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Carbon costs – Towards a system of indicators for the carbon impact of products, enterprises and industries[1]

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Carbon costs

Towards a system of indicators for the carbon impact of products, enterprises and industries

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Abstract

This paper studies data needs and policy options in the field of climate mitigation and sustainable finance. It presents a system of greenhouse gas (GHG) indicators that provides a large part of the information required by markets and policymakers. The system is lean and informative. It condenses the relevant product and enterprise-specific information into a single number: *carbon cost*. Like prices, carbon costs are easy to understand, manage and communicate. Implementation options are discussed in a stylised way. A coherent system of carbon costs may evolve from an initial stage in which indirect inputs are valued using proxies. With appropriate institutional underpinning (standards, auditing requirements and dissemination), the disclosure process may become largely self-sustaining. The envisaged scenario is one in which, *at all levels of production, goods and services have two price tags – the financial price to pay and the carbon cost.*

At an enterprise level, carbon costs can be computed using standard information from environmental data providers. The paper provides a brief introduction to the empirics.

From the discussion on how a system of carbon costs could be implemented, the paper derives a number of policy options for central banks and international organisations that aim at supporting the creation and diffusion of a comprehensive indicator system. Specifically, a centralised data platform for reference purposes is needed.

Keywords: carbon footprint, GHG intensities, carbon accounting, environmental accounts, carbon disclosure, green finance

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1. Introduction and summary

Today, climate mitigation occupies the centre stage of policy discussion and planning. We expect policymakers to act and markets to react proactively and efficiently. As statisticians, we can contribute data, and, what is more, concepts. If there are concepts but no data, we can begin gathering the missing data. However, if there are data but no concepts, we will not be able to make meaningful use of the information we have.

This paper proposes a consistent system of indicators for the carbon impact of industries, companies, products and activities, from the top level aggregate down to the level of single activities. The framework condenses the existing information on carbon impacts for decision makers – in the policy arena, on the financial markets as investors and on the commodity markets as producers and consumers – in a way that is easy to interpret and to process. It allows consumers, investors and policymakers to differentiate between goods, activities and firms based on their carbon impact.

The main contribution of the paper is to look at carbon costs as a price system. Besides describing a useful information structure, the paper also shows how this system of indicators can be generated in an almost entirely decentralised way. The carbon impact of a certain activity or product is analogous to a price tag, and exactly in the way input prices are processed in cost calculation, the carbon impact of activities and products can be passed along the stages of the value chain. Just as in the case of product prices, consumers or producers of final goods do not have to be aware of the stages of the value chain – they only need the carbon cost indicators of their immediate suppliers.

In the world of sustainable finance, carbon costs can provide the granular-level information for climate mitigation issues that is so badly needed. Considering the proposed system will help us understand what is required and thus be useful in the discussion regarding the desired format for carbon disclosures. It may inform policy activity. New disclosure directives are beginning to take shape, but there is much that remains undefined. At the same time, central banks and international organisations are considering assuming an active role in sustainability issues in line with their mandates. The paper develops a perspective both for disclosure legislation and the role of central institutions.

This paper aims at convincing the reader that carbon costs is a promising way to go. Outlining an "ideal" information system and the conditions under which it can be made operational may, as an additional merit, provide a reference that allows discussing the trade-offs that go with less encompassing alternatives.

Annex 1 reviews IO models that may be used for approximating input carbon costs. Annex 2 gives an overview of the availability of microdata on emissions and describes some of the key legislative initiatives regarding mandatory disclosure of environmental information.

2. Carbon cost and carbon cost accounting

2.1 An indicator system —the vision

At the heart of environmental problems is a situation in which the effect that producing and using goods has on scarce resources is not properly reflected in the price system. In the case of greenhouse gases (GHGs), the scarce resource is the capacity of the environment to absorb carbon emissions – or, to be more precise, the maximum quantity of carbon emissions in line with global warming targets.

For a massive reduction of GHG emissions, it is vital that consumers, investors and policymakers be able to properly evaluate the environmental consequences of production activities so that they can make the right choices as decision-makers.

What is it one would ideally expect from an indicator system for the use of climate mitigation and specifically for financial sustainability purposes? We need exact quantitative information on the relevant emissions on the level of both firms and products. All emissions, direct and indirect need to be covered, the latter not as loose estimates, but based on realised material flows and micro level production interdependences. Granular information is notably scarce, especially on the Scope 3 level. It is granular information that is needed, however, to make meaningful distinctions that go beyond favouring products and firms in sectors with a low carbon intensity or selecting stocks that happen to be in high tech sectors.

A metric that summarises all the relevant information needed to make decisions on the production, use and consumption of goods and services is the *carbon cost, defined as the total amount of carbon emitted in the course of production of a good or service, either directly or indirectly through the use of intermediate input products.*[2]

Consumers can use carbon costs to compare alternatives. If they systematically choose less carbon-intensive alternatives and they are willing to pay the price, this creates competitive pressure. The pressure carries over to earlier stages of production: Along the entire value chain, buyers of intermediate inputs will opt for less carbon-intensive alternatives. Supervisors and policymakers are provided with a solid foundation for classifying firms – for taxes or subsidies, industrial policy or taxonomies for sustainable finance purposes. As an example: carbon cost information is precisely what is needed to get EU plans for a carbon border adjustment mechanism off the ground.[3] At each stage of production, the metric captures and carries forward the resources that have been used up to that point. In a peer group of goods that are close substitutes, carbon costs allow for the identification and weeding-out of inefficient producers and production technologies. Regarding unrelated goods, consumers and policymakers can compare and weigh their respective usefulness against their consequences for the climate.

2 Other expressions in use for related concepts are “carbon footprint” and “carbon content”. While the author appreciates how both of these terms can be intuitively understood, the term “carbon cost” has a price-like connotation.

3: As part of the European Green Deal, the European Commission intends to put a carbon price on targeted imports by 2026 to avoid “carbon leakage”, i.e. the migration of industries to countries with more relaxed emissions policies. Technically, importers need to buy carbon certificates corresponding to the carbon price that would have been paid if the products had been produced in the EU; see here official information with further links to the proposed legislation. Without a quantification of carbon content, the WTO may well consider the proposal an illegal tariff.

This is all that measurement can give. The rest of this paper argues that this metric can in fact be implemented. The key is the recursive nature of the concept.

2.2 Defining carbon cost

Here and in the following, the terms "carbon" and "carbon cost" refer, as a shorthand, to all GHGs. GHG emissions are converted into carbon equivalents using global warming potential (GWP) factors. To evaluate the carbon impact of a given production process or of the resulting product, it is not enough to consider direct GHG emissions. Direct emissions critically depend on the level of vertical integration. We therefore need to take into account the indirect emissions, as given by intermediate products or services that went into the production. To fix ideas, consider the following. In production planning, every process is defined by a *bill of material* (BoM) that specifies all inputs, plus a *route sheet* that explains how to combine them. A complex production process may be decomposed into several stages. Consider the BoM of product *k*,

$$\mathbf{a}_k = \begin{pmatrix} a_{k1} & a_{k2} & \dots & a_{kK} \end{pmatrix}',$$

with a_{ki} being the quantity of good i needed in the production process. Let the amount of carbon emitted directly be given as d_k. Let scalar c_i be the (total) carbon cost of good *i*, the quantity of carbon that is emitted in the production of one unit of good *i*. List the carbon cost of all input goods in a vector as well:

$$\mathbf{c} = \begin{pmatrix} c_1 & c_2 & \dots & c_K \end{pmatrix}'.$$

The carbon cost of good *k* is then given as the sum of direct and indirect emissions:

$$c_k = d_k + \mathbf{c}'\mathbf{a}_k = d_k + \sum\nolimits_i c_i a_{ki} \, . \tag{1}$$

Equation (1) takes the form of a cost equation, where the a_{ki} are input quantities and the c_i are the corresponding factor prices. The equation is both perfectly general and encompassing. It relates to products and activities and – for a defined time span – to enterprises and sectors as well.

The equation is a definition. It helps us understand the problems associated with gathering and processing information. For actual computation, all the c_i corresponding to non-zero elements of the BoM of product *k* are required.[4] If $\mathbf{c}$ is known, we calculate the carbon cost of product *k* in a straightforward way from direct emissions and the BoM. This is like computing the energy content of food: it is enough that producers know the composition of their product and the energy content of the ingredients.

