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STRATEGIC CLIMATE METRICS: PRIORITISING KEY FACTORS FOR ENHANCED DECISION-MAKING

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Abstract

This paper explores an alternative approach to assess climate-related credit risks by focusing on material emissions across industries' value chains. This proposition seeks to overcome key challenges that the GHG Protocol confronts, including those emerging in cost effectiveness, comparability, and contextual accuracy. Following the Kaya Identity, an equation to identify key aspects of global warming, this paper proposes a model to assess corporate transition risks by focusing on three key drivers: raw materials, products, and production efficiency. Data collection consists of a large sample of emitters from automakers, cement, and steel sectors from 2018 to 2021. Results show that, in the case of the automakers' sector, emissions are concentrated within purchased goods (steel and batteries) and the use of sold products (vehicle emissions). In the cement sector, the main forces of emissions emerge from fossil fuels in combustion furnaces and the percentage of clinker in the cement mix. Finally, iron and basic oxygen furnaces are the primary determinants of emissions in the steel sector. Therefore, the proposed model allows focusing information efforts on a limited number of decarbonization levers, reducing the costs of data collection and assurance and, even more importantly, creating a robust model with climate metrics that help in decision-making for credit risk assessment. This work aims to accelerate the integration of climate transition risks into risk models by focusing on transformative activities.

Keywords

GHG Protocol; Kaya identity; Climate-related credit risks; Corporate decision-making; Carbon accounting.

1. Introduction

Science is clear: the world needs to transit to a net-zero[1] economy by 2050 to limit global warming to 1.5ºC (IPCC, 2023). Despite the slowness of global agreements, most jurisdictions have recognized the need and opportunity to face the grand challenge of decarbonization. Indeed, more than 90% of global GDP is covered by net-zero commitments (Net Zero Tracker, 2024). In this context, companies have a salient role in the pathway to a low-carbon future (Österblom et al., 2022), something motivated by their environmental impacts but also due to their effects on capital markets.

Climate-related transition risks may entail extensive policy, legal, technology, and market changes to adapt to a decarbonized economy (TCFD, 2017). The assessment of these risks is based on the analysis of the corporate financial impacts, including credit risk. For example, certain sectors face the risk of stranded assets in a decarbonized future, leading to impairments on their balance sheet. This weakens the company's financial position and raises questions about its ability to repay existing debts and fulfill contractual obligations to creditors. In this regard, accounting systems build the basis for connecting financial and climate risks.

The final goal of creating consistent, comparable, and useful decision-making information about climate-related financial risks (FSB, 2022) requires a massive work, i.e., translating of different measures into a common metric (Espeland & Stevens, 1998, 2008) or reducing corporate activities into a standardized metric for decarbonization (i.e., tCO_2e). In this respect, the GHG Protocol emerges as a mainstay framework to render emissions arising from corporate data (GHG Protocol, 2023).

Indeed, the recent sustainability standards proposed by regulators, such as the International Sustainability Standards Board (ISSB) or the European Financial Reporting Advisory Group (EFRAG), rely on the GHG Protocol to build the basis of the GHG corporate inventory. Despite the widespread use in the sustainability field, previous accounting scholars have made a call to revisit the GHG Protocol (see, for example, Andrew & Cortese, 2011; Antonini & Larrinaga, 2017) and its associated accounting technical details (He et al., 2022), which have tangible consequences in organizations.

Considering the significant role of corporate inventories and the ongoing discussions about the dominant use of the three scopes established in the GHG Protocol, this paper investigates the feasibility of alternative approaches. These approaches focus on a simplified set of measures centered on material emissions throughout industries' value chains to enhance decision-making regarding climate-related credit risks.

For this purpose, in this paper we first explain the methodology of the GHG Protocol and problematize its limitations in decision-making for decarbonization. Then, we present an alternative to the GHG Protocol for measuring corporate emissions. In particular, we build on the Kaya Identity (Kaya & Yokobori, 1997) to identify the decarbonization levers across key aspects of organizations' value chains: raw materials, products, and production efficiency. The Kaya Identity is a widely used mathematical model to assess the main factors

[1] The Intergovernmental Panel on Climate Change (IPCCC, 2018) describes *net-zero* emissions as the period when "anthropogenic emissions of greenhouse gases to the atmosphere are balanced by anthropogenic removals over a specified period" (p.555). In this definition, decarbonization (i.e., emissions abatement) is critical to limit warming to 1.5ºC. This work focuses on decarbonization, which is used interchangeably with net-zero.

