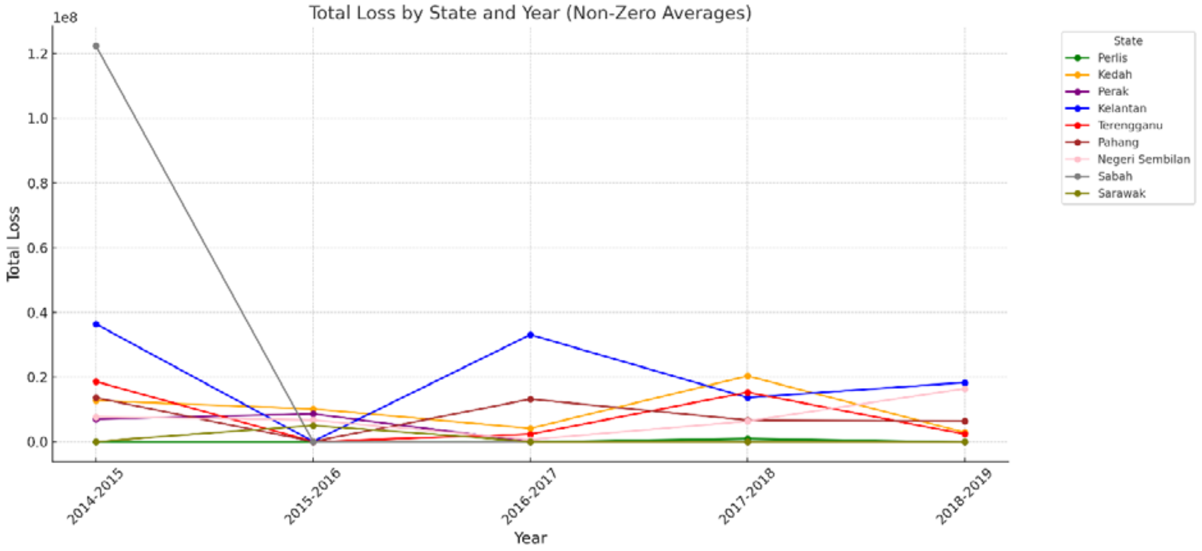
Chart 3



Source: Annual flood reports since 2014-2022 by Department of Irrigation and Drainages (DID), Malaysia, author's own illustration

The Malaysian flood data from 2014 to 2022 in Chart 3 reveals a volatile pattern with a significant spike in 2017, prompting a review of flood mitigation tactics, suggesting the need for sturdier infrastructure, and highlighting the necessity of factoring flood risks into urban planning and resource distribution. This trend also emphasises the importance of public awareness and the urgency for ongoing research aimed at sustainable environmental practices in the face of climate change. Despite a marginal decrease in floods in 2022, the data remains essential for refining flood management strategies and enhancing emergency preparedness.

Total Loss by State and Year (Non-Zero Averages) Chart 4



States with recorded zero average losses are not included: FT Kuala Lumpur, FT Labuan, FT Putrajaya, Selangor, Melaka, Johor, Penang. The loss estimation figures are no longer available in the 2020 Annual Flood Report and beyond

Source: Annual flood reports since 2014-2019 by Department of Irrigation and Drainages (DID), Malaysia, author's own illustration

These are the average loss estimation from 2014-2019 based on Chart 4 across 5 years (in descending order):

Sabah: 24,491,000; Kelantan: 20,281,880; Kedah: 10,016,680

Pahang: 7,945,800; Terengganu: 7,685,400; Negeri Sembilan: 7,534,900

Perak: 3,103,900; Sarawak: 1,001,000; Perlis: 178,000

The data reveals significant variability in collateral losses across states and years, with some regions being more vulnerable to catastrophic events. These losses can have profound socioeconomic consequences, such as disruptions to infrastructure, food security, health, and economic activities. Some states have managed to reduce losses over time, indicating effective recovery efforts and improved resilience. However, high collateral damages may affect insurance premiums, availability of insurance, and financial health, potentially impacting the region's economic viability. Repeated high losses in certain areas could deter investment and lead to migration to less risky areas, affecting the local labour market and economy. Government policy and aid may be influenced by the pattern of losses, potentially leading to more targeted disaster preparedness and mitigation programmes. Social cohesion can also be impacted by disaster responses, with effective community response strengthening social ties. Yearly trends show decreases in losses, suggesting improvement or less severe flood events. The data can be used for forecasting and planning, guiding risk assessments and designing socioeconomic policies to mitigate the adverse effects of future flooding events.

To further assist the risk assessments as such, we can utilise the geospatial analysis to visualise the extent of impact across the country, by referencing the latest Annual Flood Report (2022) for such purposes. Based on the report, we geocoded 2,290 locations using the Malaysian government website, GeoTranslator.

Afterwards, the geomapping is done via the QGIS software according to the Malaysian districts, with the overlaying of coordinates above. Below are some of the findings from the geocoding:

Unique Count of Affected Locations by State

In Descending Order

Table 2

No.	State	Total	No.	State	Total
1	Sarawak	479	8	Negeri Sembilan	114
2	Sabah	419	9	Pahang	99
3	Kedah	315	10	Melaka	64
4	Selangor	226	11	Penang	56
5	Johor	173	12	Federal Territories	49
6	Kelantan	144	13	Perak	15
7	Terengganu	131	14	Perlis	6

Note: Sarawak and Sabah have much more granular flood locations such as schools, offices, indigenous community houses etc. compared to those in Peninsular Malaysia based on the 2022 Annual Flood Report. The counting is based on one-time occurrence.

Most Affected District by State

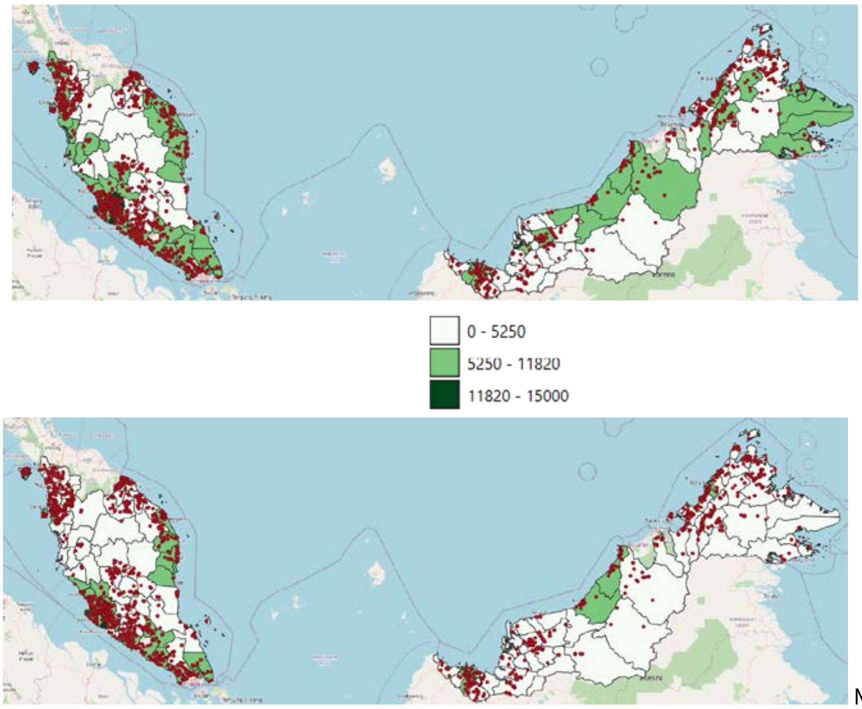
Table 3

State	District	Total	State	District	Total
Sarawak	Sibu, Kanowit & Selangau	233	Negeri Sembilan	Kuala Pilah	41
Sabah	Beluran	87	Pahang	Raub	39
Kedah	Baling	158	Melaka	Alor Gajah	45
Selangor	Klang	84	Penang	Barat Daya	25
Johor	Batu Pahat	60	Federal Territories	Kuala Lumpur	46
Kelantan	Kuala Krai	42	Perak	Kinta	7
Terengganu	Besut	31	Perlis	Kangar	4

Note: Sarawak and Sabah have much more granular flood locations such as schools, offices, indigenous community houses etc. compared to those in Peninsular Malaysia based on the 2022 Annual Flood Report. The counting includes repetitive cases.

The interrelation of socioeconomic factors and flood incidence in Malaysia, as depicted through analytical mapping, paints a multifaceted picture of how disparities in wealth both shape and are shaped by the onslaught of natural disasters. The color-coded maps not only demarcate districts by income levels and Gini coefficients — a statistical measure of income inequality — but also overlay the stark realities of flood occurrences, visualised through red dots that mar the landscape.

Mean & Median Income Distribution by District Diagram 5



Mean Income

Median Income

[2]Bottom 40 (B40) monthly income threshold is below RM5,250; Middle 40 (M40) monthly income threshold is between RM5,250-RM11,820; Top 20 (T20) monthly income threshold is beyond RM11,820

Source: QGIS, author's own illustration

In the economically vulnerable B40 districts where both the mean and median incomes suggest limited financial means, a high density of flood occurrences (36.65% for mean income, 60.56% for median income) reveals the disproportionate impact on these already strained communities. These are not mere watermarks on a map but indicators of deeper susceptibility to disaster, where the lack of resources amplifies the hardships wrought by flooding. Meanwhile, the green-coded M40 districts, which exhibit greater economic stability, still show a significant presence of flood events (55.89% for mean income, 59.12% for median income). These districts face the dual challenge of ensuring their infrastructural and fiscal capacities can weather the floodwaters while avoiding a false sense of security due to their middle-ground economic status. Conversely, the dark green T20 districts, with their sparse flood occurrences (7.46% for mean income, 1.44% for median income, exclusively in Sepang district), illustrate the buffering effect of affluence against floods. Here, robust economic underpinnings presumably support stronger flood defences and recovery strategies. However, the infrequent but present flood events remind us that wealth

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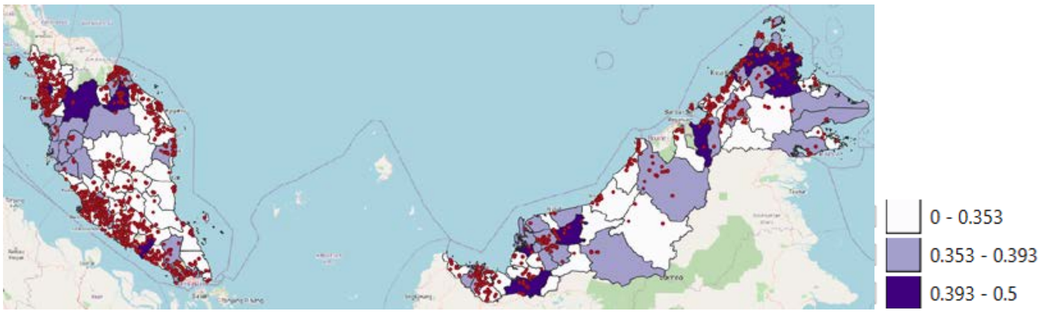
[2] Refer to the Household Income Survey Report 2022, page 52. Released by Department of Statistics Malaysia (DOSM): https://www.dosm.gov.my/portal-main/release-content/household-income-survey-report--malaysia--states

cannot entirely ward off the vagaries of nature; affluence can mitigate but not wholly eliminate flood risk.

Gini Coefficient for Disposable Income by District

Diagram 6



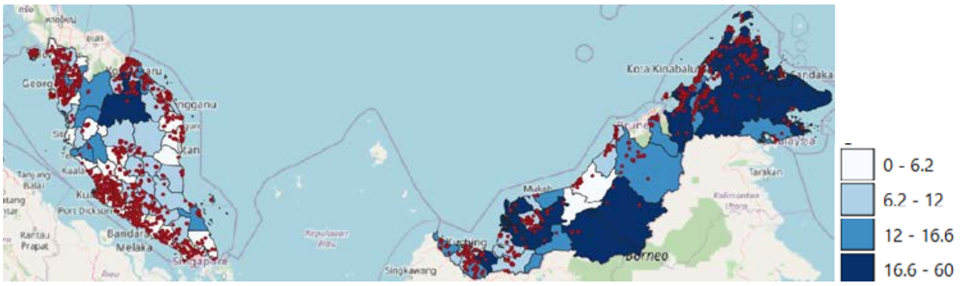
[3]0.353 is the average GC in rural region for disposable income, 0.393 is the national GC for disposable income

Source: QGIS, author's own illustration

The purple hues on the maps indicate a Gini coefficient reflective of the national average, portraying a moderate level of income inequality. Flood events distributed across these districts suggest that while income disparities are prevalent, they are not the sole determinants of flood risk. Notably, 9.60% of floods occurred in districts with a higher-than-national Gini coefficient of 0.393, and 45.16% of flood occurrences are in areas with a Gini coefficient beyond the rural average of 0.353. This distribution implies that greater income inequality within a district may correlate with increased vulnerability to floods. These findings underscore the need for policies that bridge the divide, ensuring that relief and recovery efforts effectively reach the most disadvantaged communities.

Poverty Rate (%) by District

Diagram 7



[4]6.2% is the national absolute poverty rate, 12% is the absolute rural poverty rate, 16.6% is national relative poverty rate

Source: QGIS, author's own illustration

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[3] Refer to the 2022 Highlights: Income, Expenditure Poverty Inequality, page 168. Released by DOSM: https://www.dosm.gov.my/uploads/release-content/file_20230808213355.pdf

[4] Refer to the 2022 Poverty in Malaysia report, page 4. Released by DOSM: https://www.dosm.gov.my/uploads/release-content/file_20230806212629.pdf

Layered atop this narrative is the reality of poverty rates, represented by varying shades of blue indicating escalating percentages from below the national average to areas where relative poverty ensnares a sizable portion of households. The overlapping of flood locations with these regions delivers a stark message: the higher the poverty rate, the more pronounced the impact of flooding. Notably, 45.86% of flood occurrences are in districts with poverty rates exceeding the national average of 6.2%. Furthermore, 16.89% of flood occurrences are in districts with poverty rates higher than the national relative poverty rate of 16.6%, with larger concentrations in states like Kelantan in Peninsular Malaysia, and Sabah and Sarawak on Borneo Island. This is especially alarming in Sabah, where one district, Pitas, registered ~2.3% (53) of flood locations with a poverty rate of 52.7%, indicating that half the population lives in subnormal conditions exacerbated by natural disasters. This reveals an urgent need for targeted interventions to address the dual challenges of poverty and flood risk, highlighting the critical importance of building robust support systems for the most vulnerable, not just for immediate relief but also for enduring risk reduction and poverty alleviation.

The academic discourse on disaster management would emphasise the strategic integration of development planning with disaster preparedness, stressing that effective poverty reduction is integral to enhancing societal resilience to environmental hazards. To mitigate the compounded threats of poverty and flooding, policies must be devised to bolster infrastructural defences, enhance early warning systems, and foster equitable access to disaster response mechanisms. Furthermore, fortifying the economic base of communities through diversification of livelihoods and the strengthening of social safety nets can augment their intrinsic resilience.