If $\mathbf{c}$ is unknown, we can use equation (1) recursively and try to compute the carbon cost c_k, going up the value chain from more complex intermediate inputs to primary and primitive inputs. It is helpful to note that equation (1) and the corresponding equations for all other goods constitute a simultaneous equation system. The structure of the problem is well known from linear production planning and input-

[4] We may even need to know c_k itself if a certain quantity of the product *k* is used as an input for its own production, as will be the case in biological processes or the production of electricity. We can avoid this by defining the left-hand side as the carbon content of *net production*.

output analysis.[5] Conceptually, we can solve for the carbon cost of all products simultaneously. Let

$$\mathbf{A} = \begin{pmatrix} \mathbf{a}_1 & \mathbf{a}_2 & \dots & \mathbf{a}_K \end{pmatrix}$$

be the matrix of the BoMs for all output goods, $1,\dots K$. With $\mathbf{d}$ being the column vector of direct emissions for products $1,\dots K$, one may write:

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

This structure is equivalent to the (open) Leontief model of production.[6] Reordering and postmultiplying the "Leontief inverse" $\left(\mathbf{I}-\mathbf{A}\right)^{-1}$ yields for $\mathbf{c}$:

$$\mathbf{c}' = \mathbf{d}'\left(\mathbf{I}-\mathbf{A}\right)^{-1} . \tag{2}$$

The carbon cost of products (product *k* and all the others) result from their respective direct carbon inputs and the direct inputs of all the intermediate goods used for their production by intermediation of a matrix derived from the BoM that reflects the interlinkages in production. If the coefficients in the carbon cost equation refer to empirical production technologies actually being used to produce goods $1,\dots K$, it can be taken for granted that the inverse exists and all its elements are non-negative.[7]

As simple and beautiful as this relationship is, it cannot be used directly. **A** comprises the BoMs for all products in the economy, including those that have been imported, and if a certain input is produced using two different technologies, it should actually have two separate entries. Meanwhile, **d** collects the direct emissions that characterise all of these processes. Except for simple cases, this is impossible to deal with at the micro level. However, sector-level approximations of factor intensities using input-output (IO) models are feasible, as will be explained in more detail later. And just as the price mechanism is able to process an enormous amount of information in a decentralised way, we can think of ways to make the coordinated exchange of information between producers do the work.

In the following, equations (1) and (2) will enable the tracing of information requirements and policy options for setting up a comprehensive and informative system of GHG indicators. Before this, however, a third equation is presented that allows for the identification of carbon costs at the enterprise level.

5 Input-output analysis is closely associated with the name Wassily Leontief, who was awarded the 1973 Nobel Prize for the development of this model. Leontief (1966, 1986) covers much of his work.

6 See Miller and Blair (2009), ch. 10, for a description of this structure on the industry level. To be precise, the structure corresponds to the "dual" price system that results from the Leontief structure, yielding a linear relationship between the value added of industries and the prices of goods; see Pasinetti (1977), chapter 4. Interestingly, Pasinetti (p. 61) writes that no important practical application of the dual system has yet been found.

7 If some of the relationships are estimated, postulated or extrapolated from the past, as will be the case in real-world implementations, the existence of non-negative solutions **c** given non-negative elements in $\mathbf{A}$ and **d** cannot be taken for granted a priori. For a non-negative solution to exist, it is necessary and sufficient that all principal minors of $\mathbf{I}-\mathbf{A}$ are positive (Hawkins-Simon conditions). Equivalently, all characteristic roots of $\mathbf{A}$ are less than 1. See e.g. Takayama, (1985), chapter 4, specifically the summary collection on p. 386. Intuitively, the amount of direct carbon emissions needed must not "explode" as we use equation (1) recursively. Iteratively, the Leontief inverse can be computed as a power series, $(\mathbf{I}-\mathbf{A})^{-1} = \mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \cdots$. This expansion will converge only if the eigenvalues of $\mathbf{A}$ stay within the unit circle. Pasinetti (1976), chapter 4, specifically pp. 66 ff. and the references to the appendix, and Schumann (1968), pp. 35 ff., give clear expositions.

2.3 Carbon cost and GHG emission classes

Given the widespread use of the GHG Protocol emission classes in environmental reporting (see the Annex 2), it is useful to rephrase the definition of carbon cost in these terms. In the production of good k, let $sc1_k$ and $sc2_k$ be Scope 1 and Scope 2 emissions, and $sc3u_k$ be *upstream* Scope 3 emissions (cradle to gate). Then we have:

$$c_k = sc1_k + sc2_k + sc3u_k. \tag{3}$$

Carbon cost is equal to the sum of Scope 1, Scope 2, and upstream Scope 3 emissions. Downstream emissions critically depend on decisions to be made by others, and their inclusion would destroy the recursive nature of the carbon cost: they lead to double counting if later stages of production use carbon costs to evaluate their inputs.[8] The identity in equation (3) ensures that we can make use of GHG Protocol standards for data gathering and processing, specifically the binding norms relating to Scope 1 and 2 emissions. Regarding upstream Scope 3 emissions, it is necessary to make decisions on a number of options in the GHG Protocol standards for practical implementation purposes. The carbon emissions of commuting workers, for example, are difficult to monitor and only loosely related to the company and its product.[9]

Using equation (3), carbon costs and carbon cost intensities can be computed at the enterprise level for companies that report their emissions in compliance with the GHG Protocol; see section 5 below.

2.4 Carbon cost and carbon accounting

Carbon costs are framed here as a close, almost perfect analogue to financial costs. Both are *valued resource consumption*. The same input vector may figure in both the financial cost equation and the carbon cost equation, with only the valuation vectors differing. This analogy enables making use of standard accounting techniques, the outcome of centuries of experience with valuation problems. Carbon costs are fraught with a large number of such valuation issues: emissions from overhead activities such as the heating of production facilities and office buildings, transportation, the carbon costs of capital goods, or combined production technologies. They require the *allocation* of company-level costs. The good news is that all of these issues have been solved conceptually, at least to a large extent. The cost accounting solutions that exist simply need to applied to the task of calculating carbon costs. The close analogy has been noted; see e.g. Stechemesser and Guenther (2012) for a literature review on carbon accounting or, for a practical introduction, Eitelwein and Goretzki (2010). With a valuation vector for input goods at hand, it is possible to carry out information

8 One could choose to define the carbon cost slightly differently in terms of carbon *input* (as opposed to *emissions*) in order to take account of the physical carbon content of the product that will lead to emissions at a later stage. If d_k in equation (1) is the direct carbon input into production at the given stage rather than direct emissions, then c_k and all the $c_i, i = 1, \dots, K$ are to be interpreted as physical carbon content, emissions included. The difference between this concept and the one given in equation (1) above would largely be waste disposal emissions as a part of downstream Scope 3 emissions.

9 For direct emissions and the use of energy, see the standards for disclosure of GHG Scope 1 and 2 emissions: WRI and WBCSD (2004). For Scope 3 (indirect) emissions, see the two closely related standards for enterprise-level and product-level disclosure: WRI and WBCSD (2011a and 2011b). Further, see the Technical Guidance for Calculating Scope 3 Emissions in WRI and WBCSD (2014).

aggregation and processing using standard cost accounting software, both at the product and at the enterprise level.

At this point, one might ask whether carbon costs should not better be stated in monetary units. Physical carbon quantities may be converted in monetary units using a "carbon price", a factor that indicates the value of saving one unit of carbon. However, this price will change over time, affecting comparability. Carbon costs from earlier periods could not easily be used as weights for inputs.

For final demand, especially in private and government consumption, stating carbon costs in monetary units may help decision makers, as they enable comparisons with the utility of the product to the consumer. Decision makers may ask themselves whether this utility really justifies the damage to climate. Thus, on the retail level, it may be useful to state carbon costs both in physical and in value terms.

Result 1: *The carbon costs of an activity or product are a simple recursive metric for climate effects. Used consistently in a production system, they yield a set of metrics that allow consumers, producers and policymakers to make informed decisions. Corresponding metrics can be calculated for enterprises and sectors. They are consistent with the carbon intensities from IO models and with emission classes according to GHG Protocol standards. Given carbon costs for inputs, the carbon cost computation for a product or an enterprise can rely on established cost accounting procedures.*

3. Towards informative carbon cost valuations

As equation (1) shows, a producer's problem of calculating carbon cost is recursive. Imagine for a moment that the producer knows the carbon costs of inputs. Then they only need to allocate direct emissions and set up a detailed list of inputs, based on the knowledge of their own production technology. This is a *Hayekian situation: just like the price system, the resulting system of carbon costs embodies all the technology constraints and interdependencies of the entire system, without any individual producer having to know more than their own technology and the cost vector common to all agents.*

In general, however, producers will be ignorant of the carbon costs of their inputs. On the way towards the Hayekian situation, there is already much to be gained from a valuation vector for the inputs that is only approximately accurate. It gets the proportions right and makes environmental accounting independent of the level of vertical integration. Market participants and supervisors obtain product and enterprise-level information on Scope 1, 2 and upstream Scope 3 emissions into which the producers' knowledge of production technology and the composition of inputs is fully incorporated. Today, the information available at the enterprise level is on Scope 1 and 2 emissions at best; information on Scope 3 emissions is a rare exception.