governing global CO_2 emissions (Kaya & Yokobori, 1997). Following a parallel reasoning, this work proposes identifying material aspects for assessing companies' climate risks in order to design more suitable and useful metrics for decision-making. For this purpose, we select a sample of 20 largest emitters across three critical sectors for decarbonization (automakers, cement, and steel). with a complete and consistent set of data provided to Carbon Disclosure Project (CDP) for the period 2018-2021. Data collection to exemplify the limitations of the current GHG Protocol and to develop the empirical analysis proceeds from corporate responses provided to CDP questionnaire.

This research indicates that emissions originating from automakers, cement manufacturers, and steel producers are associated with specific sources of material emissions within their supply chains. These emissions serve as key factors driving their vulnerability to climate transition risks. In the case of the automakers' sector, emissions are concentrated within purchased goods and the use of sold products. In the cement sector, the main forces of emissions emerge from fossil fuels in combustion furnaces and the percentage of clinker in the cement mix. Finally, iron and basic oxygen furnaces are the primary determinants of emissions in the steel sector. The model proposed allows focusing information efforts on a limited number of decarbonization levers, reducing the costs of collecting and assuring the information and, even more importantly, creating a robust model with climate metrics that help in decision-making for credit risk assessment.

Prioritizing carbon-intensive factors within the companies' GHG inventory is a trend already observed in equity investors, who discriminate by carbon in a few industries, such as oil and gas, utilities, and automobiles. However, no premiums in valuation are found for improvements associated with metrics such as emission intensity (Bolton & Kacperczyk, 2024). In this context, we aim to fill this gap by considering strategic climate drivers that help in decision-making for credit risk assessment. In a modest way, this paper seeks to advance knowledge by proposing an accounting model that identifies the key drivers of decarbonization that responds to the urgent transformations required to achieve net-zero emissions (IPCC, 2023). This way, this work contributes to the call for integrating sustainability in the credit risk assessment of non-financial firms (IMF, 2024).

This paper is structured as follows. Section 2 discusses the limitations of the methodology of the GHG Protocol as the leading accounting standard for building the corporate emissions inventory and creating the basis for decision-making. Section 3 presents our theoretical model by building on the Kaya Identity. Then, Section 4 develops the empirical case. We first explain the sample and methodology and then disclose the findings for the automotive, cement, and steel sectors. Finally, Section 5 concludes the work.

2. Problematizing the GHG Protocol: the current standard for measuring corporate emissions

The GHG Protocol is the most widely used accounting standard for measuring and managing corporate greenhouse gas emissions (GHG Protocol, 2023). It is currently a baseline framework for global sustainability standards (e.g., IFRS S2 or ESRS), emission calculation standards (ISO 14064, Bilan Carbone, or US EPA), and reporting standards (CDP, TCFD, or GRI).

The GHG Protocol provides standardized criteria to measure corporate emissions and categorizes them into direct and indirect sources. First, the GHG Protocol defines the *organizational boundaries*, encompassing emissions resulting from the operations owned or controlled by the reporting company (WRI and WBCSD, 2004). Organizational boundaries are defined by the consolidation approach, which can be based on economic interest (financial ownership) or control (financial or operational). Financial control occurs when the operation takes place within the financial consolidation perimeter, whereas operational control arises when there is full authority to introduce and implement operating policies (WBCSD & WRI, 2004). Second, the GHG Protocol categorizes *operational boundaries* in direct and indirect emissions across three scopes. Scope 1 emissions are direct emissions resulting from the selected consolidation approach. Scope 2 and scope 3 are indirect emissions derived from purchased electricity and all other indirect emissions, respectively (WBCSD & WRI, 2004).

The GHG Protocol has been included as the basis for calculating GHG emissions within corporate sustainability reporting standards, suggesting it will remain the main framework for measuring and reporting GHG emissions in the future. Nevertheless, its underlying complex methodology could difficult an effective decision-making for assessing climate-related credit risks. In this scenario, we have identified three issues embedded in the GHG Protocol that hinder creating consistent, comparable, and useful decision-making in climate-related financial risks, namely cost *effectiveness*, *comparability*, and *contextual accuracy*.