In sum, the maps advocate for a comprehensive and integrative approach that recognises poverty reduction as an essential component of disaster resilience. This approach calls for a calibrated distribution of resources that acknowledges the differential impacts of flooding, aspiring to a harmonious balance where resilience becomes a shared asset of the Malaysian nation, ensuring that no district is left to navigate the tempest alone.

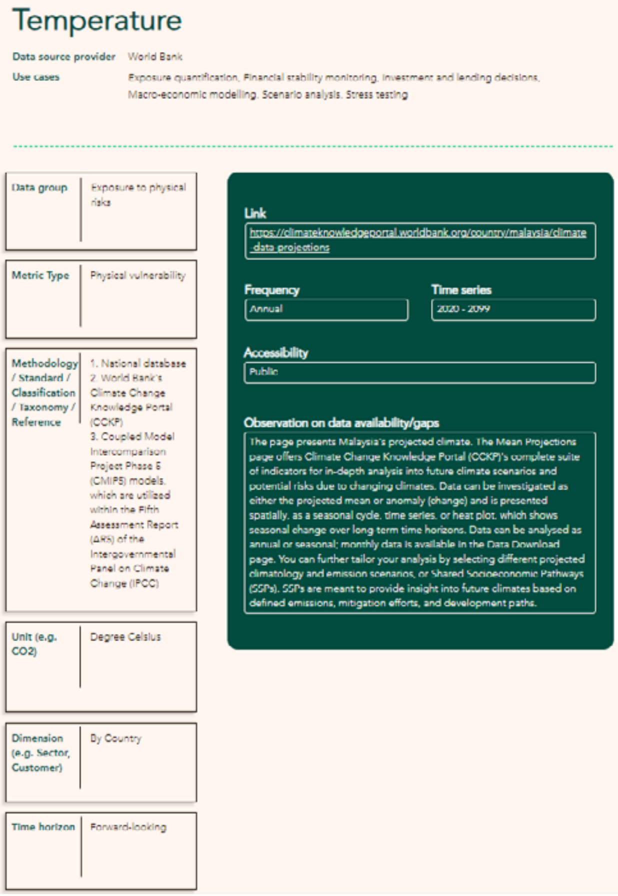
Urban Heat Islands Relating to Deforestation

Urban heat islands (UHIs) are geographical territories characterised by notably elevated temperatures in comparison to their surroundings. This phenomenon is the result of land surface temperature (LST), deforestation, and urbanisation interacting in a complex manner.

Deforestation causes fluctuations in the reflectivity of the land surface and disrupts natural cooling mechanisms such as evapotranspiration; both factors contribute to heightened heat absorption in urban regions. Urbanisation exacerbates the UHI effect through its proliferation of heat-generating activities and an abundance of impervious surfaces (Ramakreshnan, 2022). The LST, which is quantified via remote sensing, is an essential metric for assessing the intensity of UHI by illuminating the spatial pattern and gravity of the issue. Preserving and restoring forests, promoting sustainable urban design with an emphasis on green spaces, and utilising LST data to inform heat mitigation strategies are all elements that must be addressed in order to mitigate UHIs. We can only construct more resilient and comfortable cities in the face of rising temperatures by adopting such a comprehensive strategy.

To start off, one of the appropriate sources to acquire the general view of Malaysian temperature landscape would be the Climate Knowledge Portal by the World Bank[5] and can be shown via the data catalogue interface below:

Malaysia's Projected Climate in JC3 Climate Data Catalogue Finding Diagram 8



Temperature

Data source provider World Bank

Use cases Exposure quantification, Financial stability monitoring, Investment and lending decisions, Macro-economic modelling, Scenario analysis, Stress testing

Data group	Exposure to physical risks
Metric Type	Physical vulnerability
Methodology / Standard / Classification / Taxonomy / Reference	1. National database 2. World Bank's Climate Change Knowledge Portal (CCKP) 3. Coupled Model Intercomparison Project Phase 5 (CMIP5) models, which are utilized within the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC)
Unit (e.g. CO2)	Degree Celsius
Dimension (e.g. Sector, Customer)	By Country
Time horizon	Forward-looking

Link
https://climateknowledgeportal.worldbank.org/country/malaysia/climate-data-projections

Frequency
Annual

Time series
2020 - 2099

Accessibility
Public

Observation on data availability/gaps
The page presents Malaysia's projected climate. The Mean Projections page offers Climate Change Knowledge Portal (CCKP)'s complete suite of indicators for in-depth analysis into future climate scenarios and potential risks due to changing climates. Data can be investigated as either the projected mean or anomaly (change) and is presented spatially, as a seasonal cycle, time series, or heat plot, which shows seasonal change over long term time horizons. Data can be analysed as annual or seasonal; monthly data is available in the Data Download page. You can further tailor your analysis by selecting different projected climatology and emission scenarios, or Shared Socioeconomic Pathways (SSPs). SSPs are meant to provide insight into future climates based on defined emissions, mitigation efforts, and development paths.

Source: JC3 Climate Data Catalogue (https://www.jc3malaysia.com/data-catalogue/temperature/179). Accessed on 15 Jan 2024.

Some of the insights we can acquire from the website include Heat Risk, Climate Data Projections as shown in Diagram 9:

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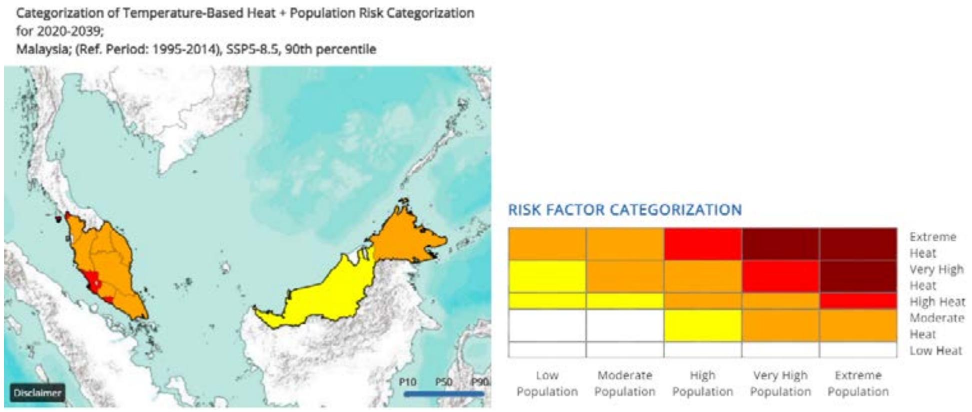
[5] Refer to the following website: https://climateknowledgeportal.worldbank.org/country/malaysia

Risk-Factor Categorisation for Malaysia, 2020-2039

Diagram 9



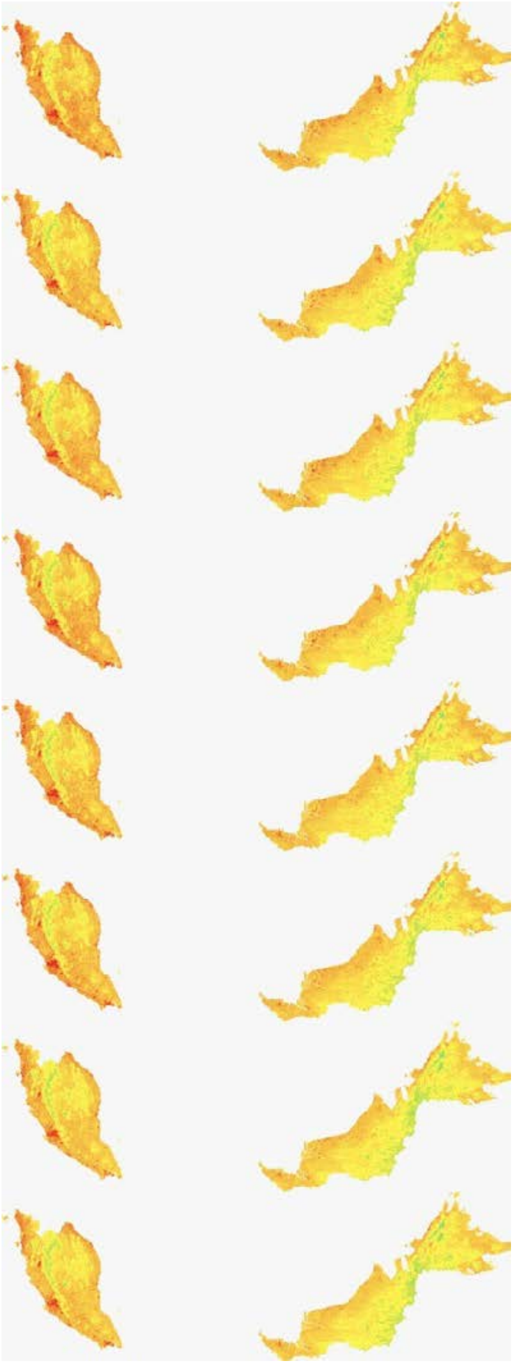
Source: World Bank, Climate Change Knowledge Portal (2024). URL: https://climateknowledgeportal.worldbank.org/ Date Accessed on 15 Jan 2024.

In the face of a ‘boiling’ world, FIs find themselves at the crossroads of risk and responsibility. The climate data, encapsulated in Diagram 9, provides a categorical risk framework for Malaysia from 2020 to 2039 under the SSP5-8.5 high-emission scenario, forecasting a substantial increase in days with temperatures exceeding 35°C. This backdrop lays the groundwork for an acute understanding of the environmental challenges and opportunities that FIs face. The elevated risk of heat stress, particularly in the interior of the Malay Peninsula as well as the northern regions of East Malaysia, would suggest significant exposure to physical risks due to climate change. This is a key input for FIs as they assess the vulnerability of their investments, especially in sectors like agriculture, real estate, and infrastructure. With hot temperatures correlating with increased energy demand, FIs must recalibrate their portfolios to prioritise resilience and adaptability.

Because heatwaves can have severe consequences for human health particularly for vulnerable populations such as the elderly, small children, and those with chronic conditions, these projections are cause for concern. Additionally, wildfires, water scarcity, and elevated air pollution levels can result from heatwaves (Bansal *et al.*, 2023).

Therefore, the paper has explored the technicalities of this aspect, using tools such as Google Earth Engine to analyse the impact of LST on urban climate dynamics, revealing trends and correlations with factors like urbanisation, deforestation, and precipitation across Malaysia. The study emphasises the importance of strategic urban planning and sustainable practices to mitigate adverse effects and envision future LST trends, advocating for collaborative efforts for climate action and sustainable development.

LST Trend Across Malaysia from 2016 - 2023 Diagram 10



Source: Google Earth Engine

Starting with Diagram 10 showing recent LST analysis for Malaysia spanning from 2016 to 2023, there is a discernible warming trend, particularly in regions like Kuala Lumpur and Johor Bahru. The red hues, indicative of higher temperatures, suggest an intensification of the urban heat island (UHI) effect. This phenomenon is critical for financial institutions (FIs) to consider as it directly impacts energy consumption patterns, with elevated demand for cooling infrastructure potentially influencing energy sector investments. The updated data from Chart 5 reinforces this warming trend, highlighting several key observations. Kuala Lumpur's LST has shown consistently high temperatures throughout the years, peaking around 2020 before stabilising slightly, yet remaining at elevated levels. Johor Bahru's LST data reveals high temperatures, with slight fluctuations but an overall steady trend, emphasising the growing UHI effect in urban areas. Sabah and Sarawak have demonstrated a relative increase in LST over the years, suggesting broader climatic changes beyond just urban influences. The general trend across most regions shows a slight upward movement in LST, indicating a national trend towards warmer LST. Labuan has shown notable increases in LST, which can be attributed to both natural climatic changes and possibly localised urbanisation effects. Other states, such as Selangor, Penang, and Pahang, exhibit moderate increases in LST, further supporting the overall warming trend. Financial institutions may face risks associated with assets that do not comply with new standards or that are rendered obsolete by emerging technologies. Consequently, FIs can use LST data to anticipate these regulatory and technological shifts, steering investments towards adaptive infrastructure and innovations in cooling technologies that align with the trajectory towards a cooler, sustainable urban environment.

Annual Forest Cover Loss from 2001-2023 Diagram 11

Source: Hansen *et al*., 2013, Google Earth Engine

Complementing the LST analysis, the deforestation trends from 2001 to 2023 in Malaysia, as shown in Diagram 11, particularly in regions such as Sabah and Sarawak, present a stark visual narrative of environmental degradation. Chart 6 and Table 4 reveal fluctuating yet substantial annual forest cover loss, with peaks around 2009 and 2013, and a notable increase again in 2023. The conversion of forested areas, visualised through a shift from green to red on the map, underscores the loss of natural carbon sinks, thereby exacerbating greenhouse gas concentrations. These trends serve as a clarion call for FIs to reevaluate investments in sectors associated with deforestation and to seek opportunities in conservation and sustainable land management practices. The deforestation data for regions like Sabah and Sarawak signals not only ecological degradation but also exemplifies transition risks, particularly for industries heavily reliant on forest resources. As the world moves towards a low-carbon economy, these industries face risks from policy changes that incentivise forest conservation, shifts in consumer preferences towards sustainability, and the potential for stranded assets. FIs equipped with this knowledge can divest from high-risk sectors and channel funds into sustainable forestry, agriculture that integrates reforestation, and other enterprises that support carbon reduction efforts, effectively managing transition risks. The integration of deforestation and LST data into risk assessment frameworks enables FIs to make informed decisions that align with the trajectory towards a sustainable and resilient future.

Incorporating temperature-based and population risk categorisations with LST and deforestation analyses provides FIs with a comprehensive framework to navigate climate risks, including pivotal transition risks associated with a global shift to sustainability. FIs' recognition of the risks and opportunities associated with climate change would influence their use of environmental data. The positive correlation between consumers' attitudes towards sustainability and their behaviour, as demonstrated by Chamhuri *et al.* (2023), reflects the financial sector's increasing reliance on comprehensive climate-related data from the JC3 Climate Data Catalogue to inform risk assessments and investment decisions. Emphasising the requirement of easily available and trustworthy data to support such decisions, this shows a more general tendency towards sustainability in both consumer and business actions. By means of a proactive approach to risk management, FIs not only facilitate to reduce possible losses but also seize opportunities resulting from the change to a sustainable, low-carbon economy. Key elements of a climate-smart investing approach —environmental, technological, and regulatory changes — will determine the direction of the financial sector.