Thus, to start with, we may assume that no granular, product-level valuation vector for inputs is available. What happens if every producer is willing to make and provide their best estimate for others to use? It will be demonstrated that this leads to an efficient equilibrium of decentralised information processing. In practical terms, producers can use their BoM with the carbon costs provided by their suppliers, if available. If not, carbon costs of reference products or sectoral approximations from IO models can be used instead. This will discussed in more detail below.

3.1 Top down: using EEIO models for generating proxies for input carbon costs

It was already mentioned that, conceptually, input-output (IO) models are the appropriate approach to deal with the recursive nature of the carbon cost definition. The total emission intensity of a sector, as calculated from an input-output model, can be used as sector level proxy for input carbon costs on the right hand side of equation (1). In principle, carbon intensities can be calculated with any IO model that depicts the relevant industry interlinkages, provided that appropriate sector level information on direct carbon emissions are available. IO models with a focus on environmental issues are called "environmentally extended IO models", or EEIO models.[10]

For the purpose at hand, it is useful to have those interlinkages defined in terms of physical units and not, as it is the rule, in value terms. Given the strong interdependence of national economies, the IO base should be international and not treat the "rest of the world" as a black box. In order to capture heterogeneity, the model ought to distinguish a variety of sectors, possibly considering certain types of firms separately.[11] Ideally, the IO model comes near to providing carbon cost proxies at a product level. Therefore, fine distinctions are important especially in sectors with strong industry interlinkages, eg manufacturing. Data quality is of paramount importance, however, and there is no use in trying to make distinctions that cannot be supported with reliable data.

Annex 1 gives a short overview of some of the existing IO data bases potentially suitable for generating proxy information on input emission intensities.

Result 2: *Carbon content according to EEIO models may serve as an industry-level proxy for the carbon costs of inputs according to equation (2). In the case of missing product or firm-specific information on inputs, we can use the carbon intensity of the respective industry to generate product-specific carbon costs in equation (1).*

This allows producers or analysts to characterise the carbon costs of inputs on an industry-by-industry basis. It yields initial values for an iterative approach. Near the bottom of the supply chain, producers can compute rather accurate carbon costs using sector proxies for their inputs. At later stages, producers will still obtain consistent and mean-preserving estimates into which their detailed micro-level knowledge of production technology is fully incorporated.

3.2 Other approximations for the carbon cost of inputs

Using sector-level intensities from EEIO models is indeed one of the ways proposed by the GHG Protocol guides for calculating Scope 3 emissions. There are other ways

10 Again, it was Wassily Leontief (1970) who first proposed using IO models for analysing pollution generation associated with interindustry activity. For input-output analysis in general, see Miller and Blair (2012), and specifically ch. 10 for environmental input output analysis. Suh (2010) collects extensions and applications in industrial ecology.

11 In analysing global value chains, Fortanier et al. (2019) suggest distinguishing multinational enterprises and domestic controlled firms. The production technology of MNEs as well as their import content and export orientation are sources of intra-industry firm heterogeneity. In the same vein, in some developing countries one may want to distinguish between informal and formal activities within the sector, as the former may be less responsive to government environmental policy.

of obtaining estimates. The GHG Protocol guides generally recommend an in-depth and detailed analysis of the entire product value chain. Producers should then make an effort to gather intelligence on Scope 1 and 2 emissions at earlier stages. While this is feasible in cases where producers oversee the entire value chain, or within the confines of companies of the same group, it is tedious and impractical in the more general case of dispersed production activity. Input suppliers will not be forthcoming with providing detailed technological information to their B2B customers. The beauty of carbon cost is that it encapsulates all required information on carbon use without disclosing anything technology-related beyond this, not even on the amount of direct emissions.

Apart from analysing the supply chain, the GHG Protocol recommends the use of proxies and of firm-level information on the emissions of the provider. If the carbon cost is known for one input good, it can be used to calculate carbon costs for close technological substitutes. Using standardised intensities is especially practical for staple goods, where there is little technological variability. Low-intensity goods and services such as banking and insurance can be grouped and accounted for using an overhead factor common for the industry of the producer. If the product-level carbon cost is not available but the input provider publishes enterprise-level GHG Scope 1 and 2, or even Scope 3, emissions, the resulting intensities can be used as a basis for an estimate, similar to EEIO sector-level intensities. Section 5 below takes a first look at such intensities. If they contain direct information on Scope 1 and 2 emissions, enterprise-level intensities are preferred to their sector-level counterparts, even if the Scope 3 emissions figure is based on estimates.

3.3 Bottom up: pulling oneself up by one's bootstraps

With initial values for the carbon costs of inputs, e.g. from sectoral or firm-level intensities, the carbon cost of a product can be calculated according to equation (1). This will not immediately lead to a consistent set of measures: typically, the carbon cost c_k according to equation (1) will not be equal to the approximations used for the same good in calculating the carbon costs of other goods.

Importantly, however, each producer will be able to pass a measure of carbon content on to the buyers of intermediate products. Assume that, along with the price of the product, producers communicate a measure of its carbon content. This allows for a *second stage*. If the buyers of intermediate products use the approximations of their suppliers instead of the industry averages, the estimation error will diminish greatly, as the direct emissions of intermediate inputs are correctly accounted for. In equilibrium, the error will disappear completely, provided there are no products without proper carbon content estimates, such as imports. It is easy to see why: industry averages or other approximations are needed only when there is no individual-level carbon cost available. If there is one such measure for every good, and if these measures are consistently used to evaluate inputs according to equation (1), the industry averages will never enter the picture, not even indirectly.

Result 3*: If all producers give a fair estimate of equation (1) using the information they have, i.e. direct emissions, BoMs, and carbon costs of input or estimates thereof, and if this information is passed on to the market, in equilibrium the resulting system of carbon costs will correctly reflect the interlinkages as given by equation (2).*

This is key for feasibility: producers do not need to know the carbon costs for products in the entire economy, only those of their own suppliers (or estimates thereof), just as for cost accounting we do not need to know the entire price system, but only what our suppliers charge. If not all carbon costs are available, producers can use proxies, either from reference products or from sectoral models. Over time, the system will converge.

4. Is there scope for voluntary disclosure?

To a certain extent, carbon cost disclosure may rely on voluntary action by producers. The existence of the GHG Protocol and its increasing use shows that there is a distinct commercial interest in obtaining and communicating carbon accounting information; see Annex 2. In 2016, according to the GHG Protocol, 92% of the Fortune 500 enterprises that responded to a survey on carbon disclosure were running programmes based on GHG Protocol standards. Another non-profit-entity, CDP (formerly the Carbon Disclosure Project), disseminates a standardised questionnaire on GHG activities. More than 2,000 companies worldwide provide answers on a voluntary basis, which are then made available to the public and used as inputs in commercial databases.

On the other hand, it is also clear that some firms have reasons to declare their carbon costs either incorrectly or not at all. Just as with financial costs, if there is an opportunity to make products look cheaper than they really are or to avoid talking about prices altogether, some market participants will take it.

To establish a carbon cost system, some reporting obligations will be necessary. However, this section makes the argument that reporting obligations may not have to be broad-based. Instead, legislation only needs to make sure that a threshold volume of disclosure, e.g. from large companies, is surpassed. *Under certain conditions, this will trigger a process that will end in almost universal voluntary disclosure.*

As a first component, we need *formal auditing* to make sure that the carbon cost is a fair estimate, using the information on direct emissions and production interlinkages existing at the company level. The auditing is carried out against disclosure standards that have to be specified in advance. It is best organised in parallel with financial auditing, with governments having the right to scrutinise dubious statements. In this respect, it is extremely promising that the IFRS is about to change its statutes in order to set up a board on disclosing standards for environmental information.

Second, an *information platform* is required that makes available the existing information on:

- industry averages;
- direct emissions from company reports;
- carbon cost estimates, as far as they exist.

There is a path that leads to voluntary disclosure by (almost) all firms. Suppose that the information platform, in addition to making existing information publicly available, computes estimated average carbon content for firms of a given industry that do not disclose their carbon cost -- from the known industry averages and the known carbon costs of the firms that do disclose. These estimates will be used to evaluate the carbon cost of inputs produced by non-disclosing firms.