Cost effectiveness:

Cost effectiveness seeks to find the least-cost way of achieving a goal, which, in the context of climate change, would refer to achieving decarbonization (Otto et al., 2015). Indeed, cost effectiveness emerges as a tool to guide decision-making in prioritizing interventions, allocating resources efficiently, and designing effective policies to address the challenges of a low-carbon future.

In assessing climate-related financial risks, the GHG corporate inventory is one of the most used climate-related investment approaches. However, investors and policymakers lack prospective, granular, and verifiable data, especially regarding companies' efforts to shift to sustainable business models (e.g., reducing their greenhouse gas emissions) (Ferreira & Natalucci, 2021). Investors consider the availability of information as one of the factors that most directly affect managers and asset owners' investment strategies and climate-related decisions (Eurosif, 2023). Although the number of jurisdictions incorporating mandatory reporting is increasing, studies suggest that companies are failing to report emissions accurately and exhaustively (BCG, 2021). In addition, companies face the absence of incentives to accurately account for their emissions inventory due to the high cost of data collection (Lee et al., 2022). Indeed, according to the US Securities Exchange Commission, companies, on average, annually spend between USD 420,000 for small companies and USD 530,000 for large companies (Eaglesham & Kiernan, 2022) in reporting GHG corporate emissions inventories, climate scenario analysis, and internal climate risk management controls. For the case of European companies, these expect to face, on average, a total of EUR 287,000 as a one-off cost of reporting and about EUR 320,000 on annual basis (of which EUR 173,000 for own costs equivalent to between 2 and 2.5 FTEs on average) (EFRAG, 2022)

Comparability:

The GHG Protocol provides a consistent framework to build companies' inventories (Andrew & Cortese, 2011). Still, it allows the application of different criteria that compromise the principle of comparability. Below, we present five aspects that jeopardize the principle of comparability (consolidation approach, greenhouse gases considered in each company's inventory, accounting for scope 2 emissions, estimation of scope 3 emissions, and the use of emission factors).

On the one hand, the *consolidation approach* (equity or control – financial or operational) determines the responsibility for reported emissions. However, there is currently no consensus regarding the most appropriate consolidation method for the company and the reasons for the selection. In fact, according to the data from a sample of 70 companies included in the EuroSTOXX Index, 69% of companies use operational control as the consolidation approach for emissions, 27% use financial control, and 4% do not specify their consolidation method.

On the other hand, the *inclusion of greenhouse gases* in the company's emission inventory is also problematic. Although the GHG Protocol covers the gases included in the Kyoto Protocol[2], evidence from the sample suggests that a large percentage of the sample (64%) does not include the entirety of the quantities emitted by greenhouse gases other than carbon dioxide.

Likewise, there are specific *implications associated with scope 2 and scope 3* (i.e., indirect emissions, according to the GHG Protocol classification). Within scope 2 emissions, purchased electricity and heat generation account for over one-third of global GHG emissions, being mainly used in industrial and commercial processes (Sotos, 2015). To reduce these emissions, companies often resort to efficiency improvements and the substitution of fossil fuel supply with renewables, either through on-site installations or by changing the energy products purchased (through contracts and electricity suppliers).

Scope 2; The location and market methods in Scope 2 introduce significant differences.

The calculation of scope 2 emissions is established from two methods: (a) location-based methods and (b) market-based methods. The former reflects the intensity of the country's generation mix where energy is consumed, whereas the latter reflects emissions from electricity that companies supply to the reporting entity (WBCSD and WRI, 2004).

Both methods are admitted and have two design differences that prevent comparability. For example, renewable energy purchased from a renewable provider cannot be accounted for with the location-based method since this takes the country's average emission factor where the electricity is purchased. Thus, the GHG Protocol establishes that accreditation of renewable energy purchase is only applicable for the market-based method.

Table I below presents the differences in tons of CO_2 emissions between the location- and market-based approach of the 20 largest scope 2 emitters of the N=70 sample in 2021.

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[2] Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_3O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6) (UNFCCC, 2013).

Table 1: Differences in scope 2 data emissions resulting from the selection of location- or market-based approach N=70, 20 largest scope 2 emitters[3].