4. Challenges & Opportunities

i. Data Availability: The challenge of accessing comprehensive climate-related information is significant for FIs in assessing risks and shaping investment strategies. Often, available data do not adequately cover essential aspects such as asset types, sectors, geographies, and predictive timeframes. Issues with granularity and proprietary barriers further complicate the scenario. Enhancing data availability require a concerted effort among data providers, regulatory bodies, and FIs to create standardised, transparent, and detailed climate datasets that are crucial for informed decision-making in the financial sector.

ii. Data Reliability: The reliability of climate data is often compromised by uncertainties and a lack of consistency across different sources. Quality issues, including discrepancies in accuracy and audit trails, contribute to a lack of confidence in the data. The varied methodologies and frameworks used by different data providers add further complexity. Addressing these challenges will necessitate a collaborative approach to establish stringent quality controls and improve transparency, thereby ensuring that climate data is dependable enough to support resilient financial decision-making in response to climate change.

iii. Data Comparability: The ability to compare climate data across different sources is hindered by variations in data formats, structures, and definitions. The complexity is exacerbated due to many disparate disclosure frameworks positioned on different areas of focus, creating more challenges for investors trying to wrangle all the information together to produce meaningful insights. Efforts to standardise methodologies and harmonise reporting standards are necessary to ensure that climate data can be used well in an era when risk assessment segues into just plain observation.

iv. Miscellaneous Issues: Beyond the challenges of availability, reliability, and comparability, the management of climate data also grapples with issues arising from its decentralised nature, which complicates comprehensive risk assessments for financial institutions. Legal and regulatory constraints, along with fragmented data ownership and access issues, add further layers of complexity. The cultivation of data-sharing agreements, streamlining of access protocols, and addressing of legal impediments, as suggested by Gao et al. (2020), are crucial steps in overcoming the challenges associated with decentralisation and restricted data flow. Moreover, the limited data contributions from small and medium enterprises (SMEs) obscure vital portions of the economic spectrum, necessitating initiatives focused on enhancing disclosure and building capacity among these entities. Through these efforts, it is possible to develop a unified and accessible climate data resource that empowers financial institutions to make informed decisions and effectively contribute to sustainable development.

5. Conclusion

While BNM has made notable progress in bridging data gaps via its JC3 Subcommittee, challenges persist in the journey toward climate resilience. Data gaps and quality issues in climate-related information remain, signalling the need for continued investment in data infrastructure. Building capacity within BNM and the broader financial sector to effectively assess and manage climate risks remains a top priority. Long-term strategies for adapting the financial system to a changing climate are deemed crucial, emphasising the need for sustained efforts. Leveraging innovation in data analytics and technology to improve climate risk assessment and monitoring points to a more technologically sophisticated and resilient financial industry, therefore pointing out prospects.

By tackling these issues and leveraging current projects, BNM aims to be especially important in creating a financially climate-resilient system for Malaysia. This guarantees long-term stability of the financial system in addition to helping to create a more sustainable economy. By means of national and international partnerships, creative frameworks, and proactive attitude toward changing climate threats, BNM's multifarious strategy positions Malaysia as a leader to attain finance sector climate resilience.

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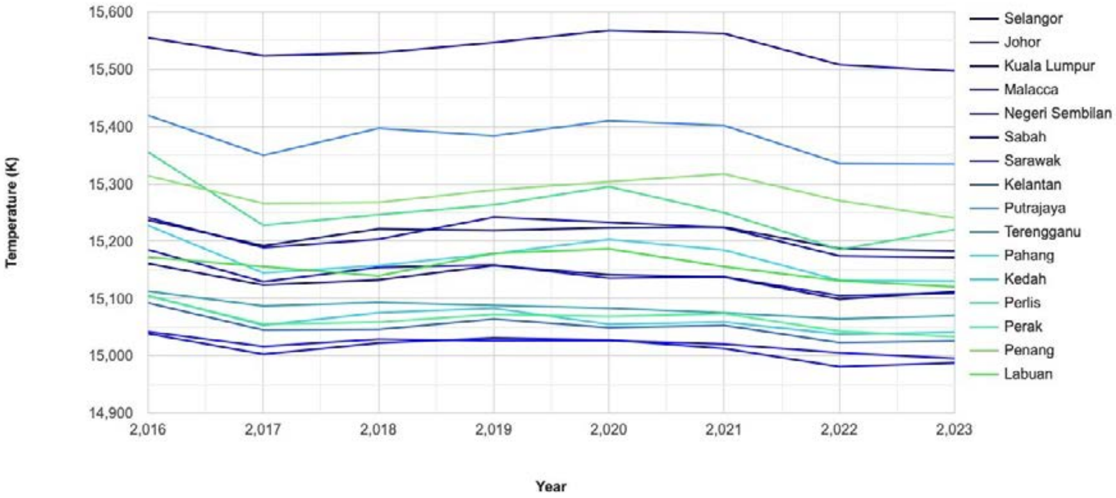
7. Annex

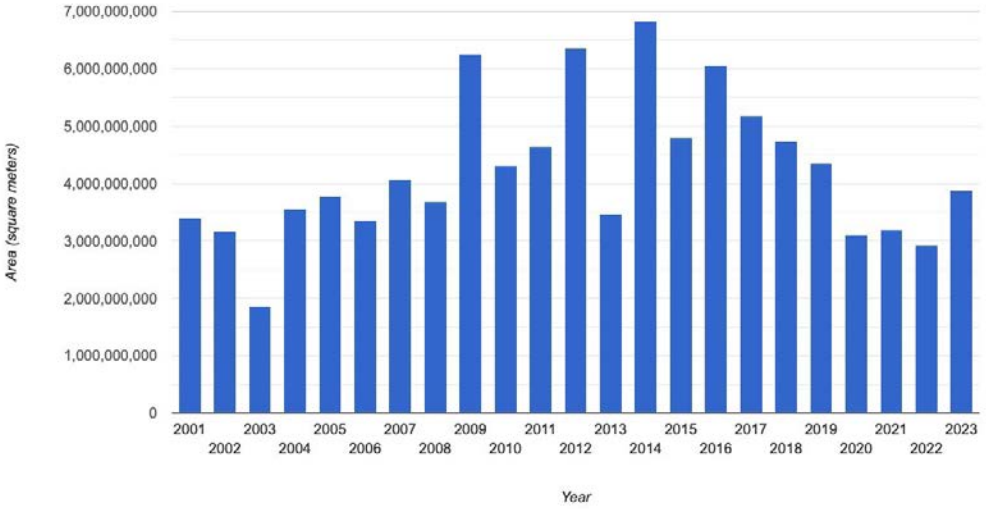
Annual Average Land Surface Temperature (LST) by Region from 2016-2023 Chart 5



Note: The Federal Territories of Putrajaya, Kuala Lumpur, and Labuan are illustrated separately.

Source: Google Earth Engine, author's own calculation

Annual Cumulative Forest Loss per Square Meters of Area from 2001-2023 Chart 6



Source: Hansen *et al.*, 2013, Google Earth Engine, author's own illustration

Decadal Forest Loss per Square Meter of Area by Region from 2001-2011, 2012-2023

Table 4

State/Year	2001-2011	2012-2023
Johor	4,067,764,449.82	4,307,419,675.90
Kedah	869,309,258.46	1,547,134,820.17
Kelantan	1,873,670,052.55	2,951,229,332.06
Kuala Lumpur	8,273,992.81	7,871,899.91
Labuan	3,892,888.92	9,210,471.78
Melaka	272,613,420.88	442,977,240.75
Negeri Sembilan	1,421,046,996.09	1,550,338,046.49
Pahang	5,383,082,924.05	7,797,807,293.02
Penang	51,665,496.39	82,818,746.52
Perak	2,090,526,155.70	3,055,025,618.80
Perlis	19,916,423.92	81,081,003.65
Putrajaya	3,049,702.88	1,791,236.64
Sabah	8,166,123,171.31	11,994,571,355.87
Sarawak	15,750,171,844.35	18,180,966,831.20
Selangor	888,299,252.09	1,059,428,978.80
Terengganu	1,252,526,767.94	1,837,288,107.03

Note: The Federal Territories of Putrajaya, Kuala Lumpur, and Labuan are illustrated separately

Source: Hansen *et al.*, 2013, Google Earth Engine, author's own calculation

IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

Financing the decarbonization of hard-to-abate sectors: trends, issues, and ways forward[1]

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KAPSARC, SA

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

Financing the decarbonization of hard-to-abate sectors: Trends, issues, and ways forward

This draft: October 2, 2024

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Abstract

The decarbonization of hard-to-abate sectors, such as steel, cement, petrochemicals, and heavy transportation, is essential to achieving global net-zero targets and maintaining financial stability. Despite a significant increase in global transition investments, the funding directed toward critical technologies like carbon capture, utilization, and storage (CCUS) and clean hydrogen remains insufficient. These sectors face unique challenges, including high capital intensity and technological barriers, making conventional electrification strategies less applicable. Current investments in CCUS and clean hydrogen fall well below the levels required to meet climate targets, with government subsidies playing a key role in financing these projects. However, gaps remain, particularly in developing countries with limited public resources and private finance. Addressing these challenges requires a comprehensive approach that includes robust regulatory frameworks, innovative private financial instruments, and global coordination to scale up decarbonization efforts. This paper explores the investment trends, challenges, and opportunities in financing the transition of hard-to-abate sectors, offering policy recommendations to close the investment gap and ensure a successful global transition.

Acknowledgements. The author thanks Rami Shabaneh and Mohamad Hejazi for their invaluable input in various capacities and Maha Balatif for her research assistance.

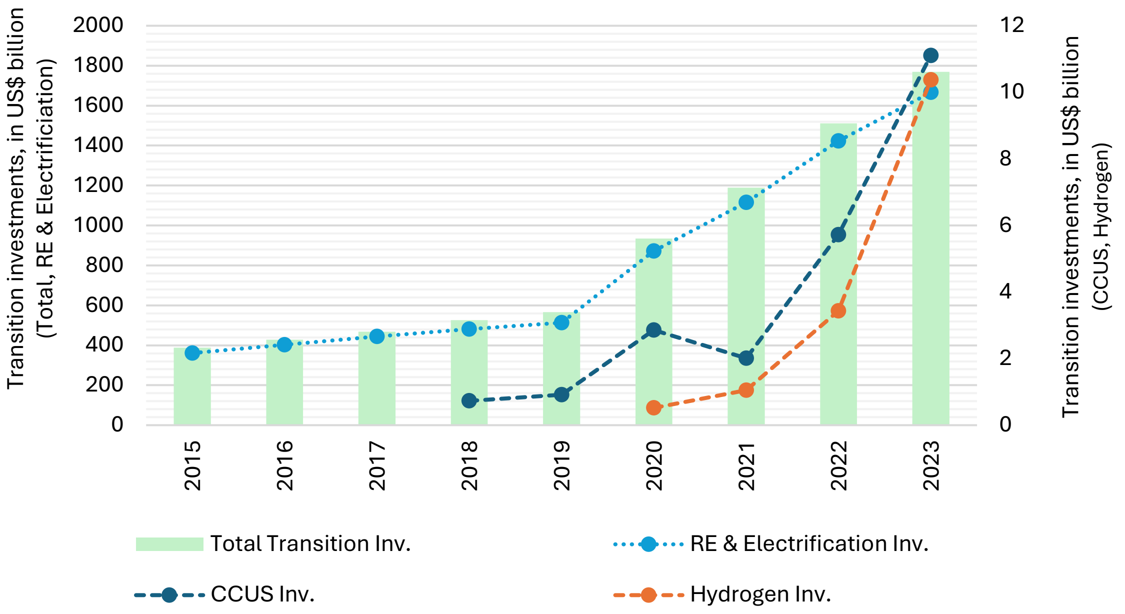
1. Introduction

Global transition investments have witnessed incredible growth and progress with the growing participation of private actors in recent years. The investment flows in clean technologies have increased significantly, particularly after the COVID era, reaching US$ 1.8 trillion in 2023, up from only half a trillion in 2019. While achieving a successful transition scenario aligned with the Paris Agreement goals requires a significant increase in current efforts (Yilmaz et al., 2023), an even greater challenge lies in securing financing for the decarbonization of hard-to-abate sectors. These sectors, such as steel, cement, petrochemicals and heavy transportation, face unique challenges due to their hard-to-abate nature with conventional electrification technologies, making the adoption of environmentally sustainable practices more complex. Consequently, their decarbonization strategies hinge on technologies such as carbon capture, utilization, and storage (CCUS) and clean hydrogen, which are capital-intensive and require substantial investments to scale up.

Despite the accelerating transition investment action, most of it disproportionately concentrated on renewable energy and electrification, constituting more than 90 % of the investment flows (Figure 1). While investments in technologies for hard-to-abate sectors, such as CCUS and clean hydrogen, have seen a remarkable increase during this period, the actual funding directed toward these two technologies remains minimal. For instance, in 2023, only US$10.4 billion was invested in clean hydrogen technologies and US$11.1 billion in CCUS technologies. Considering the actual investment needs of these technologies for a successful net-zero transition of the related sectors, which is multiple times higher, these figures remain significantly low to meet climate targets by 2050.

Decarbonization of hard-to-abate sectors is essential for financial stability due to their critical role in the global economy and the large size of capital stock. These sectors, such as heavy industry and transportation, are foundational to economic systems, providing direct or indirect inputs to almost any of the goods and services transacted in the markets. Moreover, the risk of stranded assets looms large as climate regulations tighten, threatening financial losses for businesses that fail to transition (McKinsey & Company, 2023; CFA Institute, 2023). Investor confidence is also at stake, with capital increasingly shifting toward sustainable investments, making effective decarbonization vital for maintaining access to financing. Nations that lead in transitioning hard-to-abate sectors will enhance their long-term economic competitiveness and resilience in emerging low-carbon markets (World Economic Forum, 2021).

Figure 1: Global annual transition investment flows in clean technologies, by total, renewables (RE) and electrification, CCUS and clean hydrogen breakdown, over time



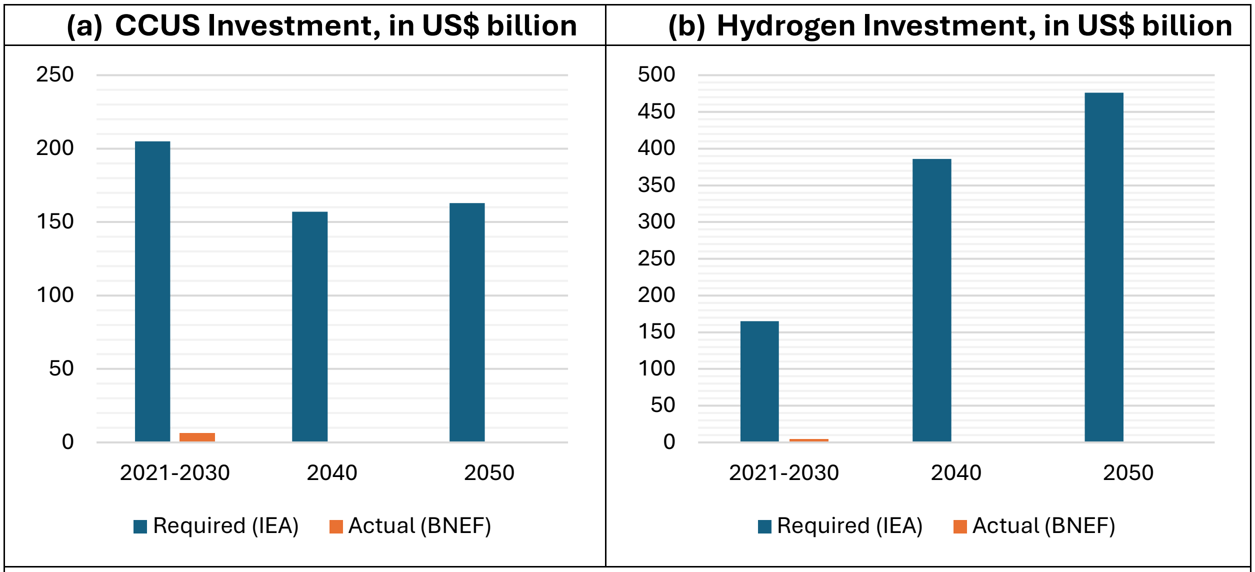
Source: Author's construction from Bloomberg NEF.
Notes: "Total Clean" includes all clean technology investment flows, including renewable energy, electrified transport and heat, power grids and energy storage, clean industry, nuclear, clean shipping, CCUS, and clean hydrogen. "RE & Electrification" covers the sum of renewable energy, electrified transport and heat, power grids, and energy storage.