Producers with low carbon costs, relative to their peer group, will have a clear incentive to disclose. With low carbon costs, they can charge higher prices or reap the rewards of positive publicity. This generates a signal value for the decision not to disclose. The signal will be reinforced by calculating sector averages for carbon costs conditional on not disclosing. With many companies disclosing, those that do not disclose will look increasingly unattractive. We may envisage an iterative process where first the cleanest firms disclose, then those that are not top tier, but still well above average, etc. In the end, the only firms to not disclose will be those with rather extreme carbon costs, and the fact that they do not disclose will be informative enough. In order to create an incentive that is large enough to get this mechanism going on a broad scale, we may need to overcome a threshold number of participating firms.[12]

This process of unravelling due to using the industry average as a proxy for non-disclosing firms is quite similar to the Stiglitz and Weiss (1981) account of the possible breakdown of the credit market under asymmetric information. In the scenario at hand, however, the result is a separating equilibrium with voluntary disclosure.

Result 4*: Given a sufficient degree of competitive pressure, an equilibrium with voluntary disclosure will result if:*

1) *firms are audited according to predefined disclosure standards;*
2) *sector-level information and the disclosed carbon costs are made publicly available; and*
3) *carbon intensity estimates based on the unaccounted-for parts of industry totals are disseminated to be used for firms that do not disclose.*

By mimicking the diffusion of information via the price system, information on carbon usage can be processed in a decentralised and efficient manner, even without any formal reporting obligation. The key ingredients are micro-level auditing and a centralised information platform. This is where central banks may have an important role to play. They need to collect much of the required information anyway in order to classify their assets and collateral and, at least in some cases, to rate companies. In addition, they have the mandate to disseminate statistical information for policy purposes as well as all the necessary infrastructure, experience and working routines.

One obvious challenge is imports. Exporters may not have the same incentives to disclose if their markets are located largely outside a country that implements a system of carbon cost indicators. Many large international companies disclose their carbon usage data voluntarily, and the upcoming EU legislation on the carbon border adjustment mechanism will further expand the information available on emissions. Still, for many products and companies, the information will likely be missing permanently. For those products and firms, industry averages specific to the exporting country can be used. See Destatis (2019) for a tabulation of the carbon content of imports from major trading partners by industry in the years 2013 to 2015. Alternatively, one can find reference producers in the home country. It is clear that

[12] Some enterprises are already reporting carbon costs for their products today. A Swedish company producing oatmeal gathered more than 57,000 signatures for its petition to the Deutsche Bundestag, the German Federal Parliament, to make carbon cost disclosure obligatory for retail food. Given the size of the petition, there was a public hearing. There is also a market for consultancies that help compute product-specific carbon costs; see here a link to a Frankfurt consultancy. Competitive pressure will increase considerably once reporting carbon costs becomes commonplace and accountants offer standardised and cheap solutions.

the problem is less acute if countries within a large economic zone such as the European Union act in unison.

5. Company level carbon costs: some descriptives

Equation 3 allows us to study carbon cost at the (aggregate) company level. Since the GHG Protocol first published emission reporting standards in 2001, an increasing number of companies have been voluntarily reporting on Scope 1, Scope 2 and even Scope 3 emissions. This information is collected by centralised data platforms, with CDP being the most prominent. Commercial providers augment them with imputations on missing data and estimations to give investors a broad information base; see Annex 2 to this paper.

Based on equation (3) above, company-level carbon costs can be computed if information on the components of emissions according to scope is available. This is the case for the emissions data of Trucost.[13] In this section, they will be used to show some stylised facts and provide initial insight into magnitudes.

For 2019, Trucost reports GHG emission data on 19,405 companies, most of them listed. Among them are 4,576 companies from China, including Hong Kong, 3,134 from the United States, 2,397 from Japan and 343 from Germany. Only a fraction of these emissions data is fully collected from company disclosures: 9.2% of the Scope 1 emissions data worldwide and 19.8% from Germany are collected as exact figures. Fortunately, reporting incidence is much higher for large companies. Weighted by revenues, 69.9% of Scope 1 emissions data worldwide and 81.1% in Germany are collected as exact figures from company reports. The rest are either derived from partial information or estimated using the Trucost EEIO model. Trucost also reports upstream and downstream Scope 3 emission intensities. For upstream Scope 3 emissions, the agency does not make use of reported information: all data are estimated using its proprietary EEIO model.[14]

[13] Trucost is an affiliate of S&P Global.

[14] Downstream emissions data make partial use of reported information.

Table 1: Company-level GHG emission intensities and carbon costs

Trucost environmental data, 2019, worldwide

	Mean	Median	Std Dev	# Obs
Intensity levels				
Scope 1 & 2	338.56	39.33	2034.17	19,405
Scope 3 upstream	160.29	97.70	197.07	19,405
Carbon cost	498.84	169.84	2073.89	19,405
Log intensities				
Scope 1 and 2	3.794	3.672	1.790	19,405
Scope 3	4.577	4.582	0.990	19,405
Carbon cost	5.150	5.135	1.266	19,405

[1] Emission intensities are given as tons of CO2 equivalents, normalised by company revenue in USD million. Scope 1 and 2 emissions are direct emissions plus purchased electricity, heat and steam. Scope 3 upstream emissions are indirect emissions that result from intermediate inputs. Carbon cost is defined according to equation (3) as the sum of Scope 1, Scope 2 and upstream Scope 3 emissions. All data are reported unweighted.

Sources: Trucost environmental data, author's calculations.

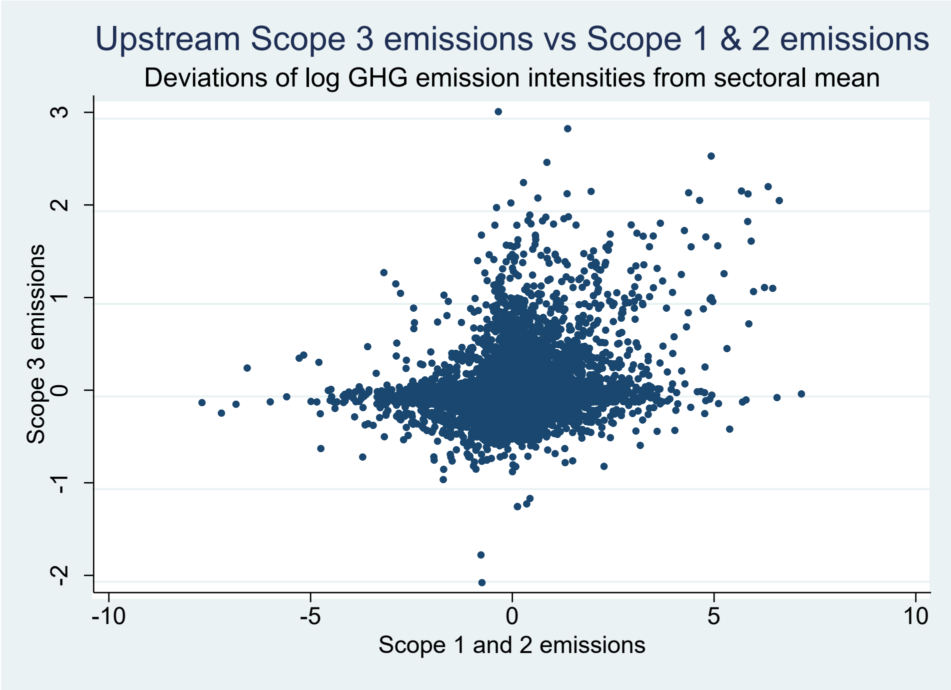
Table 1 lists descriptives on company-level emission intensities (normalised by revenues) according to scope, namely the sum of Scope 1 and 2 emissions, the Scope 3 emissions, and the resulting carbon costs. The table provides descriptive information on both the levels of intensity and the logs. The Trucost database contains both holdings and operative companies, thus there may be some double counting. The data have not been cleaned to remove outliers.

Scope 1 and 2 intensities are highly skewed. The standard deviation is dominated by extreme values, it is much higher than the mean. The upstream emissions, being fully estimated, do not contribute much to the variability of the carbon cost measure, although in terms of levels they have a share of around one-third. The logs are far better behaved. Means and medians are about equal. With log intensities, average upstream Scope 3 emissions are larger than Scope 1 and 2 emissions. For carbon costs, therefore, the carbon content of inputs is of central importance.

Much of the information on intensities is associated with the sector of the producer. This may be especially the case for estimated emissions. Scope 3 emissions are a key component of the carbon cost concept. It is interesting to see whether and how much individual variation the estimated Scope 3 emissions can contribute beyond the level information from the sector. To this end, the deviations of log intensities from their sectoral means are computed.[15] Graph 1 plots the mean deviations of log Scope 1 and 2 intensities against the mean deviations of log Scope 3 intensities. It is clearly evident that the dispersion of Scope 3 mean deviations is lower than those computed from Scope 1 and 2 emission intensities, but it is equally clear that Scope 3 emission data do carry a considerable amount of independent information.