Company	Location-based method (tCO_2)	Market-based method (tCO_2)	Difference
Linde PLC	20.063.000	20.969.000	-5%
Air Liquide	12.516.000	17.184.000	-37%
Royal Dutch Shell	11.000.000	9.000.000	18%
ENEL SpA	4.990.685	7.855.954	-57%
Holcim Ltd.	6.387.520	6.910.207	-8%
BP	3.700.000	3.800.000	-3%
BASF SE	3.362.000	3.279.000	2%
TotalEnergies	2.791.597	2.847.912	-2%
Deutsche Telekom AG	4.815.423	2.276.607	53%
National Grid PLC	2.216.265	2.264.950	-2%
Nestlé	3.052.234	1.898.395	38%
Iberdrola SA	1.890.456	1.882.654	0%
Rio Tinto	7.812.000	1.701.000	78%
Anheuser Busch InBev	2.227.758	1.633.815	27%
Bayer AG	1.750.000	1.570.000	10%
Ahold Delhaize	1.820.000	1.457.000	20%
Vodafone Group	2.035.571	1.096.240	46%
Daimler AG	1.492.000	1.035.000	31%
Danone	864.710	479.210	45%

The differences location vs market figures increase as the company reduces its carbon exposure by self-generating renewable energy, consuming more renewable energy through a clean energy purchase agreement, or simply because the electricity supplier mix differs from the national mix, impede comparability since companies can select the method that will be disclosed to investors (Pasley, 2022).

As market data becomes more difficult to obtain, issuers reporting Scope 2 with the location-based method increase and opt to take Scope 2 based on the market method so that information providers are incentivized to use the location method to construct the inventories with which they work their models.

Scope 3; encompasses the largest segment of corporate emissions, collected across 15 categories that vary widely in emission types, control, and reliability.

Regarding the calculation of *scope 3 emissions*, three issues arise from capturing the emissions that companies generate by consuming or producing goods along the value chain. First, the relevance of this scope is due to its significant volume. In fact, CDP (2023) quantified that, on average, supply chain emissions are 11.4 times greater than those

[3] Unilever was excluded of N=70 largest scope emitters sample due to inconsistency in the CDP available data.

occurring under organizational boundaries. Second, the fact that scope 3 emissions are outside the corporate perimeter complicates their calculation and the possibility of reduction. Finally, scope 3 is problematic due to its double counting, as scope 3 emissions of the reporting company correspond to the scope 1 and 2 emissions of others.

Assessing GHG emissions across the entire value chain is complex, and for this reason, the GHG Protocol establishes 15 categories that seek to provide a systematic framework for measuring, managing, and reducing these emissions (see Table 2). These emissions are scope 1 emissions from their suppliers, employees, or customers. The categories are designed to be mutually exclusive to prevent a company from double counting emissions across categories.

The GHG Protocol provides two pathways for accounting for scope 3 emissions. On the one hand, companies can use primary data, which includes information provided by suppliers or others that relate directly to specific activities in the reporting company's value chain. On the other hand, scope 3 emissions can be calculated through estimation. This calculation involves multiplying activity data by an emission factor (WBCSD & WRI, 2011). Activity data include, for example, liters of fuel consumed or kilowatt-hours of electricity used. The emission factors aim to convert activity data into GHG emission data (e.g., kg of CO_2e emitted per liter of fuel consumed). However, these estimates include unreliable data and emission factors that offer multiple options, making the resulting information not comparable.

As shown in Table 2, there are three situations regarding the calculation of scope 3 emissions (A, B, and C). With the sample of 70 companies, scope 3 emissions have been broken down by categories. In addition, table 2 reports the percentage of emissions of each category over the total scope 3 emissions, as well as the percentage of reporting companies in the sample in each category, has been calculated.

<u>Table 2:</u> *Volume and quality of the information of the scope 3 emissions of the sample N70*

- **A:** Percentage of companies in the sample that estimate emissions are not relevant to their inventory.
- **B:** Percentage of companies in the sample that estimate emissions are relevant and have been calculated.
- **C:** Percentage of companies in the sample that estimate emissions are relevant but do not know their volume, deciding not to calculate them.