In this paper, we examine the current state of hard-to-abate sector decarbonization. We first summarize the current investment gaps in hard-to-abate sector technologies, namely CCUS and clean hydrogen, to align with net zero targets. We then review the current project outlook and global trends, discuss mainstream financing practices and issues, and finally, conclude with a policy discussion for ways forward.

2. Investment Gaps and Challenges

According to the International Energy Agency's (IEA) net-zero emissions (NZE) scenario (IEA, 2021), annual investments of US$205 billion in CCUS and US$165 billion in clean hydrogen are required between 2021 and 2050. Accordingly, only in the current decade until 2030, we need a total of US$2 trillion in investment in CCUS and US$1.6 trillion in clean hydrogen (Figure 2). The IEA's NZE scenario highlights that investment needs for these critical technologies will continue to grow over the next two decades, from 2031 to 2050, with clean hydrogen investment needs projected to reach nearly US$9 trillion. On the contrary, the average annual investment recorded is only US$6.3 billion for CCUS and US$5 billion for clean hydrogen in the current decade. This stark disparity between required and actual investments underscores the significant gap that demands urgent attention.

Figure 2: Investment gaps in CCUS and clean hydrogen, over time



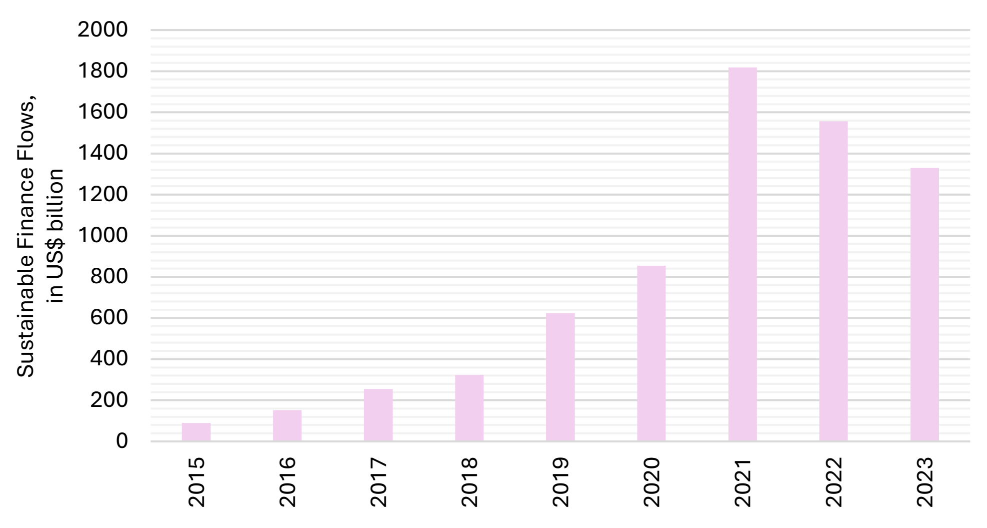
(a) CCUS Investment, in US$ billion

(b) Hydrogen Investment, in US$ billion

Source: Author's construction from Bloomberg NEF.
Notes: "Require" levels indicate annual investment needs based on the IEA net-zero emissions scenario, and "Actual" covers average investment into the technology in the current decade between 2021 and 2023.

CCUS and clean hydrogen technologies encounter significant challenges, including inadequate transportation and storage infrastructure, the absence of standards for measuring, reporting, and verifying (MRV), and an evolving regulatory landscape. Additionally, establishing a stable market for sequestered carbon and clean hydrogen remains critical. However, securing private finance is perhaps the most substantial obstacle for CCUS and clean hydrogen projects. As shown in Figure 3, the increasing trend of annual sustainable debt issuance, which represents the largest source of private financing for transition investment projects, closely parallels the rise in investments in renewable energy and electrification (as displayed in Figure 1). On the contrary, the recent spike in CCUS and hydrogen investments corresponds to the declining era of sustainable finance flows due to global monetary tightening after the COVID-19 pandemic. Consequently, the recent increase in these projects was mostly triggered by government subsidies in the form of off-take agreements and tax incentives. An example of the latter is the Inflation Reduction Act (IRA) in the United States, which provides a tax credit to businesses registered in the United States for each unit of carbon captured or hydrogen produced. Beyond these challenges, uncertainties and inadequate treatment of these technologies in current global Environmental, Social, and Governance (ESG) reporting frameworks, taxonomies, and rating practices hinder efforts to scale up the necessary private finance (Global CCS Institute, 2020 and 2022).

Figure 3: Global sustainable finance flows, over time



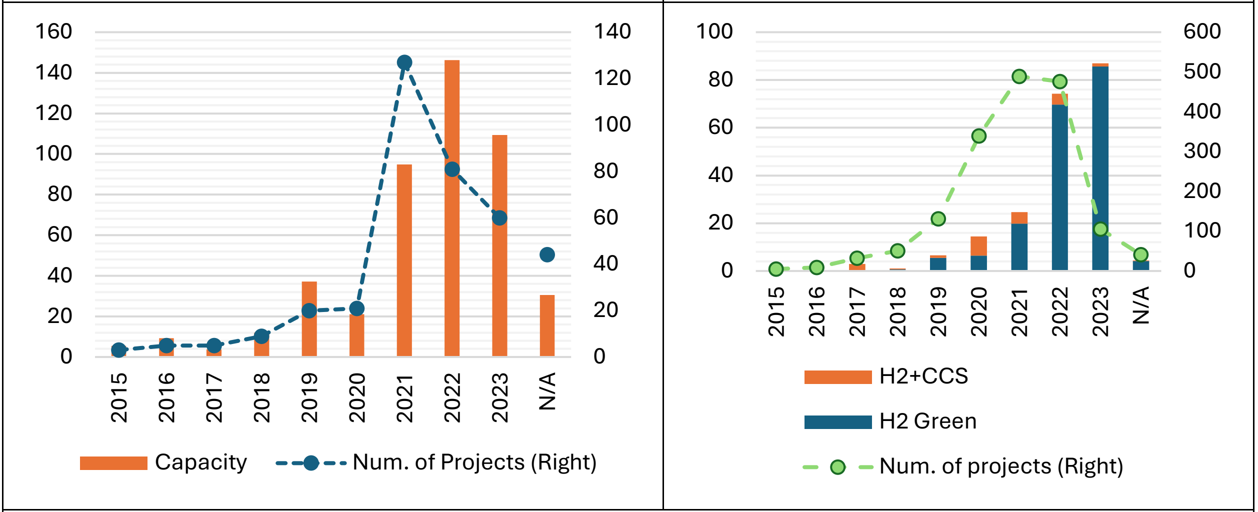
Source: Author's construction from Bloomberg NEF.
Notes: "Sustainable Finance Flows" includes green, sustainable, sustainability-linked and transition bonds and loans. "RE & Electrification" covers the sum of renewable energy, electrified transport and heat, power grids, and energy storage.

3. Current CCUS and Clean Hydrogen Projects Outlook

There has been a growing global interest in CCUS and clean hydrogen technologies in recent years. Project announcements have increased since 2022, especially following the release of generous subsidy programs in major countries, as discussed later. Furthermore, the announcement of the Carbon Border Adjustment Mechanism (CBAM) by the EU Commission in 2021 with a transitional phase, bringing additional carbon taxes, especially on hard-to-abate sector exports to the European Union (EU) markets from the rest of the world, also reiterated the importance of investing in the decarbonizing technologies for these sectors.

According to the project data shown in Figure 4, the number of announced projects and their capacities have increased significantly compared to pre-2019 levels, with continuous growth in subsequent years. For CCUS, the average project size has expanded considerably, with more recent projects concentrating on hubs with substantial capture and storage capacities. Similarly, there has been a notable increase in the size of clean hydrogen projects, particularly those focusing on renewable energy as a source of energy, usually labeled as green hydrogen.

Figure 4: CCUS and clean hydrogen project trends, number of announced projects and their capacity over time



(a) CCUS Projects (million tonnes CO_2/year)

(b) Hydrogen Projects (million tonnes H_2/year)

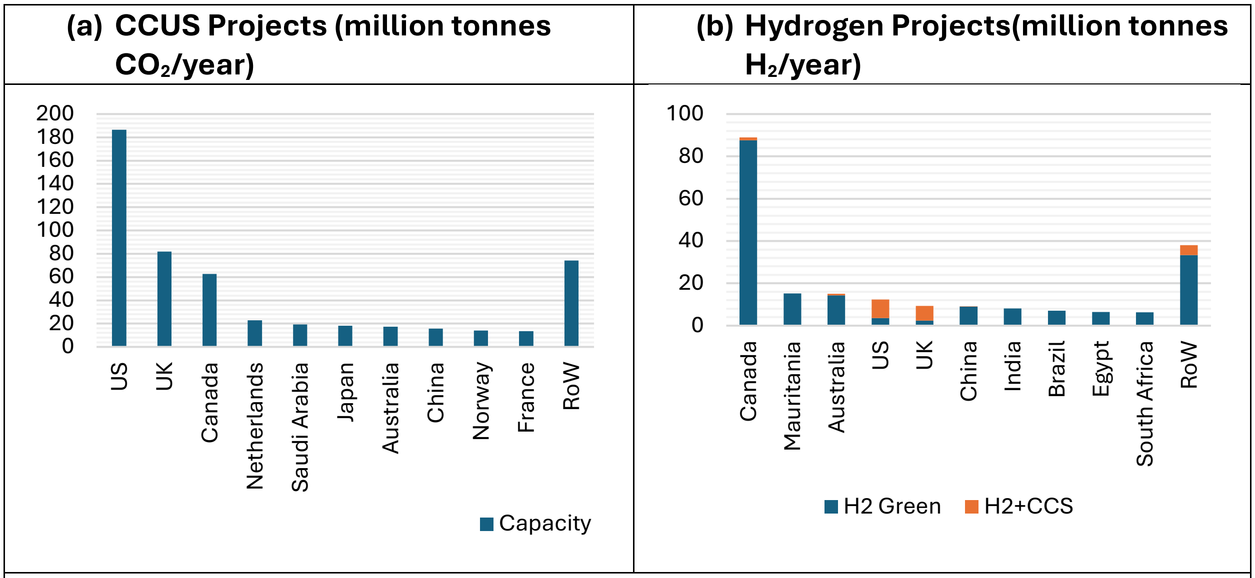
Source: Author's construction from Bloomberg NEF.
Note: The data includes projects with commercial scale or hubs and capture capacity. Projects that are canceled or suspended are excluded. "N/A" implies that the project's announcement date is unavailable.

Some of the biggest subsidy programs from major developed countries include the United States Inflation Reduction Act (including 45Q and 45V credits), Canada's Investment Tax Credit program for hydrogen, and various hydrogen innovation programs from the EU, typically in the form of tax credits and grants. These government incentives represent the bulk of available external finance for these capital-intensive projects, leading to a concentration of CCUS and clean hydrogen projects in developed countries (Figure 5). For instance, about one-third of the global CCUS capacity currently under construction is located in the United States, with the United Kingdom and Canada accounting for another third. Similarly, approximately half of the announced clean hydrogen projects are situated in Canada (Figure 5b). Canada's hydrogen strategy emphasizes green hydrogen, while the United States and the United Kingdom have announced the largest blue hydrogen projects (i.e., relying on natural gas as a source of energy with CCUS) worldwide.

Although there have been project announcements in some developing countries, they are generally smaller in scale compared to their urgent decarbonization needs and the relatively more carbon-intensive nature of their economies (Yilmaz et al., 2022). Only Saudi Arabia and

China have announced sizable CCUS projects among developing nations, accounting for about 7 percent of the globally planned capacity. Developing countries are relatively more active in clean hydrogen projects than CCUS, with sizable announcements from Mauritania, China, India, Brazil, Egypt, and South Africa collectively representing about one-third of the global announced capacity. Unlike the government incentives prevalent in developed nations, state-owned enterprises (SOE) in developing countries are more active with their internal funds to finance these projects.

Figure 5. Total announced CCUS and clean hydrogen project capacities by location



(a) CCUS Projects (million tonnes CO_2/year)

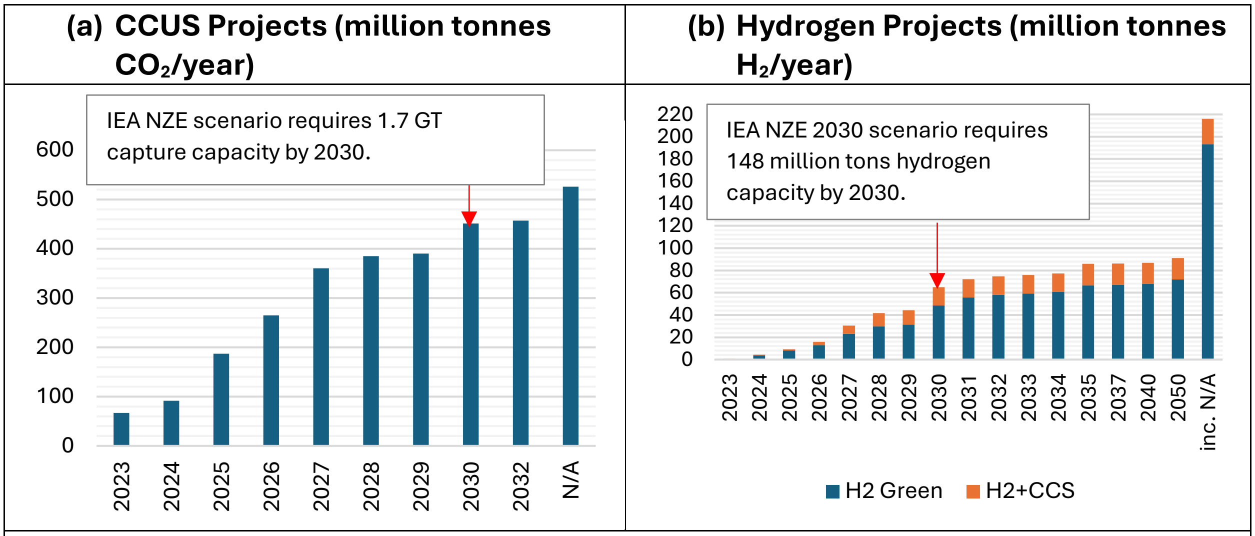
(b) Hydrogen Projects(million tonnes H_2/year)

Source: Author's construction from Bloomberg NEF.

Note: The data includes projects with commercial scale or hubs and capture capacity. Projects that are canceled or suspended are excluded. "RoW" implies the rest of the world.