[15] For 2019, the standard deviation of this measure takes a value of .9273174. For Scope 2 and Scope 3 emissions the standard deviations are .835826 and .2129105, respectively.

Graph 1: Carbon cost: checking information content of main components



6. Policy perspectives

At the heart of sustainable finance is the idea that investors need to *distinguish*: between aligned and non-aligned projects, between firms with a higher or a lower environmental risk, and between portfolios with a higher or lower carbon footprint. The information used to make this type of distinction is granular by necessity, i.e. firm-level or even product-level. Carbon costs make it possible to evaluate whether a firm's output portfolio is sustainable. If carbon costs are higher than the carbon costs of similar products, chances are high that the firm is not viable if the environmental cost of production is duly taken into account. More generally, if the carbon cost of a firm's output is high compared with that of others (similar or not), it can be expected that the growth potential of this business model is limited. High carbon costs therefore reflect an elevated market risk.

Currently, there is much to be done and, by consequence, there is much that can be achieved. Annex 2 describes two strands of current and upcoming EU legislature. The draft CSRD, which is yet a rather empty legislative shell, will soon be filled with concrete reporting requirements. The Taxonomy Regulation and its associated delegated acts aim at distinguishing firms that are aligned to environmental transition goals from those that are not, and this policy will need a firm foundation. Apart from these two strands, the "Fit for 55" legislative package envisages new reporting requirements for key activities, and it enlarges the scope for emission trading considerably.[16] The European Banking Authority (EBA) discusses a framework for

[16] For an overview on the entire "Fit for 55" package, see the official communication. There will be separate emissions trading systems (ETSs) for buildings and road transport, and the existing ETS will cover maritime transport. The ETS is important for data availability as it creates a need for careful accounting. Here is a link to the proposed Directive.

prudential disclosures on ESG risks that would force banks to report on their engagement with counterparties that are among the top carbon-intensive in the world, be it in the European Union or in the home country of the institution.[17] The IFRS Foundation is overhauling its statutes to set up a board for sustainability-related reporting. Politically, the need for a coherent and relevant indicator system such as carbon costs is obvious.

In discussing information requirements and implementation, this paper has implicitly described some of the policy options for central banks and international organisations to support the evolution of a broad-based and consistent system of GHG indicators. The following is a list of policy options resulting from the discussion above:

1) Cooperate with Eurostat and the NSIs in setting up a **rather disaggregated EEIO model** for the euro area, and also for some of the larger countries within it if this is warranted by observed heterogeneity. This would be very effective in creating a joint framework for condensing data at a sectoral level.

2) Set up and maintain a **dissemination platform for carbon cost data** at the level of sectors, enterprises and products. Disclosure standards may oblige producers to use carbon cost data published on that platform for their inputs. These platforms may also name and make available reference proxies for cases where product-level input carbon cost information is not available, especially in the case of imports.

3) Develop and propagate **disclosure standards** and assist in setting them as a basis for comparability and auditing. Those rules can build on the relevant GHG Protocol standards.[18] What inputs to consider and how to evaluate them needs to be determined. In this context, it is necessary to make concrete decisions on the options in Scope 3 accounting, with a view to practicability and informational content. The organisations that support the GHG Protocol, namely the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD), may have a leading role to play here. There are also ISO standards that bear a strong resemblance to the corresponding GHG Protocol standards.[19]

4) Interact with the European Commission and possibly also with the IFRS on potential **disclosure requirements**, especially regarding the CSRD (see Annex 2). In light of the discussion above, possible disclosure requirements should target large companies so as to overcome a threshold that will induce voluntary disclosure by others, and producers of primary goods and import goods so as to ensure valid carbon costs at the front end of the value chain.[20]

17 See the Consultation Paper Draft Implementing Standards on prudential disclosures on ESG risks in accordance with Article 449a CRR, especially paragraphs 40-42 and the corresponding annexes.

18 See, in particular, WRI and WBCSD (2004) as a standard for Scope 1 and 2 emissions, WRI and WBCSD (2011a) for Scope 3 emissions at the enterprise level, WRI and WBCSD (2011b) for corresponding standards for Scope 3 emissions at the product level, and the Technical Guide on Scope 3 emissions in WRI and WBCSD (2013).

19 From the ISO 14060 family of GHG standards; see specifically ISO 14067:2018 on GHG reporting at the organisation level and ISO 14067:2018 on reporting at the product level.

20 As already mentioned, the upcoming legislation on the carbon border adjustment mechanism and the enhancement of the scope of the carbon emissions trading systems are beneficial in this respect.

It would be helpful if financial and environmental disclosure auditing could be carried out in synchronicity.

These are largely the same options that are available with respect to any other meaningful system, but the system presented in this paper is useful in showing how these policy measures fit together and how they interact.

A simplified solution would aim at producers to disclose carbon costs only for a targeted subset of products, eg from parts of the manufacturing sector. This is easier to initiate, but the simplicity comes at a cost. For many input goods, carbon cost coefficients need to be estimated permanently, as even in the steady state there are no values from input providers. Result 3 would not hold. Even in this case, though, valuable granular information would come from producers using their private knowledge on technology and input composition. This is perhaps the most important feature of a system of carbon costs.

References

Destatis, Umweltökonomische Gesamtrechnungen. CO2-Gehalt der Güter der Endverwendung, Berichtszeitraum 2008-2015. Wiesbaden, 2019 (download).

Eitelwein, Oliver, and Lukas Goretzki, Carbon Controlling und Accounting erfolgreich implementieren – Status Quo und Ausblick. ZfCM | Controlling & Management 54 (1). (2010), 23-31.

Fortanier, Fabienne, Guannan Miao, Ans Kolk and Niccolò Pisani, Accounting for firm heterogeneity in global value chains, Journal of International Business Studies 51 (2020), 432–453.

ISO (International Organization for Standardization), Greenhouse gases — Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals, ISO 14064-1:2018.

ISO (International Organization for Standardization), Greenhouse gases — Carbon footprint of products – Requirements and guidelines for quantification, ISO 14067:2018.

Leontief, Wassily, Input-Output Economics. New York, Oxford University Press, 1966; 2nd ed. 1986.

Leontief, Wassily, Environmental Repercussions and the Economic Structure: An Input-Output Approach. Review of Economics and Statistics 52 (1972), 262-271.

Merciai, Stefano and Jannick Schmidt, Methodology for the Construction of Global Multi-Regional Hybrid Supply and Use Tables for the EXIOBASE v3 Database. Journal of Industrial Ecology, Journal of Industrial Ecology 22, 516-531 (2018).

Miller, Ronald E. and Peter D. Blair, Input-Output Analysis. Foundations and Extensions. Cambridge University Press, Cambridge etc., 2nd ed. 2009.

Pasinetti, Luigi L., Lectures on the Theory of Production, London and Basingstoke, McMillan, 1977.

Remond-Tiedrez, Isabelle and José M. Rueda-Cantuche, EU inter-country supply, use and input-output tables — Full international and global accounts for research in input-output analysis (FIGARO). Luxembourg, Publications Office of the European Union, 2019.

Schumann, Jochen, Input-Output-Analyse. Berlin, Heidelberg, New York, Springer-Verlag 1968.

Stadler, Konstantin, Richard Wood, Tatyana Bulavskaya, Carl-Johan Södersten, Moana Simas, Sarah Schmidt, Arkaitz Usubiaga, José Acosta-Fernández, Jeroen Kuenen, Martin Bruckner, Stefan Giljum, Stephan Lutter, Stefano Merciai, Jannick H. Schmidt, Michaela C. Theurl, Christoph Plutzar, Thomas Kastner, Nina Eisenmenger, Karl-Heinz Erb, Arjan de Koning, and Arnold Tukker, EXIOBASE 3. Developing a Time Series of Detailed Environmentally Extended Multi-Regional Input-Output Tables. Journal of Industrial Ecology 22, 502-515 (2018).

Stechemesser, Kristin, and Edeltraud Guenther, Carbon accounting. A systematic literature review. Journal of Cleaner Production 36 (2012), 17-38.

Stiglitz, Joseph E., and Andrew Weiss, Credit Rationing in Markets with Imperfect Information, The American Economic Review, Vol. 71, No. 3 (1981), 393-410.

Suh, Sangwon (Ed.) Handbook of Input-Output Economics in Industrial Ecology. Springer, Dordrecht etc., 2010.

Takayama, Akira, Mathematical Economics, New York, Cambridge University Press, 2nd ed. 1985.

Trucost ESG Analysis, Estimating Environmental Impacts. An Introduction to Trucost's Environmentally Extended Input-Output Model (EEIO). Mimeo, 2020.

United Nations, System of Environmental-Economic Accounting 2012 – Central Framework (SEEA Central Framework), United Nations, New York, 2014.