	Scope 3 categories	A	B	C	Scope 3 (tCO_2)	% tCO_2	% reporters
1	Purchased goods & services	10%	81%	9%	637.054.622	9,51%	83%
2	Capital goods	41%	50%	9%	18.488.289	0,28%	57%
3	Fuel- and energy-related activities	30%	64%	6%	486.558.124	7,26%	76%
4	Upstream transportation & distribution	24%	70%	6%	61.591.374	0,92%	71%
5	Waste generated in operations	40%	54%	6%	19.607.567	0,29%	67%
6	Business travel	23%	74%	3%	1.763.603	0,03%	87%
7	Employee commuting	36%	57%	7%	5.578.937	0,08%	67%
8	Upstream leased assets	83%	14%	3%	2.302.368	0,03%	19%
9	Downstream transportation & distribution	40%	51%	9%	54.350.948	0,81%	54%

	Scope 3 categories	A	B	C	Scope 3 (tCO_2)	% tCO_2	% reporters
10	Processing of sold products	90%	6%	4%	502.066.876	7,49%	6%
11	Use of sold products	30%	66%	4%	4.829.405.742	72,07%	64%
12	End of life treatment of sold products	53%	41%	6%	60.354.420	0,90%	49%
13	Downstream leased assets	84%	14%	1%	5.105.018	0,08%	17%
14	Franchises	89%	10%	1%	3.239.806	0,05%	10%
15	Investments	77%	14%	9%	13.207.598	0,20%	20%
	Others (not included in GHG Protocol categories)	44%	3%	53%	74.091	0,00%	3%

Finally, another key aspect that prevents comparability is the use of *emission factors* in calculating scope 1, 2, and 3 emissions. Although there is an equation for calculating emission factors, companies choose the most representative one to develop their emissions inventory. Indeed, the GHG Protocol explains that companies can choose between 80 different emissions factors (WBCSD & WRI, 2011). In this way, companies can use the Emission Factor Database of the Intergovernmental Panel on Climate Change (IPCC), the GHG Emission Factors Hub of the Environmental Protection Agency (EPA), the database of the International Energy Agency (IEA), or the conversion factors provided by the UK's Department for Environment, Food & Rural Affairs (DEFRA). Similarly, other national entities and research and business organizations (for example, WorldSteel or ICAO) also provide emission factors for companies. This situation implies that companies in the same sector with similar operations can end up with very different emission figures due to the selection of different emission factor databases.

Contextual accuracy:

Even though the carbon budget is a global estimation, some risks derived from climate change, such as extreme weather events or health impacts, are linked to a specific geography. Therefore, providing granular information connected to the context becomes necessary for an adequate valuation of risks (FSB, 2022). In addition, climate risks are also connected to the business context in which climate policies, regulations, technological changes, or consumer preferences for a more decarbonized offering emerge (FSB, 2022). Then, the nature of these risks is specific to particular jurisdictions (OECD, 2023).

The need for better contextualization of emissions is also related to the assurance of the GHG emissions inventory. The GHG Protocol itself does not require inventory verification and it does not consider the location where corporate-level emissions occur. Conversely, a significant number of companies often externally assurance their inventories (Dutta & Dutta, 2020), partly due to the requirements of sustainability frameworks, such as the European Sustainability Reporting Standards (ESRS), or with the aim to internally evaluate their environmental performance.

Diverse assurance standards and providers exist, in addition to companies providing different levels of emissions information, resulting in differences of assurance quality. For example, among the top 25 emitters in the N70 sample, the proportion that externally verified their inventories (i.e., scope 1, 2, and 3 emissions) remained relatively stable from 2018 to 2021. In 2021, 76% of these companies opted for limited assurance of their emission inventories, 16% sought reasonable assurance, and only 8% did not pursue external assurance for their emissions. Predominantly, three standards are used for assurance: ISAE 3000 (52%), 3410 (22%), and ISO 14064 (22%).

With these covertures of assurance, the confidence and credibility in corporate inventories should be higher, so it could be thought that also because of these data, the problem only partially resides in the way companies collect and report information, and the issue could reside in the metric.

As explained above, the methodology of the GHG Protocol hinders decision-making for decarbonization. The costly resources required to measure the GHG inventory, the multiple choices for calculating scope 1, 2, and 3 emissions that result in an incomparable framework, and the inherent contextual characteristic of sustainability information require a simplification of the main variables model in its application to credit risk models, which can be a positive measure to facilitate urgent action and decision-making, as well as an interoperability with countries' emission inventories.

3. Theoretical model

The use of the GHG Protocol and its three scopes has been very useful over the last few years to promote awareness of climate issues in companies, establish initial calculations of systemic climate risk, or explain the development of green financial products. However, the problems with the GHG Protocol discussed in the previous section limit a complete assessment of the corporate decarbonization pathway.