Despite the recent growth in hard-to-abate technology investments, the total announced capacity of the current projects remains significantly below the required levels. The project data indicates that commissioning all the announced CCUS and clean hydrogen projects will not suffice to meet the net-zero transition requirements projected by the IEA scenarios (Figure 6). For instance, the IEA's NZE scenario estimates a global need for 1.7 gigatons (Gt) of annual CO2 capture, utilization, and storage capacity by 2030, a target the currently planned projects fail to achieve. Even considering all current projects with known and unknown commissioning dates, the 2050 target of 7.6 Gt per annum remains unattainable. Similarly, the IEA NZE scenario anticipates an annual hydrogen production capacity of 148 million tonnes by 2030, which must expand to 520 million tonnes by 2050. Similarly, operationalizing all the current clean hydrogen projects by these dates will not be sufficient to meet even half of the stated targets. The disparity between the projected needs and actual deployment underscores a significant gap that can only be addressed through substantial scaling up of efforts in the coming years and decades.

Figure 6. Cumulative CCUS and clean hydrogen announced capacity by commissioning year



(a) CCUS Projects (million tonnes CO_2/year)

IEA NZE scenario requires 1.7 GT capture capacity by 2030.

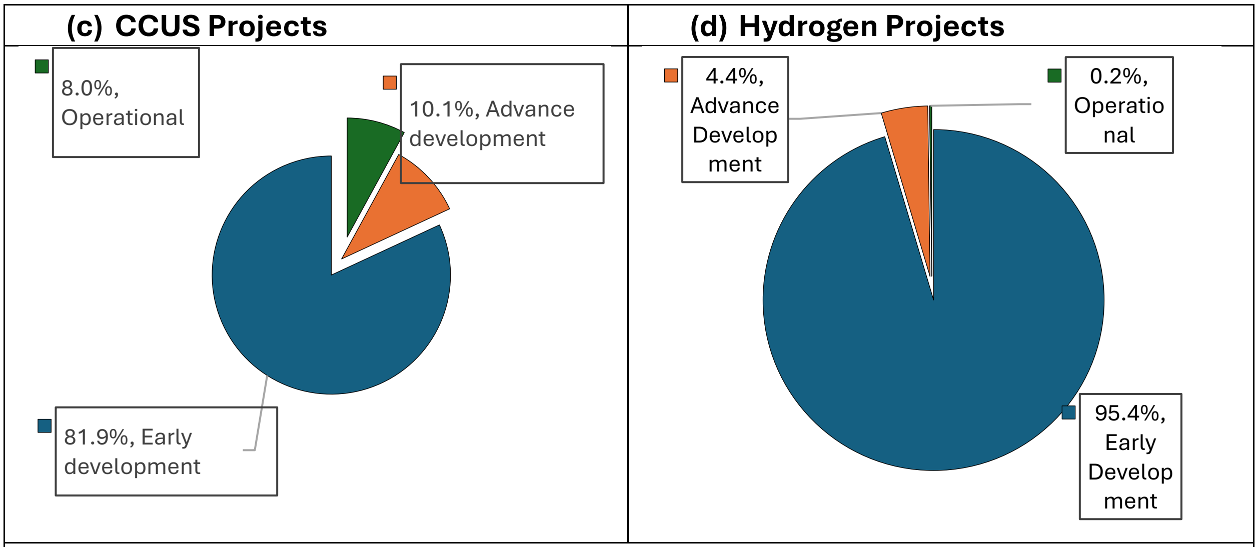
(b) Hydrogen Projects (million tonnes H_2/year)

IEA NZE 2030 scenario requires 148 million tons hydrogen capacity by 2030.

Source: Author's construction from Bloomberg NEF.
Note: The data includes projects with commercial scale or hubs and capture capacity. Projects that are canceled or suspended are excluded. "N/A" implies that the project's commission date is not available.

It is important to note that only 8 percent of the current CCUS and less than one percent of the clean hydrogen projects are currently operational. Additionally, CCUS and clean hydrogen projects at the advanced development status constitute about 8 percent and 5 percent of globally announced capacity (Figure 7). Put differently, most of the current projects are in the very early development stages, which generally have not secured solid funding nor obtained the required permits. While funding has been the most critical concern in these projects, the lengthy government subsidy approval and provision processes, permitting time, and regulatory requirements further complicate the project development. Such difficulties, in addition to the long construction times, which may take several years, raise concerns about the project's economic viability and may even result in cancellations (S&P Global, 2023).

Figure 7. The current status of the announced CCUS and clean hydrogen projects



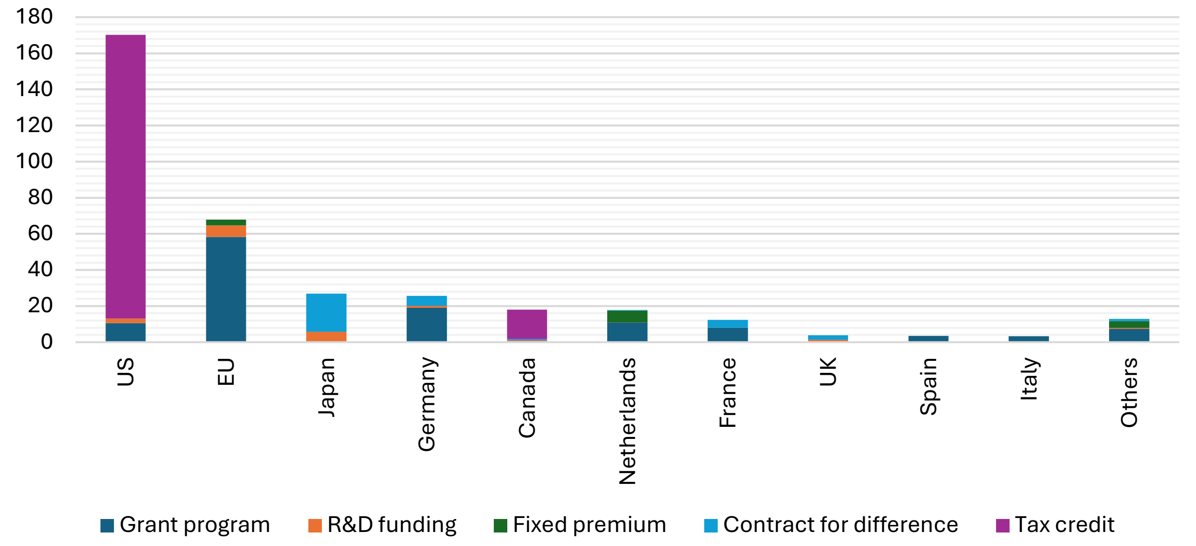
Source: Author's construction from Bloomberg NEF.
Note: The data includes projects with commercial scale or hubs and capture capacity. Projects that are canceled or suspended are excluded. Percentages are the shares of the total announced capacity. "Advance development" includes projects that are currently under construction, have obtained permits and/or secured finance. "Early development" covers planned and/or announced pipeline projects.

4. Current Financing Practices

As briefly discussed above, most CCUS and clean hydrogen projects are financed via government subsidies along with some support from corporate equity. For instance, Figure 8 presents government incentives for clean hydrogen's demand and supply development. Some of the incentives include CCUS projects, like the 45 Q of the US's IRA, and the CCUS component involved in blue hydrogen production along with other industrial applications. The incentives can take different forms, such as grants, R&D support, fixed premiums, contracts for differences, and tax credits. Grant programs and R&D funding are usually deployed to establish a robust demand for clean hydrogen and support clean hydrogen innovation. The fixed premium (i.e., a fixed price for a unit of output) and contract for difference (i.e., the lowest price for a unit of output) programs aim to ensure an acceptable and stable price for producers that can at least breakeven the marginal costs. Finally, investment tax credits directly aim to support project deployment.

According to the data in Figure 8, tax credit programs are particularly popular in the US (e.g., 45 V for hydrogen production and 45 Q for carbon capture and storage), estimated to reach a total budget of US$157 billion under the IRA, according to Bloomberg NEF. Similarly, Canada provides around US$16 billion in investment tax credits for hydrogen production and carbon capture and storage. The bulk of these credit programs target the supply side with some incentives for the demand side, e.g., hydrogen fuel cell electric vehicles. On the contrary, the EU-level incentives, such as the EU Innovation Fund – targeting industry decarbonization – and individual European countries, such as Germany, tend to employ grants and other price-fixing policies.

Figure 8. Government incentives for clean hydrogen projects (in millions US$)

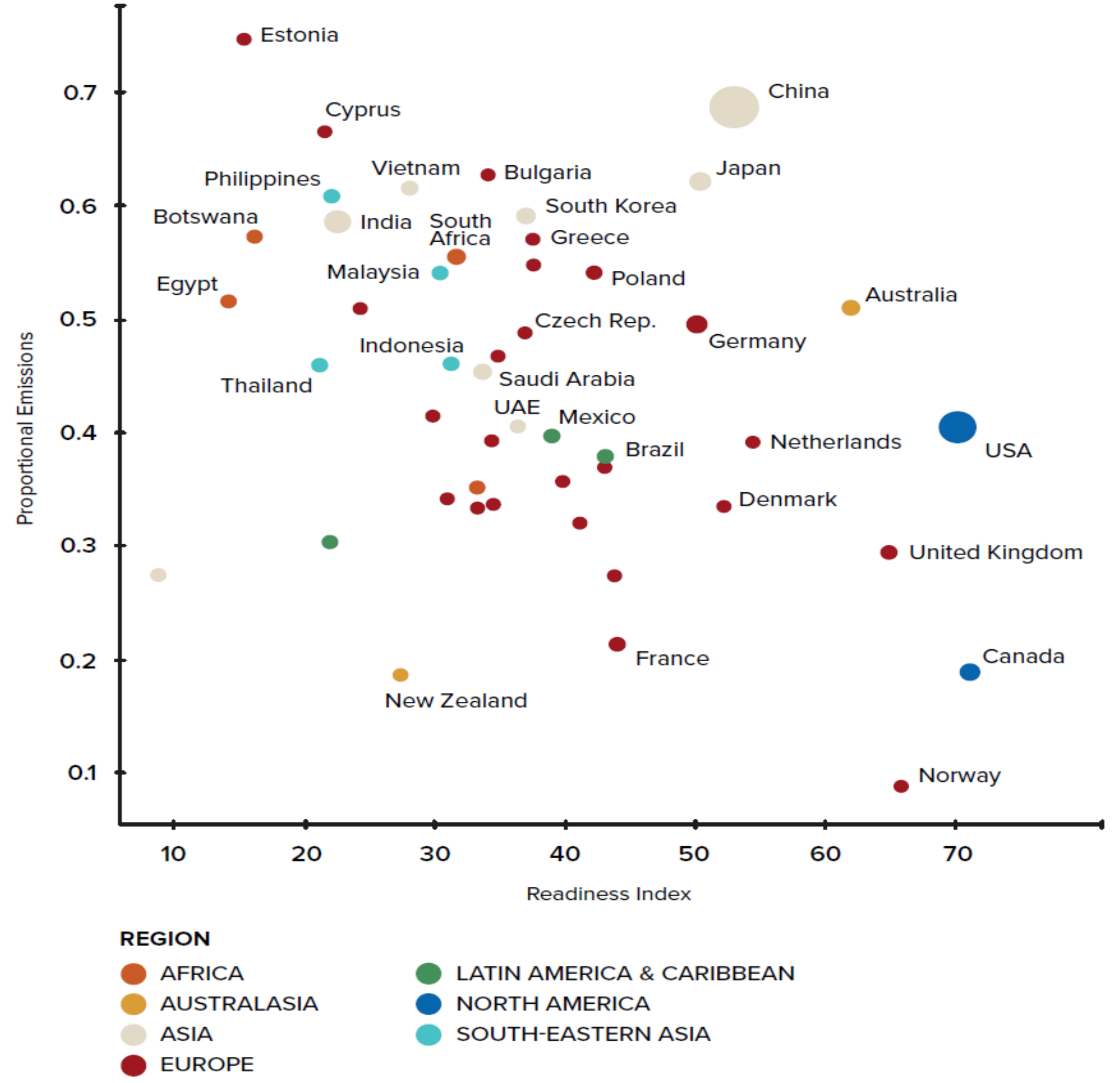


Source: Author's construction from Bloomberg NEF.

These incentives depend highly on countries' fiscal budget availability, which is certainly limited in developing countries. Accordingly, developing countries cannot provide any or as wide incentives to attract the deployment of these technologies. This is visually evident in the current deployment of CCUS and clean hydrogen projects worldwide, where penetration of the technologies, especially in middle- to low-income developing countries, is mostly missing. On the contrary, developing countries perhaps need these technologies more, given the dependence of their economies on hard-to-abate sectors, as described in the so-called environmental Kuznet's curve argument (Yilmaz et al., 2022). For instance, China and India produce more than half of the global steel (World Steel Association, 2023), producing nearly 60 percent of global cement production (MRC, 2024). Major petrochemical producers, including products like methanol, ethylene, and propylene, tend to be in developing Asia and the Middle East. Similarly, a significant portion of global oil and gas production occurs in developing countries. The larger appearance of hard-to-abate sectors in developing countries implies higher needs for CCUS and clean hydrogen deployment in these countries. This is summarized in Figure 9, which presents the CO_2 share of the hard-to-abate sectors against country readiness for CCUS deployment, based on the Global CCS

Institute's CCS Readiness Index[1]. The figure indicates that most developing countries reveal a high level of need for CCUS technology, although their readiness is significantly lacking.

Figure 9. Country-level needs for CCUS technology and their current readiness



Source: Rassool (2021)

Note: Countries' proportional emissions (representing their need for CCS in iron and steel manufacture, cement production, power generation from fossil fuels, and bioethanol production) are measured against their scores in the Global CCS Institute's Readiness Index. The higher the value of proportional emissions, the greater the need for CCS. The larger the size of each circle, the greater the country's overall emissions.

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[1] See the link for further inference about the index: https://co2re.co/ccsreadiness

In developing countries, these projects are usually financed by either SOEs and sovereign wealth funds or company equities. For instance, Aramco is partially investing in the Jubail CCUS-hub project in Saudi Arabia, contributing to the company's blue hydrogen production. Saudi Arabia's Public Investment Fund heavily invests the Saudi NEOM Green Hydrogen Company's project. ADNOC, the United Arab Emirates' SOE, has invested in CCUS and blue hydrogen projects. Similarly, China National Offshore Oil Corporation has partnered with Shell and ExxonMobil to build the biggest CCS hub project in China, the Daya Bay project in Guangdong Province, and the Indian Oil Corporation has announced various clean hydrogen projects.

Overall, most developing countries face significant challenges in decarbonizing hard-to-abate sectors. Along with limited public resources, they struggle with inadequate private financing mechanisms and technical deficiencies. Consequently, one-sided approaches like the CBAM, which require the rapid adoption of decarbonization technologies for hard-to-abate sectors, without offering sufficient support (e.g., financing), could further hinder the transition efforts, particularly in the Global South.