Wiebe, Kirsten S. and Norihiko Yamano, Estimating CO_2 emissions embodies in final demand and trade using the OECD ICIO 2015. Methodology and results. OECD Science, Technology and Industry Working Paper, 2016/05, Paris 2016.

WRI and WBCSD [World Resources Institute and World Business Council for Sustainable Development], The Greenhouse Gas Protocol. A Corporate Accounting and Reporting Standard. Revised Edition, 2004.

WRI and WBCSD, Corporate Value Chain (Scope 3) Reporting Standard. Supplement to the GHG Protocol Corporate Accounting and Reporting Standard, 2011a.

WRI and WBCSD, Product Life Cycle Accounting and Reporting Standard: A standardized methodology to quantify and report GHG emissions associated with individual products throughout their life cycle, 2011b.

WRI and WBCSD, Technical Guidance for Calculating Scope 3 Emissions. Supplement to the Corporate Value Chain (Scope 3) Accounting and Reporting Standard, 2013.

Yamano, Norihiko and Joaquim J. M. Guilhoto, Emissions Embodied in International Trade and Domestic Final Demand. Methodology and results using the OECD Inter-Country Input-Output Database. OECD Science, Technology and Industry Working Papers 2020/11, Paris, 2020.

Annex 1: IO models potentially useful for generating proxy carbon costs for input goods

It was argued in Section 3.1. that the total emission intensity of a sector, as calculated from an input-output model, can be used as sector level proxy for input carbon costs on the right hand side of eq (1), if product level information is missing. This Annex looks closer at IO models as a source for emission data.[21]

The System of Environmental Economic Accounting (SEEA) is a multipurpose conceptual framework that describes the interactions between the economy and the environment, and the stocks and changes in stocks of environmental assets. It is a satellite account of the System of National Accounts (SNA) and uses definitions of sectors, industries, time and space consistent with the National Accounts. The framework is a United Nations system. Many countries, including Germany, maintain reporting systems that conform to SEEA standards. In the following, we refer to the SEEA Central Framework adopted in 2012 in United Nations (2014). The SEEA is divided into three areas. First, the *physical flow accounts* describe flows of material between the environment and the economy and its sectors and industries, very much in the same way as flows of goods and services and funds are described in the National Accounts. Additionally, the *environmental activity accounts* identify economic transactions within the SNA that may be considered environmental, such as environmental protection. Finally, the *asset accounts* focus on the recording of stocks and flows associated with environmental resources of many kinds. For the purpose of this analysis, it is the physical flow accounts that are relevant.

These accounts depict the flow of designated substances from the environment to the economy and its sectors and industries, and vice versa – among them, of course, carbon dioxide and other greenhouse gases. Importantly, the accounts are disaggregated by industry in a way that is consistent with the supply and use tables and standard input-output tables as part of National Accounts. On the first level of analysis, the direct emissions of industries are recorded. This makes it possible to look at the emissions of industries and hold them against, for example, their value added. This gives us a first impression of the carbon impact of industries, not just in terms of absolute size, but also in terms of intensity. Second, using the machinery of supply and use tables and input-output analysis, it is possible to calculate the carbon impact of *final demand as well as of its components* – consumption, investment, imports and exports by industry. This calculation fully reflects the industry interlinkages that are discussed above, using the same analytical apparatus. The matrix of industry interlinkages used in input-output analysis corresponds to the matrix **A** in section 2, albeit at an industry level. This is of high analytic value: the direct carbon emissions of electricity production may be of interest in and of themselves, but to the degree that electricity feeds as an input into the production of other goods of final demand, the emissions need to be attributed to these goods. As an example, in Destatis (2019), Tables 2.1.1. and 3.1.1. show the carbon content of final demand in Germany for the years 2013 to 2015, both in total and for 49 industries and product groups. Similar tabulations exist for the final demand components import, export, consumption and

[21] See footnote 10 for references on IO models for industrial ecology.

investment separately. What is more, the publication also gives estimates of carbon content by industry for imports from all major trading partner countries.[22]

The OECD Inter-Country Input-Output (ICIO) tables are the basis for the Trade-in-Value-Added (TiVA) project. They have been successfully employed to compute the carbon content employed in final demand and in international trade, see Wiebe und Yamano (2016) and Yamano and Guilhoto (2020). Partly building on the ICIO tables, Eurostat has made accessible a new database, the 'Full International and Global Account for Research in Input-Output analysis' (FIGARO).[23] Since May 2021, the FIGARO tables are part of the annual production process. They link data on national accounts, business, trade and labour markets for the EU member states and its main trading partners. The relationship between the EU countries, the United Kingdom and the United States are depicted at a level of 64 industries. For the remaining EU partner countries, the data come from the OECD ICIO and cover 30 industries. IO tables are notorious for their long publication lag. Using nowcast methods, FIGARO tables are published with a lag of only 2 years, ie in 2022, tables for 2020 will be available. The data for the two most recent years are at a higher level of aggregation than the rest.

Beyond official statistics, there are Extended Environmental Input-Output (EEIO) models for academic and commercial research that can be used for analysing emissions. They collect information on the physical flows of goods and services from official and private sources and combine them with estimates to get a more disaggregated picture. EXIOBASE is an important academic endeavour. The hybrid version of the multiregional model EXIOBASE 3 is based on physical, not monetary units. The data base features 43 countries, 5 Rest of World regions, 200 products, 164 industries, 39 resources, 5 land categories and 66 emissions. Unfortunately, the time series of the hybrid version only extends to 2011. Ultimately, the EEIO model of Trucost, an environmental consulting agency affiliated to S&P, is based on supply and use tables from the United States Bureau of Economic Analysis. Enriching these with additional breakdowns, Trucost arrives at an EEIO model with no less than 464 sectors.[24] The model helps to estimate firm level emission intensities, see Section 5 for more information on these data.

22 The entire set of tables can be downloaded here as Excel files.

23 See the FIGARO website and Remond-Tiedrez and Rueda-Cantuche (2019). To the knowledge of the author, FIGARO has not yet been used to compute emission intensities.

24 See Trucost (2020). While this is an impressive figure, the issue of whether it is appropriate to use US-based intensities for companies all over the world, even in countries that are far from the technological frontier, is up for debate.

Annex 2: Microdata on emissions – availability today and upcoming EU disclosure requirements

1. Voluntary disclosure

Today, the disclosure of carbon emissions is largely voluntary. In 2001 (revised in 2004), the *GHG Protocol* published standards that are being followed by a growing number of large companies. The GHG Protocol is maintained and supported by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). The latter is an association of private enterprises that is committed exclusively to the topics of economics and sustainability. The GHG Protocol defined three scopes for carbon accounting purposes:[25]

- *Scope 1* – Direct GHG emissions: Direct GHG emissions occur from sources that are owned or controlled by the company,
- *Scope 2* – Electricity (indirect GHG emissions): GHG emissions from the generation of purchased electricity consumed by the company.
- *Scope 3* – Other indirect GHG emissions: Scope 3 is an optional reporting category in the GHG Protocol that allows for the treatment of all other indirect emissions, upstream or downstream. These are a consequence of the activities of the company, but occur from sources not owned or controlled by the company, such as extraction and production of purchased materials, transportation of purchased fuels, and use of sold products and services.

Disclosures of Scope 1 and 2 emissions are binding under the standard. On top of this, the GHG Protocol has issued detailed recommendations regarding Scope 3 emissions, which are optional under the standard; see footnote 9 and the sources cited therein.

As the number of voluntary disclosures grows, platforms have emerged that make those disclosures available to the public. *CDP* (formerly the Carbon Disclosure Project) was founded in 2000 and has evolved into a large and comprehensive database on environmental matters. According to Wikipedia, 2,400 companies worldwide, and 82% of Fortune 500 companies, reported their GHG emissions to CDP in 2009. Most of the disclosing companies follow GHG Protocol standards: in 2016, 92% of the Fortune 500 enterprises that responded to the CDP survey were running programmes based on the GHG Protocol.[26]

CDP data are being sold to firms and universities (at a heavy discount) and form the backbone of what is available from *commercial databases*, among them Trucost and ISS ESG.[27] These companies also collect disclosures directly from websites or non-financial statements and augment them with approximations and estimates to generate a broad information base for their clients, namely institutional investors.

It is interesting to see that 89.1% of the Scope 1 data reported by Trucost as collected from companies originates from CDP. There is thus a clearly visible line running from

[25] See WRI and WBCSD (2004), chapter 4 "Setting operational boundaries".

[26] GHG Protocol website, 14 August 2021.

[27] Trucost is an affiliate of S&P Global. For more information on Trucost environmental data, see section 5. ISS ESG is a consulting company owned by Deutsche Börse.