Mathematical identities to simplify the complexity of GHG emissions: The Kaya Identity

The Kaya Identity has been used by the United Nations Framework Convention on Climate Change (UNFCCC), within the enforcement of the Kyoto Protocol, to identify key aspects involved in global warming, project future emissions of countries, and thereby propose appropriate reduction targets. The Kaya Identity is formulated through the following equation (Kaya & Yokobori, 1997):

$$\overset{\Delta}{\rightarrow} CO_{2e} = Population\ x \frac{GDP}{Population}\ x\ \frac{Energy}{GDP}\ x\ \frac{CO_{2e}}{Energy}$$

- *Population: number of people in a given country or region.*
- *GDP per capita: proxy of economic production related a population.*
- *Energy intensity: amount of energy consumed per unit of economic production.*
- *Carbon intensity: amount of CO_2 emissions produced per unit of energy used.*

The use of the Kaya Identity illustrates the benefit of decomposing emissions into key or material factors to understand their driving forces and, therefore, analyze their interconnections with other variables (Janssens-Maenhout et al., 2013).

In this way, Kaya identifies population as the main driver of a country's emissions and therefore the factors that influence its growth ($\overset{\Delta}{\rightarrow} CO_{2e}$); an activity factor which in this case is the population and its production capacity; and the transformation of this activity into emissions occurs to the extent that it depends on the energy intensity of the country's production and the carbon intensity of this consumed energy.

Given the significant utility that Kaya's identity has had in the design of climate policies during the first binding climate agreement, when country inventories were still immature, this article proposes an experiment with the advantages that this approach would have as an alternative method for making decisions in the field of climate exposure.

Application of the Kaya Identity in corporate transition risk assessments

As an alternative to calculating corporate emissions through the GHG Protocol, this paper proposes a new model based on the Kaya Identity. The emissions decomposition analysis consists of an accounting identity (similar to the ones used in National Accounts). The identity decomposes emissions into component indicators, in order to describe the driving forces of emissions in a given inventory. The resulting accounting identity can be multiplicative or additive.

Following parallel reasoning, this work proposes a model that identifies the main driving forces of GHG emissions across the value chain. Therefore, this model seeks to (i) simplify data collection, (ii) drive attention to material aspects within the value chain, and (iii) present more precise and useful metrics for decision-making in assessing companies' climate risks

As shown below, the proposed model is presented at the corporate level and, in addition, disaggregated at the value chain level.

a) *Corporate level*

Following Kaya's model in which population is the key driving factor, the main catalyst in companies is sales. In this regard, the transition exposure factor is also dependent on the physical intervention in production, energy consumption, and the carbon intensity of the energy produced.

- Activity: sales.
- Transformation efficiency: emissions from the conversion from input to output.
- Energy intensity of outputs: energy used per output.
- Carbon intensity of energy: Emissions from energy used.

$$\overset{\Delta}{\rightarrow} CO_{2e} = Activity\ x\ \frac{Production}{Activity}\, x\, \frac{Energy}{Production}\, x\, \frac{CO_{2e}}{Energy}$$

Where $\overset{\Delta}{\rightarrow} CO_{2e}$ is a so-called transition exposure factor.

b) *Decomp*osition at value chain level

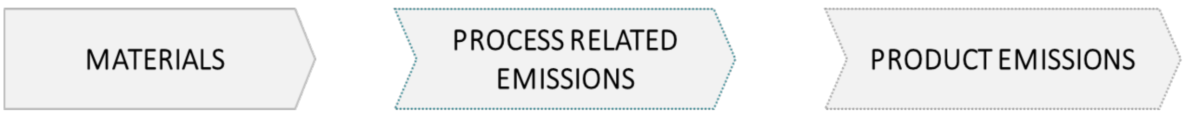
The abo*ve elements are broken down into an efficiency factor and an emissions intensity factor of the energy used.*

$$\overset{\Delta}{\rightarrow} CO_{2e} = f(output)\ \frac{Input}{Output}\, x\, f(rm, P, p)\, \frac{Energy}{Input}\, x\, \frac{CO_{2e}}{Energy}$$

Process efficiency factor *Emissions intensity factor*

- *rm: Materials/Raw materials input*
- *P: Process input*
- *p: Product input.*

c) Process level



$$f(rm)(\frac{Energy}{Input}\, x\, \frac{CO_{2e}}{Energy}) \qquad F(Output)\, x\, \frac{Input}{Output}\, x\, f(P)(\frac{Energy}{Input}\, x\, \frac{CO_{2e}}{Energy}) \qquad f(p)(\frac{Energy}{Input}\, x\, \frac{CO_{2e}}{Energy})$$