5. Concluding Remarks with a Policy Context

Given the complexity of decarbonizing hard-to-abate sectors, a holistic approach is necessary to address their financing needs. Critical technical and market shortcomings must be tackled in parallel with ESG reporting, taxonomy, and rating practices to derisk projects and create a supportive environment for investors. This entails multi-faceted mechanisms that include establishing robust regulatory and legal frameworks, creating stable market opportunities, including carbon and hydrogen markets, and advancing inclusive ESG practices alongside innovative financial instruments all at once to pave the way forward.

Private capital is essential for achieving global net-zero goals, necessitating inclusive global practices, such as those ESG frameworks and standards developed by the International Sustainability Standards Board (ISSB) under the IFRS Foundation, alongside global banking regulations under the Basel Committee on Banking Supervision. The emerging global ESG standards under ISSB must address existing shortcomings by adopting an inclusive, flexible, and holistic approach to technologies relevant to heavy industries. Clear guidelines and standards will aid investors in navigating the complex landscape of heavy industry transitions, thereby enhancing confidence in financing for these projects.

Policymakers must adopt a more comprehensive vision that considers the benefits of successfully decarbonizing heavy industry. These sectors are integral parts of global supply chains, and disruptions in their transition to sustainability can have cascading effects on various parts of the global economy and the financial system. For instance, the asset portfolios of banks, insurance companies, and equity markets in the most advanced and emerging economies have significant exposure to these sectors. According to the European Central Bank's financial stability review (ECB, 2022), European banks have a loan exposure of around 60 percent to high-emitting firms, presumably located in hard-to-abate sectors. The review also states that despite ongoing sustainability efforts, the share of high-emitting firms' securities held by the European financial system is still above 30 percent. A potential disruption in asset values caused by a disorderly transition in these sectors can trigger the subsequent economic turmoil. Therefore, policymakers must carefully manage the transition, considering broader economic implications and implementing measures to prevent sudden financial shocks.

Unilateral actions risk causing unfair competition and sectoral distortions, particularly in the Global South. While ambitious climate action is critical to achieving Paris Agreement goals, uncoordinated policy implementations, such as the EU's CBAM, and technology-prioritized project financing, as seen in current ESG practices, may stigmatize hard-to-abate sectors and the relevant technologies in the ongoing energy transitions. Such stigmatization could impede global decarbonization efforts, especially in the Global South, and shift the focus away from a balanced net-zero agenda.

In conclusion, while challenges persist in financing for hard-to-abate sector transition, addressing these challenges presents an opportunity to drive meaningful change. Policymakers, financial institutions and the investor community, and the global standard-setters need to work collaboratively. A successful transition in hard-to-abate sectors will contribute to the net-zero goals and safeguard the stability of the global economy.

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IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

Central bank’s approaches to fill data gaps on green debt securities: case of Indonesia[1]

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

Central Bank's Approaches to Fill Data Gaps on Green Debt Securities: Case of Indonesia

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Climate change has become one of the main issues in Indonesia. Low Carbon Development and climate resilience in Indonesia has incorporated into the National Long-Term Development Plan (RPJPN) for 2025-2045, making emissions reduction a concrete target for sustainable development. In accordance with the Paris Agreement, Indonesia commits to achieve net zero emission in 2060 or earlier. The Ministry of Finance has issued Green Sukuk and Sustainable Development Goals Bond as a form of the government's commitment in financing sustainable development. Moreover, The Financial Services Authority (FSA) supports the government policy by issuing some regulations related to the issuance of debt securities in financing the green project (green bond). However, currently in Indonesia, there are data gaps on securites-by-securities data for green, sustainability, and sustainability-linked bond in terms of type of issuer-holder, currency, maturity, and market issuance.

Central bank plays a critical role in collecting green financing data to support policy recommendations. Thus, we need to answer the challenges on these data gaps to address climate change data that policy maker needs. This paper proposes a different approaches to fill data gaps by utilizing data mining to classify and identified bonds into three categories: green, sustainability, and sustainability-linked bonds. We also proposes a framework to create data partnership to enrich green debt securities data. We believe with combination of these approaches will help the acceleration to fill data gaps needed.

Keywords: Green Debt Securities, Green Finance, Central Bank, Machine Learning, Text Mining, Data Partnership, Institutional Collaboration

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I. Introduction

In the last few decades, climate change has become a main topic in environmental issues and a very serious global threat after the pandemic. Economic growth is often used as an excuse for development by ignoring environmental aspects. The pressure to create high economic growth drives industrialization, excessive use of fossil fuels, and massive deforestation which creates carbon emissions. Therefore, a sustainable development strategy is needed, by pursuing economic growth in line with environmental conservation and responding to climate change issues. Globally, sustainable financing is considered as a key instrument to support the transition to a more resilient economy. One of instrument of sustainable financing is debt securities.

The availability of a valid, reliable, and granular data of sustainable financing is needed to support the formulation of appropriate policy to achieve the sustainable financing goals and address climate-related risks and opportunities. G20 Data Gaps Initiatives (DGI) phase 3 has identified that so far there has been a lack of reliable and comparable indicators for tracking the growth in green debt securities and green equity listed shares instruments across the G20 economies.

In Indonesia, low carbon development and climate resilience has incorporated into the National Long-Term Development Plan (RPJPN) for 2025-2045, making emissions reduction a concrete target for sustainable development. In accordance with the Paris Agreement, Indonesia commits to achieve net zero emission in 2060 or earlier. In the latest Nationally Determined Contribution (NDC) document, Indonesia increased its emission reduction target to 31.89% in 2030 with an international support target of 43.20%. Based on Indonesia's Green Climate Fund Country Programme Document published by Ministry of Finance (2021), there will be mitigation and adaption financial gap in achieving NDC targets during 2020-2030 in amount of USD 206 billion. Therefore, more financing sources are needed to close this gap either from the government or private sector. Banga (2019) also stated that developing countries require to explore new financing mechanisms, such as green bonds in order to fulfill its commitments on NDC target.

In 2017, the Indonesian government issued regulations on green bonds and green sukuk, then launched a $3 billion green sukuk in 2018. The value of sustainable finance in Indonesia as of third quarter of 2021 reached USD 55.9 billion or Rp809.75 trillion (exchange rate Rp14,440/USD). The issuance of green bonds in the domestic market was $35.12 million (Rp500 billion), representing 0,01% of the total outstanding bonds issued in the domestic market (Supriyanto, 2023). However the issuance of green bonds in Indonesia seems fluctuated with the latest figures on 1st semester of 2023 in the amount of US$1.15 billion, after achieving US$1.83 billion on 1st semester of 2022 (Triawan and Nagari, 2023)

The Indonesian government via Ministry of Finance has issued Green Sukuk and Sustainable Development Goals Bond as a form of the government's commitment in financing sustainable development. Moreover, the Financial Services Authority (OJK) has been encouraging sustainable financing practices through sustainable financial policies contained in the Sustainable Finance Roadmap Phase 1 (2015-2019) and Phase 2 (2021-2025), OJK Regulation no. 51/2017 concerning the Implementation of Sustainable Finance and the Indonesian Green Taxonomy (THI). In line with the THI program, OJK also issued a policy regarding securities issuance with the latest regulation no. 18/2023 concerning Issuance and Requirements of Sustainable Debt Securities and Sukuk. The categories of the debt securities in the regulation includes green bond, sustainability bond, and sustainability-linked bond.

However, currently in Indonesia, there are data gaps on securites-by-securities database for climate-related financing i.e. green, sustainability, and sustainability-linked bond in terms of sector of issuer, currency, maturity, and market issuance. Moreover, there has been no flagging yet on those bonds categories issued in the domestic market, and those issued in foreign markets have not been captured perfectly. Meanwhile the 2015 Paris Agreement encourages the immediate need for related sustainable financing statistics, especially green bonds, equities, and invesment funds.

Central Bank plays a critical role in collecting granular sustainable financing data to support policy recommendations. According to the Network of Central Banks and Supervisors for Greening the Financial System (NGFS, 2022), climate-related data gaps include several dimensions: the availability (i.e. coverage, granularity, accessibility), reliability (i.e. quality, auditability, transparency), and comparability. In some cases, the relevant data are not available, while other cases, the data exist but not granular. Thus, Central Bank need to answer the challenges on these data gaps specifically in the green debt securities to address climate change data that policy maker needs. The purpose of this paper are:

1. Propose a different approach to fill data gaps by utilizing text mining to classify and identified bonds into categories: green bonds, sustainability-bonds, and sustainability-linked bonds (the case of Indonesia).
2. Proposes a framework to create data partnership to enrich green debt securities data (the case of Indonesia).

II. Literature Review

II.1 ESG and Green Financing

Broad concept of Environmental, Social, and Governance (ESG) financing is financing for "activities or projects that sustain or improve the condition of the environment or society of governance practices" (OECD). According to Höhne at al. (2012), green financing 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. It includes climate finance but is not limited to it. The main instruments of ESG and green financing are debt securities, loans, and equity and investment fund shares. Debt Securities can be in the form of bills, bonds, notes, negotiable certificate of deposit, commercial paper, and similar instruments normally traded in the financial markets that serve as evidence of a debt (Handbook of Securities Statistics - IMF, 2015). Equity can refer to company shares that are oriented towards environmental sustainability in the long term, this can be assessed by the output produced by the company which has an impact on the environment.

In the issue note of sustainable finance definition in the 2025 SNA and BPM7 (2024), ESG (green) debt securities defined as negotiable financial instruments serving as evidence of debt in which the use of the debt security is restricted to finance or refinance activities or projects or where the issuer agrees to achieve performance objectives that improve the condition of the environment or society or governance practices (of the environment). These include social, green, sustainability, sustainability-linked, and other ESG debt securities. Social debt securities are not included in the DGI-3 Rec 4 because the focus is on climate-related financing. OECD (2020) emphasizes the importance of including sustainable finance statistics especially green bonds, equities and investment funds in the financial accounts and balance sheets of the national accounts for tracking investment in the green and climate/ transition economy and informing decisions on monetary and fiscal incentives.

II.2 Green Bond, Sustainability Bond, and Sustainability-Linked Bond

According to Banga (2019), in developed and emerging countries, the issuing of green bond are quickly growing to finance the adaption and mitigation projects due to factors such as yield to maturity similarity with the conventional bond, investors' climate awareness, policy makers' commitment to counter climate change and the current macroeconomic environment. Meanwhile in developing countries, a set of institutional and market barriers are preventing from appropriating the full benefits of green bonds.

Ehlers & Packer (2017) defined green bonds as fixed income securities which finance investments with environmental or climate-related benefits. This specific purpose of issuing green bonds differentiates them from the conventional bonds. In Indonesia, the definition of ESG debt securities for climate-related financing are stated in OJK Regulation No. 18/2023 as follows:

1. Green bonds and/or green sukuk are debt securities and/or sukuk whose proceeds from the issuance are used to finance or refinance environmentally sound business activities.
2. Sustainability bond and/or sustainability sukuk, are debt securities and/or sukuk whose proceeds from the issuance are used to finance or refinance environmentally sound business activities and socially minded business activities.

3. Sustainability-linked bond and/or sustainability-linked sukuk, are debt securities and/or sukuk whose issuance is linked to the achievement of certain key sustainability performance indicators.

II.3 Task Force on Climate-related Financial Disclosures (TCFD)

TCFD created by Financial Stability Board, provides a guideline for organizations to report information about climate-related financial information, including risks and opportunities. By adopting TCFD, organizations could enable stakeholders to make informed decisions in regards of organization's exposure to climate-related risks. The framework consists of four core elements namely Governance, Strategy, Risk Management, and Metrics and Targets each with specific recommended disclosures that should be explained in financial filings. TCFD relates to green bond as financial assets is a part of climate-related market opportunities.

Figure II.1 Core elements of TCFD recommendations
(TCFD Overview, 2022)

According to TCFD Status Report 2023, there are more than 4,850 supporters of TCFD consists of corporations, industry association, and governments with 51% of the supporters reside in Asia-Pacific. 19 authorities including European Commission, Singapore Exchange, US Securities and Exchange Commission have imposed or have proposed TCFD-aligned disclosure requirements for various types of company, such as listed issuers, large corporations, or financial institutions. Moreover, International Financial Reporting Standards (IFRS) in 2023 has completed IFRS S2 Climate-related Disclosures that is consistent and in line with TCFD recommended disclosures with some additional requirements (IFRS, 2023).

Although TCFD report is not yet mandatory for organizations in Indonesia, OJK Regulation no. 51/2017 mandates financial services, issuers, and listed corporations to published Sustainable Finance Report. PWC (2023) reports that in 2022, only 10% of Indonesia listed corporations incorporated TCFD framework for their sustainability report, including bank, processing industry, and oil and gas company.

II.4 Classification Modelling

The advancement of Information Technology has led to the creation of extensive databases and vast amounts of data across different fields. Research in databases and information technology has introduced methods for storing and managing this valuable data to facilitate decision-making. Data mining involves extracting useful information and identifying patterns from large datasets.

According to (Ramageri, 2010), Data mining is a systematic procedure utilized to sift through extensive datasets to unearth valuable information. Its objective is to uncover previously unidentified patterns, which can subsequently inform decision-making processes crucial for business advancement. It is alternatively referred to as the knowledge discovery process, knowledge extraction from data, knowledge mining, or data/pattern analysis.

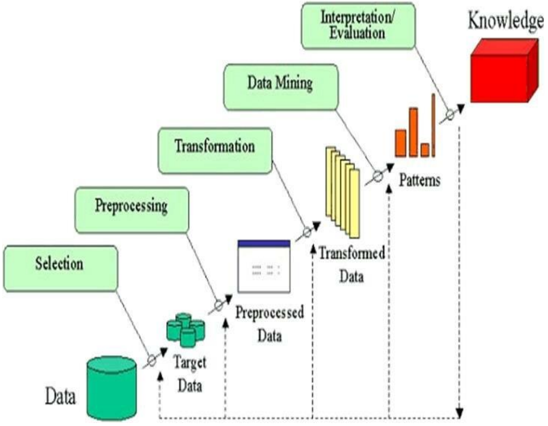

Figure 2.1 Knowledge Discovery Process

Source: (Saxena, 2020)

Data mining has various techniques like Association, Classification, Clustering, and Regression. Classification is the most commonly applied data mining technique, which employs a set of pre-classified examples to develop a model that can classify the population Ahmed, 2014). Several examples of classification algorithms include Support Vector Machine, Decision Tree, and Logistic Regression.

II.4.1 Support Vector Machine

Support Vector Machine (SVM) is a supervised learning system that employs a hypothetical space represented by linear functions in a high-dimensional feature space. This space is trained using an optimization-based learning algorithm, allowing SVM to excel in classifying data compared to prior techniques (Ovirianti, 2022). In the case of classification, SVM aims to find the hyperplane that separates two data classes with the largest margin. This hyperplane is chosen in such a way that the distance between the hyperplane and the closest point from each class, called support vectors, is maximized. In this way, SVM not only looks for a linear separator but also looks for a separator with maximum margin, making it highly resistant to overfitting. SVM is also capable of handling non-linearly separable data classes through the concept of the "kernel trick". Kernels allow SVM to map data to higher dimensions where a linear separator might be found. Commonly used kernels include linear kernel, polynomial kernel, and radial basis function (RBF) kernel.