GHG Protocol standards and via voluntary disclosures by large companies through CDP or non-financial statements through to commercial companies trying to fill data gaps to serve the needs of investors for a wide range of firms. There is readiness to disclose on the one side and there is market demand on the other. Data quality, however, is a big issue if company reports are not standardised and much of the total needs to be estimated using proprietary and partly undisclosed techniques. For investors, it is not easy to use this information to make proper distinctions at the company level. For policymakers, meanwhile, it is impossible.

2. Upcoming disclosure requirements

The current EU legislature on environmental disclosure is moving forwards on two avenues: the Taxonomy Regulation track and the Non-Financial Reporting Directive track.

Taxonomy Regulation 2020/852[28] of 18 June 2020 is designed to establish a framework for facilitating sustainable investment. Article 8 of the Regulation obliges non-financial firms to disclose the proportion of their activity (in terms of turnover) that is aligned to environmental purposes under the "Taxonomy", in order to develop criteria for whether certain investment qualify as sustainable or not. In material terms, Article 8(4) refers to associated regulations (delegated acts) that are to be adopted separately. These are commonly known as "Article 8 delegated acts":

- The *Disclosure Delegated Act of 6 July 2021* further specifies the disclosure obligations under Article 8 of the Taxonomy Regulation. It obliges non-financial and financial undertakings to disclose in non-financial statements what part of their activities is aligned to certain environmental goals. The Act defines key performance indicators (KPIs) in terms of turnover, capital expenditure and operational expenditure. It has five annexes.
- The taxonomy that classifies what activities are "aligned" is described separately in two annexes of the *EU Taxonomy Climate Delegated Act of 4 June 2021*. These annexes introduce technical screening criteria for two of the six environmental objectives specified in the Taxonomy Regulation. They determine the conditions under which an economic activity qualifies as contributing substantially to (1) climate change *mitigation* (Annex 1), or (2) climate change *adaptation* (Annex 2). They also give criteria for determining whether that economic activity causes no significant harm to any of the other environmental objectives. The economic activity is described briefly and the description is supplemented with NACE codes. Only a subset of economic activities are listed with criteria that would qualify them aligned. This is clear to see when looking at the activities listed under manufacturing or energy.

The Taxonomy Regulation and the two delegated acts are one single piece of legislation. Four more annexes with technical criteria for the other environmental objectives of the Taxonomy Regulation – sustainable use and protection of water and marine resources, transition to a circular economy, pollution prevention and control, protection and restoration of biodiversity and ecosystems – will follow separately.

In a rather radical way, the Taxonomy Regulation describes the world as black and white: activities are either aligned or not aligned. There is nothing in between.

[28] Links to all Taxonomy Regulation legislation and important metadata can be found on a dedicated European Commission webpage.

Ultimately, companies, investors and banks have to report the percentage of aligned activities. For our purposes, it is important to note that there are no GHG disclosure requirements, and the taxonomy does not refer to GHG intensities for threshold values, either in absolute terms or regarding best practices, as such comparisons cannot currently be made.

Important change is often incremental, and sometimes less environmentally friendly options may be unavoidable. Quite often, it may be worthwhile to choose carefully between existing options. The taxonomy does not provide any guidance in such circumstances.

A second track of reporting obligations, associated with the *Non-Financial Reporting Directive (NFRD)*, may in the long run be a better candidate for closing this gap. The NFRD, Directive 2014/95/EU of 22 October 2014,[29] concerns the disclosure of non-financial and diversity information by large undertakings and groups. The Directive asks large companies for a rather encompassing statement on ESG issues, but does not go into any details in terms of what should be reported and according to what standards. Essentially, large companies and the head companies of large groups are supposed to report information on "environmental, social and employee matters, respect for human rights, anti-corruption and bribery matters, including: (a) a brief description of the undertaking's business model; (b) a description of the policies pursued by the undertaking in relation to those matters, including due diligence processes implemented; (c) the outcome of those policies."

The NFRD is considered rather ineffective, as companies are mostly free to choose what to report and the metrics and format that they use. A new piece of legislation means to change this. On 21 April 2021, the Commission adopted a proposal for a *Corporate Sustainability Reporting Directive (CSRD)*,[30] which would amend the existing reporting requirements of the NFRD. The proposal:

- extends the scope to all large companies and all companies listed on regulated markets (except listed micro-enterprises);
- requires the audit (assurance) of reported information;
- introduces more detailed reporting requirements, and a requirement to report according to mandatory EU sustainability reporting standards.

Importantly, it requires companies to digitally "tag" the reported information to make it machine readable.

As it is, however, the CSRD proposal is still an empty legislative shell. It specifies who is subject to reporting requirements and the reporting process, but not what to report. Much like the Taxonomy Regulation's delegated acts, the content of the reporting obligations will be defined separately. The contents are currently being prepared by the European Financial Reporting Advisory Group (EFRAG), an EU funded non-profit organisation. A first draft of the reporting standards is expected by mid-2022. It will then be submitted for consultation. To outsiders, it is not yet readily apparent what the specifics of the reporting standards will be. Given the scope of companies it covers, the audit requirements and the type of information to be

[29] Here is a link to the NFRD, and to a press release on the reform.

[30] Here is a link to the CSRD proposal, and to a press release on the need to review the NFRD.

disclosed, the CSRD is in an ideal position to incorporate GHG emissions reporting obligations.

Carbon costs

Towards a system of indicators for the carbon impact of products, enterprises and industries

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International Conference on Statistics for Sustainable Finance

Paris, 15 September 2021

Carbon costs – the vision

- The price system does not fully account for resoure use. We need **granular data on carbon use, direct and indirect.**
- Imagine that for every good and service, **all direct and indirect carbon emissions in the course of production** are known.
- Carbon costs depend on **direct emissions**, the quantity of **inputs** and **their carbon costs**!.
- A secondary price system, indicating the use of carbon on every stage of production.
- Producers, investors, consumers and political authorities would have the information needed for decision making. Competition among producers may induce rapid adjustment!

The paper…

… introduces a consistent system of indicators for the **carbon impact of industries, companies, products and activities**

… works out **3 views**: a cost equation, an IO reduced form and a GHG Protocol representation

… shows how the system of indicators can be **generated in a largely decentralised way.** Carbon cost is like a price tag, can be handed over the stages of the value chain!

… points out the **elements of a working solution. Start with top down estimates, then boot the system bottom up**

… discusses **policy options for central banks**

(1) Cost equation

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

$$\mathbf{r}_k = (r_{k1} \quad r_{k2} \quad \dots \quad r_{kK})'$$

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

Direct emissions

Indirect emissions

Quantity structure of inputs

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

$$c_k = d_k + \mathbf{r}_k{}'\mathbf{c} = d_k + \sum_i r_{ki}\, c_i \tag{1}$$

"Price" structure of inputs

If the c_i is known, we can calculate the carbon cost of product k directly.

(2) IO reduced form

If the c_i are unknown, the equation is recursive. We can solve for the carbon content of all goods simultaneously. Let

$$\mathbf{R} = (\mathbf{r}_1 \quad \mathbf{r}_2 \quad \ldots \quad \mathbf{r}_K)$$

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

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

We do not need to compute this solution. It is enough to know that it exists and we can let decentralised information processing do the work!

and solving for **c** yields

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

Carbon costs of all goods

Leontief inverse, reflecting interlinkages

Direct emissions for all goods

(3) GHG Protocol representation

Given the widespread use of the Greenhouse Gas (GHG) Protocol emission classes in environmental reporting, it is useful to rephrase the definition of carbon cost.

In the production of good *k*, let $sc1_k$ and $sc2_k$ be Scope 1 and Scope 2 emissions, and $sc3u_k$ be upstream Scope 3 emissions (cradle to gate). Then we have:

$$c_k = sc1_k + sc2_k + sc3u_k. \tag{3}$$

Carbon cost is equal to the sum of Scope 1, Scope 2, and upstream Scope 3 emissions!