During training, SVM minimizes the loss function that includes margin and regularization terms to find the best hyperplane. This optimization is often done through convex optimization techniques such as stochastic gradient descent. The advantages of SVM include its ability to handle classification problems with high-dimensional and relatively small sample sizes, as well as its tolerance for non-linearly separable data. However, SVM tends to be less efficient in handling very large datasets.

II.4.2 Decision Tree

The decision tree methodology is a frequently employed technique in data mining for creating classification systems utilizing multiple covariates or for crafting prediction algorithms for a target variable. It works by recursively partitioning the feature space into subsets based on the values of input features, with the goal of minimizing impurity or maximizing information gain at each split. This approach categorizes a population into branch-like segments, forming an inverted tree structure with a root node, internal nodes, and leaf nodes (song, 2015). Decision trees have the capacity to perform effectively on smaller datasets due to their simplicity, reduced susceptibility to overfitting, lower computational demands, ability to discern feature importance, and inherent interpretability.

II.4.3 Logistic Regression

Logistic regression is a data analysis technique that uses mathematics to find the relationship between two data factors. It then uses this relationship to predict the value of one factor based on the other. The logistic regression model is based on the sigmoid function that maps the outcome of the linear equation into the range [0, 1], representing probabilities. During the training phase, the logistic regression model minimizes the loss function, usually the cross-entropy loss function, to find the optimal values of the regression coefficients. This is done using optimization algorithms such as gradient descent. Logistic regression is often used in various applications, including credit risk prediction, spam detection, and medical diagnosis. The advantages of logistic regression include its high interpretability and its ability to handle binomial classification problems well, despite assuming linearity between independent variables and the log-odds of the dependent variable. Thus, logistic regression is a powerful and effective analytical tool for modeling the relationship between variables in various data analysis contexts (Boateng, 2019).

II.5 Data Partnership for Data Collection

Digitalization and globalization have accelerated social and economic dynamics, including the abundance of data produced by the digital platform. From the COVID-19 pandemic lessons, there is a need for new data sources to support policymaking and ensure the relevance of the official statistics. With these challenges, Bank Indonesia needs to explore and utilize new data sources to fill the gap in our data, including the Green Debt Securities data. The different methodological approach using Data Mining that we propose on II.4 needs to be completed with a data source that is sustainable from its source to ensure its certainty to produce regularly. Thus, it is important to expand access to new data sources, as stated by G20 Finance Ministers and Central Bank Governors in their April 2021 communiqué: "*We also recognize that improving data availability and provision, including on environmental issues, and harnessing the wealth of data produced by digitalization, while ensuring compliance with legal frameworks on data protection and privacy, will be critical to better inform our decisions*." However, these new data sources are usually kept by the private sector.

As the central bank, Bank Indonesia has a well-established legal framework and mandate for data collection by means of surveys and regulatory reporting for our primary data collection, but this is not limited to these methods alone. Our regulatory reporting comprises banks and non-banks. Bank Indonesia is also utilizing transactional data, which is a product of its Payment Systems and Financial Market Infrastructure, as primary data collection sources.

For secondary data collection[6], Bank Indonesia has practiced data partnerships based on mutual recognition, trust, social responsibility, and the premise that the multi-use of the data will benefit the whole of society, including reducing the regulatory reporting burden on reporters. Besides data partnerships, other methods of collecting secondary data include, e.g., data subscriptions.

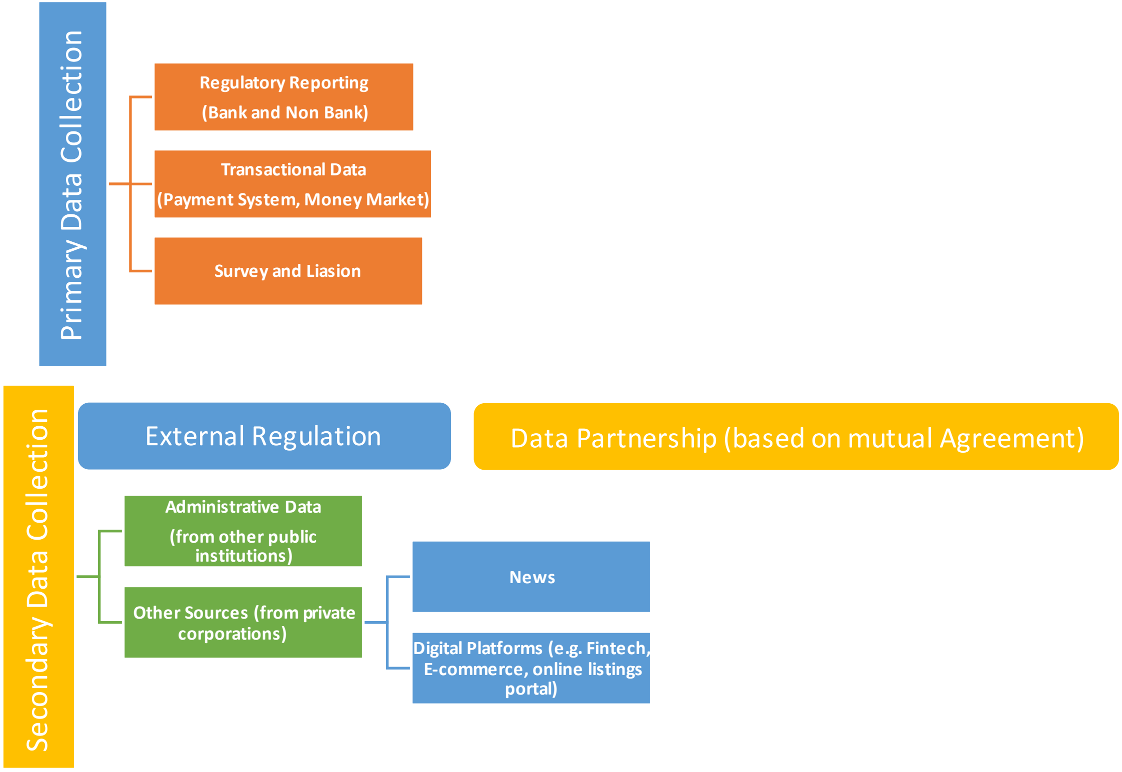

Figure 2.2 Primary and Secondary Data Collection Framework

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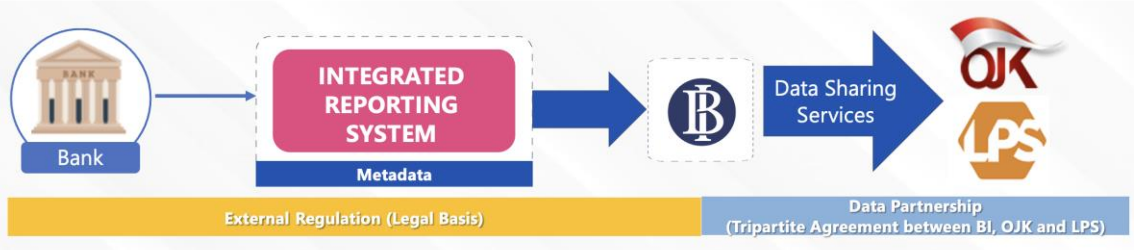
[6] Secondary data is the data that Bank Indonesia collected from other sources (e.g. other authorities or private institution)

Since 2019, Bank Indonesia has transformed most of its bank's regulatory reporting system into a national metadata-based integrated reporting application whose main goal is to capture standardized and metadata-based regulatory reporting data from Bank and reduce the reporting burden. The metadata of this reporting system is mutually agreed upon and used together by Bank Indonesia, OJK (Indonesia's Financial Services Authority), and LPS (Indonesia's Deposit Insurance Corporation). Nowadays, the metadata-based integrated reporting system covers financial, risk, and payment system activity information from Bank.



With OJK and LPS, Bank Indonesia established a data partnership in the form of a tripartite agreement between these three organizations. These data partnership goals are based on mutually agreed-upon operational modalities of data reuse. Combining the mechanisms of integrated reporting and data sharing with the basis of data partnerships is an efficient way to reduce the reporting burden of the industry to the authorities.

III. Data and Methodology

III.1 Data

The textual data used for our analysis was sourced from the prospectus of all listed corporation that issued domestic bond in Indonesia Stock Exchange[7]. Moreover, we conducted web scraping to obtain series of government bonds that have been categorized as green bonds, sustainability bonds, or sustainability linked bonds from press releases. Additionally, we also employ web scraping to gather data on corporations that have issued bonds abroad.

III.1.1 Dataset Preparation

In this stage, dataset preparation is used to collect data from various data sources and undergo a series of specific steps to produce a structured dataset with labels corresponding to the desired categories, namely green bond, sustainability bond, and sustainability linked bond. This is done because in the case of Indonesia, there has not yet database with the official flagging into the three bond mentioned categories. The dataset preparation stages can be seen in Figure III.1.

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[7] The Indonesia Stock Exchange (IDX) is the country's principal stock exchange. It facilitates the trading of stocks, bonds, mutual funds, and other financial instruments.

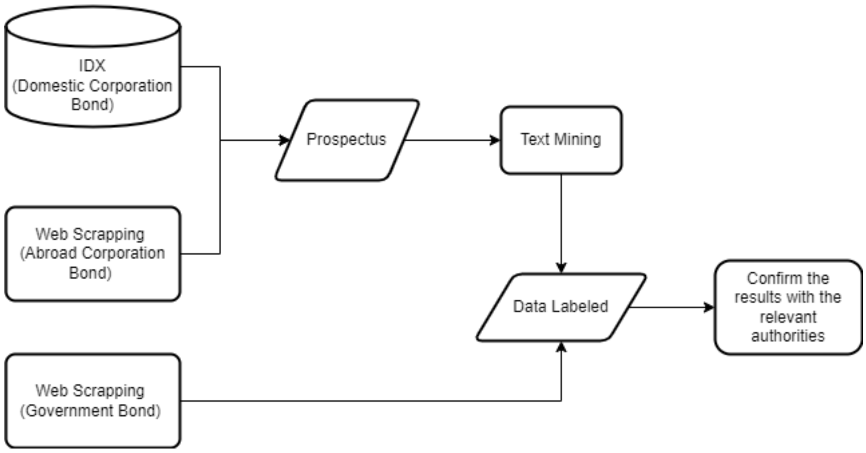

Figure III.1 Data Preparation Stages

After obtaining a list of corporations that issued bond in domestic market from IDX website, the next step is to download prospectuses from these corporations. For corporations bond that issued abroad, we conduct web scraping from news portal. Subsequently, we compile a separate list of corporations to download their prospectuses. Then, text mining is carried out by conducting text-based searches from the prospectuses based on keywords from each class. Before that, we preprocess the text by performing tasks such as text cleaning, text normalization, and stopword removal. These keywords refer to the definitions of the OJK Regulation No. 18/2023, which can be found in Table III.1. After obtaining the labeled data, the next step is to confirm the results with the relevant authorities.

Table III.1 List of Keywords for each Class

Keywords	**Class**
"green bond", "green sukuk", "kubl", "*kegiatan usaha berwawasan lingkungan*" (the environmentally conscious business activities), "*berwawasan lingkungan*" (environmentally conscious), "*efek bersifat utang berwawasan lingkungan*" (the environmental debt-induced effects).	Green Bond
"sustainability bond", "*efek bersifat utang keberlanjutan*" (the effects are debt-sustainable), "sustainability sukuk", "*ebus keberlanjutan*" (sustainable EBUS), "*lingkungan dan sosial*" (environment and social), "*kegitan usaha berwawasan lingkungan dan kegiatan usaha berwawasan sosial*" (environmentally conscious business activities and socially conscious business activities)	Sustainability Bond
"sustainability linked bond", "*efek bersifat utang terkait keberlanjutan*" (debt-related sustainability effects), "ebus terkait keberlanjutan" (sustainable related EBUS), "*indikator kinerja utama keberlanjutan*" (key performance indicators for sustainability), "sustainability linked sukuk"	Sustainability Linked Bond

Web scraping is also employed to retrieve bond series issued by the Indonesian government by press release. After completing the processes above, we obtain the labeled data of the name of corporation and the series of government bonds that fall into each three type categories of sustainable debt securities.

Furthermore, in order to obtain the securities-by-securities database of sustainable debt securities consist of issuer sector, series number/code, issuance and maturity date, currency, interest type, market of issuance, and the outstanding amount, further data collection is required. In case of Indonesia, this can be collected form the database of securities-by-securities that compiled by the Central Bank in order to fulfill the DGI2 recommendation 7. Securities Statistics. The database data sources are from integrated commercial bank reports, Bank Indonesia – Scripless Securities Settlement System, Indonesia External Debt Statistics, the Indonesia Central Securities Depository, the Directorate General of Financing and Risk Management – Ministry of Finance.

III.2 Classification Modelling

The purpose of our research is to automate the input of company prospectuses and generate their class outputs automatically. To accomplish this, classification modeling is performed. The steps involved in the process can be seen in Figure 4.1.

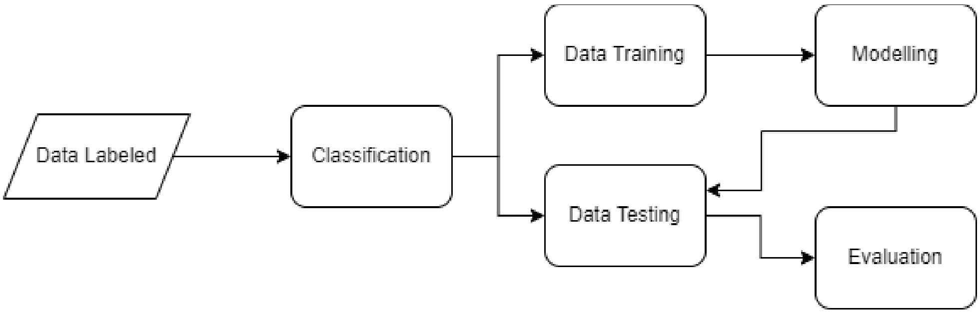

Figure 4.1 Classification Modeling Process

Once the labeled data is obtained from the dataset preparation process, the next step is classification. Following this, the dataset is divided into two subsets: training data and testing data, with a split ratio of 80:20. The training dataset is employed to train three different models: Support Vector Machine, Decision Tree, and Logistic Regression. Subsequently, these models are applied to the testing data. To assess the performance of the models, an evaluation process is conducted, involving the calculation of accuracy. Accuracy provides an overall measure of correct predictions while F1-score is a balance between precision and recall, helpful when there is an imbalance in classes or differing costs for false positives and false negatives.

IV. Results

IV.1 Classification Model Result

In this paper, analysis of different classifiers shows different results that can be shown in table IV.1.

Table IV.1 Classification Model Result

Methods	Accuracy	F1-Score
Support Vector Machine	70,9%	30,1%
Decision Tree	91,3%	68,6%
Logistic Regression	72,1%	40,3%

Among those three methods, the decision tree is superior. This is because the simple concept of the decision tree enables it to capture small data and small process effectively. The F1-score results indicate that the model is satisfying but also suggest a need for improvement.

IV.2 Classification of Corporations and Government Bonds: Categorization within the Class

From the processes conducted, several issuer names from corporation and government along with their series were obtained. In this paper, we have categorized them based on type of sustainable debt securities, issuer sector, currency, maturity, interest type, and market of issuance with position in Q1 2024 as seen in figures IV.I to IV.6.

Based on Figure IV.1, the method used to acquire sustainable debt securities in Indonesia reveals that the majority consist of green bonds (93.82%), with sustainability bonds comprising a smaller portion (6.18%). Moreover, the majority of sustainable debt securities are issued by the Central Government sector (88.6%), followed by Other Depository Corporations (8.06%), Non-Financial Corporations (3.21%), and Other Financial Corporations (0.13%). Additionally, within the ODC sector, one corporation has implemented the TCFD concept in its sustainability reports.

From the perspective of currency, the US dollar still dominates (70.95%) compared to the Indonesian rupiah (29.05%). In addition, the characteristics of sustainable debt securities in Indonesia entail long-term durations and mostly fixed interest rates (94.09%). Meanwhile, when viewed from the perspective of market of issuance, the majority of sustainable debt securities are issued abroad (70.95%) and the rest are issued in domestic market (29.05%).

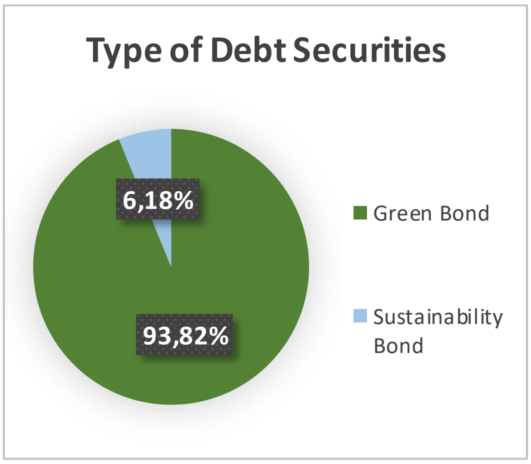

Figure IV.1 Type of Debt Securities

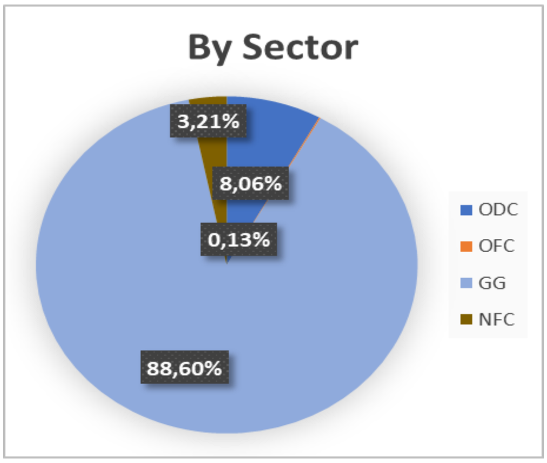

Figure IV.2 By Issuer Sector[8]

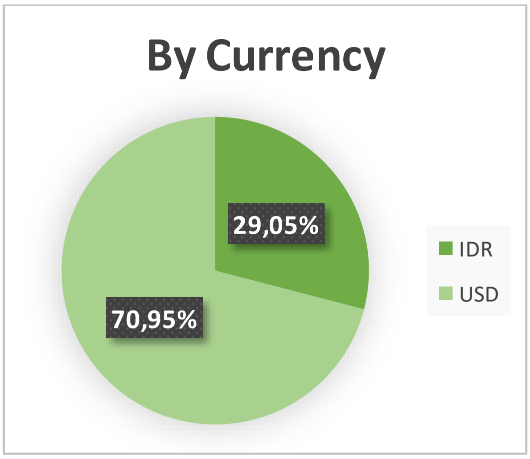

Figure IV.3 By Currency

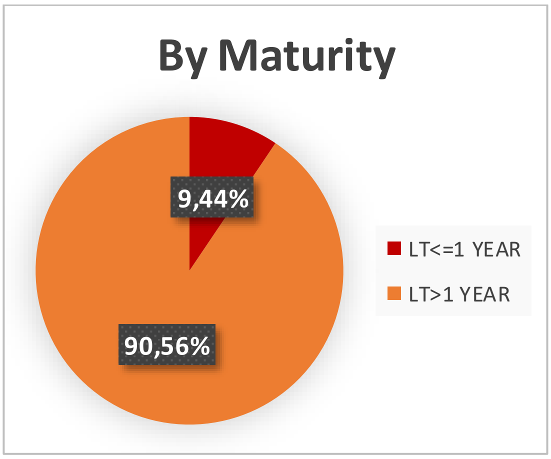

Figure IV.4 By Maturity

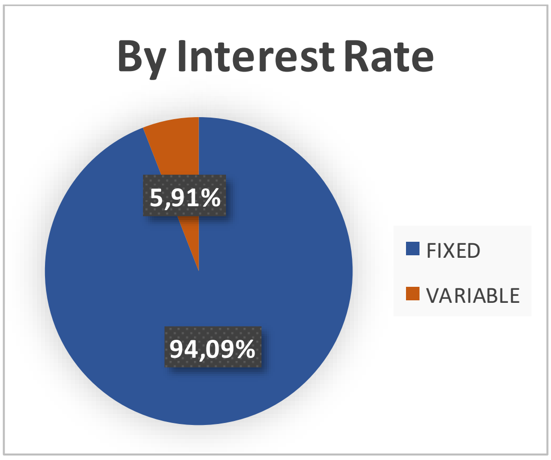

Figure IV.5 By Interest Rate

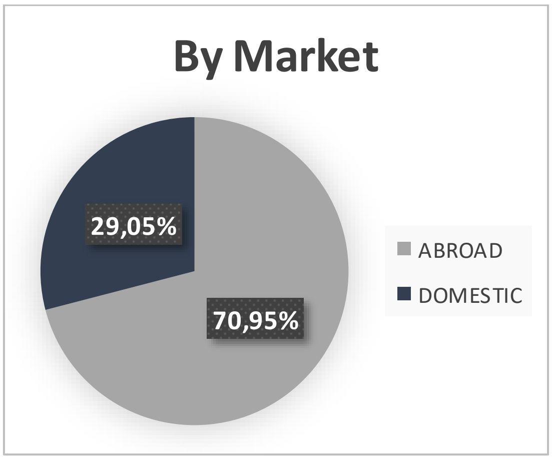

Figure IV.6 By Market of Issuance

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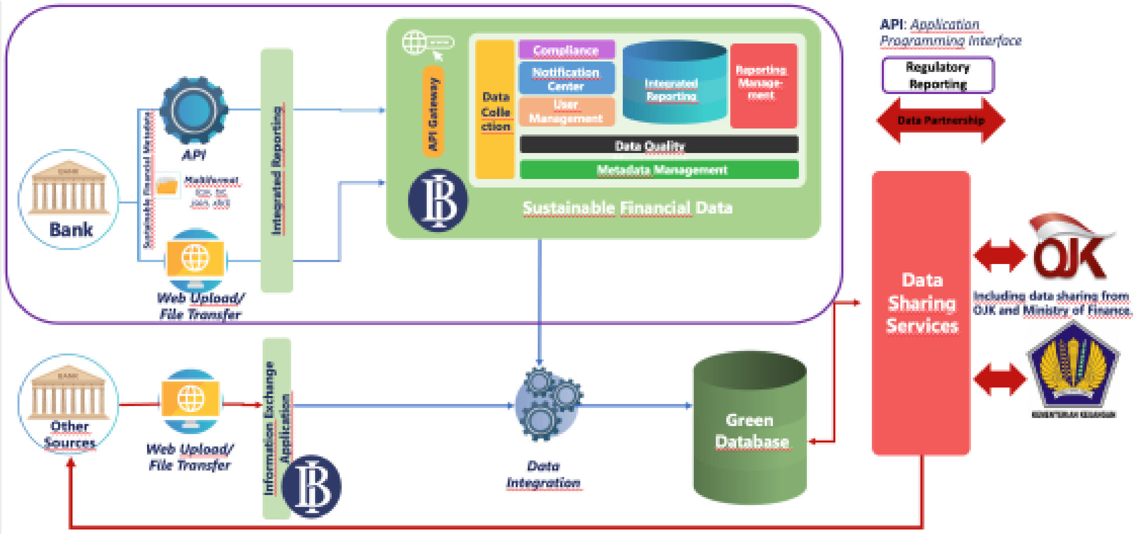
[8] NFC = Non-Financial Corporations, ODC = Other Depository Corporations, OFC = Other Financial Corporations, CG = Central Government

IV.3 Framework of Data Partnership for Data Collection

From our experienced, we learned that the metadata-based integrated reporting that build from the principles of efficiency, flexibility, consistency, and clarity, is one way to enhance data quality and significantly reduce the reporting burden. But this method must be based on and supported by the collaboration/data partnership G2G between related authorities.

Based on mandate of the new omnibus law for Financial Sector, Bank Indonesia with OJK and Ministry of Finance need to coordinate and collaborate for harnessing sustainable financial data to support its policy. This collaboration should not be limited to G2G data partnership but also with industry related as well (G2B). Therefore, we propose a framework of data collection that combine the collection of primary data that received through integrated regulatory reporting and the collection of secondary data that received through data partnership with the industry. With the advancement of frontier technologies in storage and analytics, primary and secondary data can be integrated into one format data that can be used for multi purposes policy making.



This implementation this framework is not a trivial task, because the first thing that must be agreed upon the authorities is the metadata of sustainable financial data that required to support its policy. Then, we should ensure data availability from its sources, proportionate cost and benefit, and established data sharing mechanisms that ensure data protection and confidentiality.

These technical processes need to elaborate well on the agreement of data partnership that stated the principles of data partnership which consists of but not limited to:

- Data and metadata availability: all parties need to identify, list, and make available all the data and metadata that necessary to the stated purpose of data partnership.

- Technicality mechanism: all parties need to use standard technology, security and IT solution of data sharing and data protection.
- Best practices standard: in ideal environment, all parties should refer to global benchmarks of metadata to ensure its interoperability and use standard metadata format.
- Purpose of use and utilization of data: all parties can define its use case that can be implemented and derive from data partnership.

V. Conclusion and Future Works

1. Flagging sustainable debt securities is important in gathering data to support the analysis of sustainable finance. Data mining is one of the methods that can be utilize to flag and identify the sustainable debt securities in Indonesia. Based on our paper, the decision tree method achieved the highest accuracy among the other two methods, namely Support Vector Machine and Logistic Regression, at 91.3%. However, all three models struggle to learn the data effectively due to its imbalance. Therefore, for future research, the oversampling method can be employed.
2. As per Q1 2024, the sustainable debt securities in Indonesia obtained from this method shows that most of the type is green bond (93.8%), followed by sustainability bond (6.2%) and none falls into sustainability-linked bond. From the sector issuer side, Government sector dominated the issuance of sustainable debt securities (88.6%). From the market of issuance, most of them are issued abroad (70.9%) and the rest are issued in domestic. The characteristics of most of sustainable debt securities in Indonesia are long term, fixed interest rate, and in foreign currency (USD).
3. Out of the corporations identified issued sustainable debt securities, only one company uses TCFD framework for sustainability report. This is in line with the finding on PWC report that only 10% of Indonesia listed company already used TCFD framework. Considering IFRS S2 Climate-related Disclosures is aligned to TCFD, in the future we can expect that the number of companies using TCFD framework will arise. If the authority mandates TCFD framework, the implementation will be more extensive.
4. A framework of data collection that combine the collection of primary data that received through integrated regulatory reporting and the collection of secondary data that received through data partnership with the industry is one way to fulfilled data gap on sustainable finance data. But this framework is not a trivial task. Because, to achieve its efficiency and optimalization in the industry, the most important prerequisite is to ensure an agreement between institutions regarding sustainable finance metadata. Then, we should ensure data availability from its sources, proportionate cost and benefit, and data sharing mechanisms that continue to ensure data confidentiality. Thus, with the data partnership, it needs to have a transparent methodological and quality framework that links directly to

the future production of official statistics from all the parties involved, including the same understanding of the metadata of the data sources. All parties also need technical and organizational measures that should safeguard the security and confidentiality of the data being reused.

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IFC Workshop on "Addressing climate change data needs: the global debate and central banks' contribution"

6-7 May 2024

Central banks' contribution to addressing climate change data needs: lessons from recent experience and outlook[1]

F Fortanier,
De Nederlandsche Bank

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

Concluding remarks

DeNederlandscheBank

EUROSYSTEEM

Summary and main take-aways

Climate change presents a massive negative shock to the system: environmentally, economically and financially.

This conference illustrated that this shock is already happening and will become worse

- Manifestation of physical risks: declining wheat production in Turkey; floods and hurricanes in Mexico, Malaysia, Netherlands.. land uses in Chile…
- Manifestations of transition risks: bank exposures to climate policy-relevant sectors in Poland and the USA; carbon footprints & CBAM in Turkey; BIS scenario analyses for the banking system as a whole…

These risks are spread out across space and time, and need to be managed urgently, to avoid even tougher consequences and decisions in the future.

Summary and main take-aways

This conference – including high level key notes - also highlighted that there is a broad consensus that **Central Banks, considering the implications of climate change for many aspects of our mandates, have a clear role** to help managing these risks, and to facilitate efforts to finance the transition to ensure that these risks do not become worse.

Good policy is evidence-based & what gets measured gets managed

BUT

We face a data-void

Statisticians may help!

…this conference showed we are rising to the challenge

Collaboration

- Internationally including via international organisations and via networks (like NGFS, BIS I-hubs), but also with many other stakeholders (researchers, regulators, policy makers, accountants, companies…) to accommodate a wide variety of needs

Creativity & Innovation

- New models and estimations, new technologies, new – non-economic – datasources (& non-economic colleagues)

Curiosity – asking new (sometimes uncomfortable) questions

- E.g. Before we even know who owns the building - who owns what is INSIDE?

Convergence

- Shared initiatives (like DGI 3) & the development of standards (SNA/BPM)

Communication

- Dashboards (IMF, OECD, BIS…) and repositories (NGFS)
- Transparency on methodologies and qualification of the findings
- Explanations WHY method differences exist (e.g. OECD)
- Shortcomings and what is still needed

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How full is our glass?

There are signs of hope

- For data: Growing amounts of data (partly due to regulation), insights and policy messages
- For the environment: growth in sustainable finance; some reduction in CO2 footprints; growing # of transition plans…

But are we doing enough?

- We are doing now what we have always done in the face of new policy questions…develop, experiment, discuss at conferences, standardize…
- We do this fast, with reasonable resources and strong policy support, and using new technology and sources
- We are helped by policy context (bold regulation, new accounting frameworks, many policy initiatives)

Avenues forward

- **Play our strengths:** Continue what we have done successfully in the past (More conferences on climate & data are surely forthcoming)
- **Condense complexity to actional policy messages:** highlight why indicators change, what policy measures work, to ensure policy is well-guided
- **Consider bolder steps to *really* fill the data void, lifting data to the next level:** leveraging our Central Bank position as independent, legitimate, long-term focused regulatory and internationally connected institutions.

  See: accounting for carbon in the value chain (BIS/IFC Hamburg conference) at the entity and product level: what can we do to support reporting agents – more guidance but also e.g. a data exchange system