This gives us the chance to compute *firm level* carbon costs from emissions data

Company level carbon costs – some descriptives

Level data highly skewed

Company level GHG emission intensities and carbon costs

Trucost environmental data, 2019, world-wide

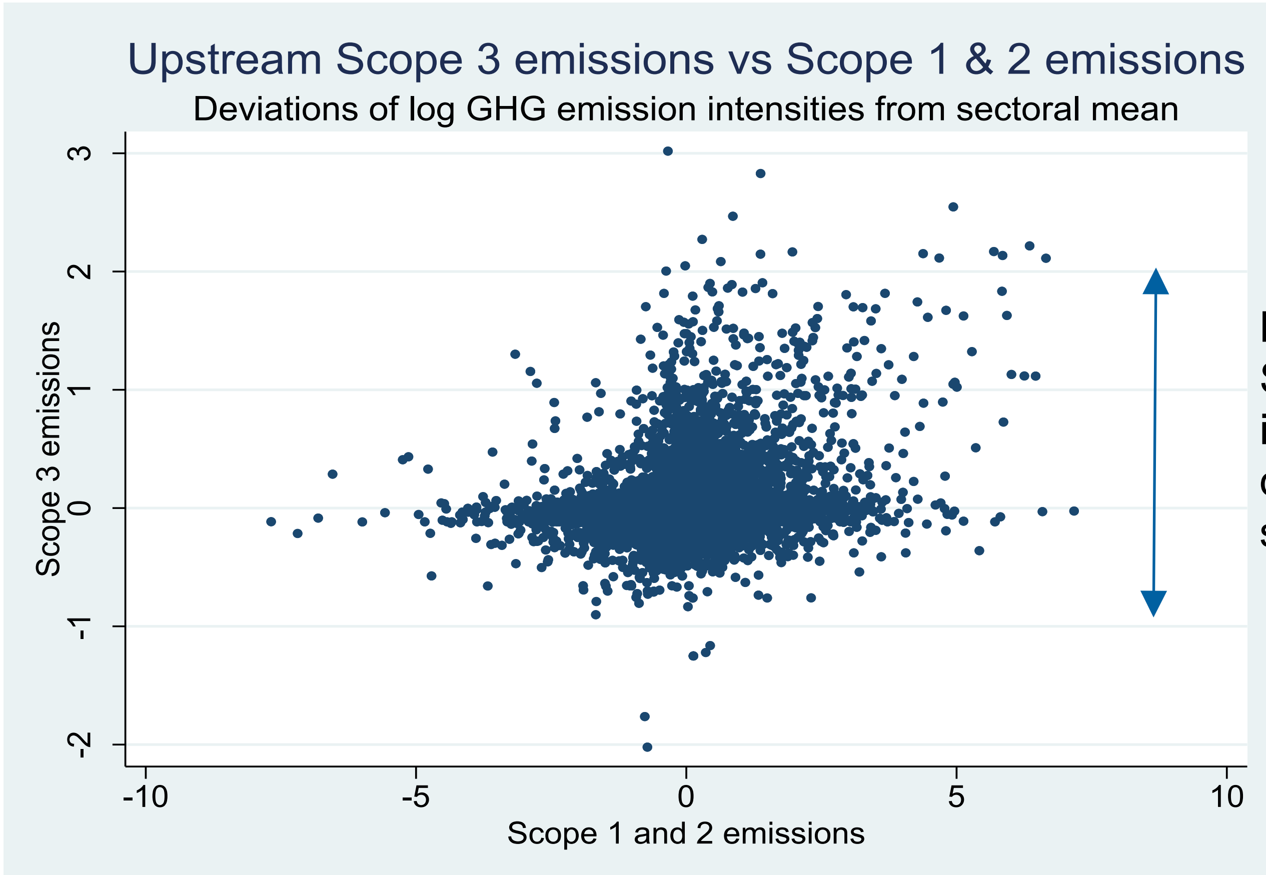
	Mean	Median	Std Dev	# Obs
Intensity levels				
Scope 1 & 2	338.56	39.33	2034.17	19,405
Scope 3 upstream	160.29	97.70	197.07	19,405
Carbon cost	498.84	169.84	2073.89	19,405
Log intensities				
Scope 1 and 2	3.794	3.672	1.790	19,405
Scope 3 upstream	4.577	4.582	0.990	19,405
Carbon cost	5.150	5.135	1.266	19,405

[1] Emission intensities are given as tons of CO2 equivalents, normalised by company revenue in millions of USD. Scope 1 and 2 emissions are direct emissions plus purchased electricity, heat and steam. Scope 3 upstream emissions are indirect emissions that result from intermediate inputs. Carbon cost is defined according to equation (3) as the sum of Scope 1, Scope 2 and upstream Scope 3 emissions. All data are reported unweighted.

Sources: Trucost environmental data, own calculations.

Logs nicely behaved. Scope 3 upstream emissions large contribution!

Company level carbon costs – checking information content



Logs of upstream Scope 3 emission intensities, deviations from sectoral means

Computing carbon costs

To evaluate inputs, we need values for **carbon costs on a product level**.

- Ideal case: Carbon costs for input goods are available from input provider. Carbon costs can be **computed** on the basis of equation (1) and cost accounting allocation models

− **We may approximate input carbon costs** using
- sectoral data from SEEA and EEIO models
- granular data from company level data of provider
- granular carbon costs of reference products

− Disclosed carbon costs and data for proxy valuations can be **disseminated centrally!** It is important that the producer uses her proprietary information!

A detour: Physical flow account of SEEA and EEIO models

- SEEA: "Standard of Environmental Accounting". A UN Standard for aggregate statistics on environmental issues. The physical flow account yields absolute values and intensities for direct and indirect emissions by sector, on the basis of IO models for the whole economy.

- Physical flow account for Germany shows the carbon content of final demand for 49 sectors

- EEIO models: specific IO models for modelling the use of ressources and emissions. The Trucost EEIO model yields carbon intensities for **464 sectors** (US based)

Eq (2) justifies the use of sectoral carbon intensities from SEEA and EEIO models as a first level estimate for carbon costs of inputs!

Top down and bottom up

Producers do not need to know the carbon costs of the whole economy, **only those of their own providers** (or estimates thereof), just as for **cost accounting** we do **not need to know the entire price system, just what our providers charge.**

If all producers give a fair estimate of eq (1) using the information they have, i.e.

- Direct emissions,
- Bill of Material (BoM),
- Carbon costs of input providers if available, estimates if not

and if this information is disclosed and used by all participants alike, in equilibrium the resulting system of carbon costs **will necessarily correspond to the solution given by eq (2)!**

Jumpstart the system with proxies and boot it bottom up!

Is there scope for voluntary disclosure?

It is conceivable to make disclosure compulsory. However, there is a path that leads to **voluntary disclosure by (almost) all firms:**

- Producers with low CC (relative to peer group) will have an **incentive to disclose.** With a low CC, **they can charge higher prices.**
- This generates a **signal value** for the **decision not to disclose**
- Can be **reinforced** by **disseminating disclosed carbon costs on a central data platform**
- Can be **reinforced further** by **calculating sector averages conditional on not disclosing**
- With many companies disclosing, those that do not disclose will **be looking really bad**.

To get this mechanism going, we may need to overcome a **threshold level of disclosures.**

How to get there?

− We need **auditing** to make sure that the carbon costs is a fair estimate, using the information on direct emissions and production interlinkages existing on the company level.

− **Centralised platforms** can make available for everybody the existing information
  - on industry averages (also reduced form from EEIO data)
  - on carbon costs on a product and on the company level, if available

In addition, platforms can compute estimated carbon content for firms of a given industry that do not disclose their CCs**,** from the known industry averages and the known CCs of the firms that do disclose. **This will give a strong incentive for disclosure!**

These measures will make carbon costs informative, an **effective instrument in competition.**

To sum up

- Simple concept: on every stage, the **cumulated carbon content** is computed. This is passed as carbon costs to the next stage.
- Starting with estimates, the **system converges** to the values given by the solution
- Information processing **mostly decentral**. Producers only need to know their technology and the carbon costs of their input. A platform is needed that communicates disclosed carbon cost
- There is a mechanism that makes **disclosure the outcome of economic incentives**
- The system will yield **encompassing and highly granular information.**
- **And central banks and international organisations may have an important role!**

Policy options for CBs and international organisations

1. Co-operate with Eurostat and the NSIs in setting up a **rather disaggregated EEIO-model for the Euro Area**, and also for some of the larger countries if this is warranted by observed heterogeneity.
2. Set up and maintain a **dissemination platform for carbon cost data** on the level of sectors, enterprises and products.
3. Develop and propagate **disclosure standards** and assist in setting them, as a basis for comparability and auditing. Those rules can build on the relevant GHG Protocol standards.
4. Interact with the EU Commission and with the IFRS on **disclosure requirements**, especially regarding the CSRD. Possible disclosure requirements should target large companies, as well as producers of primary goods and importers.

Reserve slide

Carbon costs – the three perspectives

Eq (1) is the definition of carbon costs. Carbon costs result from direct emissions and the carbon costs of other inputs. The system is recursive

$$c_k = d_k + \mathbf{r}_k{}'\mathbf{c} = d_k + \sum\nolimits_i r_{ki}\, c_i \tag{1}$$

Eq (2) gives the solution. Under standard regularity conditions, it is unique.

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

Eq (3) shows how carbon costs relate to the standard GHG protocol definitons:

$$c_k = sc1_k + sc2_k + sc3u_k. \tag{3}$$