- *Materials f(rm) depend on the energy per unit of raw materials and the carbon intensity of the energy produced.*
- *Process f(P): depends on the activity, efficiency, and the carbon intensity of the energy consumed.*
- *Product f(p): depends on the product efficiency and the carbon intensity of that energy.*

4. Empirical case

4.1. Sample of companies

Considering the distribution of the origin of GHG emissions along the global production value chain from the World Resources Institute of 2019 (WRI, 2021), three types of industries can be considered based on their different climate exposures: (i) GHG-intensive at source, (ii) GHG-dependent intensive, and (iii) GHG-leading intensive activities..

The first category comprises businesses whose main activity is directly linked to carbon dioxide emissions; fossil fuels, as well as those in the agriculture, energy, and waste sectors. These activities concentrate their emissions within their scope 1 and 3 with different abatement cost.

Regarding the second category, it includes activities that currently require fossil materials or energy for their development. More precisely, this category includes sectors as electricity and road transport (low decarbonization capex), fertilizers and maritime transport (medium decarbonization capex), and cement or aviation (high decarbonization capex).

Finally, GHG-leading intensive activities comprise those that by their nature can have an impact on demand (for example, construction, retail, tourism, telecommunications), and their emissions occur within scope 2 and 3. This classification allows understanding how economic sectors will be affected by the transition risk, depending partly on the intensity of their emissions, as well as the ability of companies to mitigate their emissions and adapt their business models (Pasley, 2022), and therefore these will be materially different to varying degrees.

Considering companies in the first category have their emissions concentrated in their emitting nature, and therefore the emission sources are direct to identify and measure. The difficulty increases in those whose exposure is more diffuse in their value chain, for this reason, three main sectors have been studied that are classified as GHG-dependent intensive: the automotive, cement, and steel sectors.:

- **Automakers**: A sample of 20 manufacturers from the main automotive companies and the data corresponding to their questionnaires submitted to CDP in the period 2018 - 2021 is taken. Hereinafter sample **NAuto.**

- **Cement:** A sample of 25 global cement manufacturers and the data corresponding to their questionnaires submitted to CDP in the period 2018 - 2021 is taken. Hereinafter sample **NCem.**

- **Steel:** A sample of 21 global steel manufacturers and the data corresponding to their questionnaires submitted to CDP in the period 2018 - 2021 is taken. Hereinafter sample **NSteel**.

The samples of the companies have been selected based on two criteria: contribution to emissions and the availability of complete series from 2018-2021. Both factors are according to the CDP database. Whenever CDP data has been handled, the original data available in the database has been considered and has not been subjected to any processing.

4.2. Results

a. Automakers

Emissions from cars, trucks, and other road transport vehicles account for about 75% of all carbon emissions from mobility, approximately 6GtCO_2 per year (15% of the total global CO_2 emissions) (Moller & Shaufuss, 2022).

Table 3 shows the volume of the emissions from NAuto industry for the years 2019 to 2021. Scope 3 emissions remain consistent during the period regardless of the category.98.21% of the reported emissions corresponded to scope 3 and are consistently concentrated in 2 categories: use of sold products (80.29%) and purchased goods and services (15.39%). And of these, 80.29% correspond to the use of the products and 15.39% to the raw materials consistently over three years.

<u>Table 3:</u> Distribution of scope 3 emissions in the NAuto sample

kgCO2	*2021*	*2020*	*2019*	*Consolidated scope 3 emissions 2019-21*	*%*
Total	**2.382.698.583**	**2.409.763.607**	**2.222.982.526**	**7.015.444.716**	**100%**
Purchased goods & services	363.958.317	379.140.215	336.777.290	1.079.875.822	*15.39%*
Use of sold products	1.926.204.748	1.920.542.322	1.786.012.272	5.632.759.341	*80.29%*
Rest of the Scope 3 categories	92.535.518	110.081.070	100.192.964	302.809.553	4.32%

In this way, for the sector, the critical exposure factors would be limited to:

$$f(rm, P, p)\frac{Energy}{Input}x\frac{CO_{2e}}{Energy}$$

$$f(rm)\frac{Energy}{Input}x\frac{CO_{2e}}{Energy} \quad x\ f(P)\frac{Energy}{Input}x\frac{CO_{2e}}{Energy} \quad x\ f(p)\frac{Energy}{Input}x\frac{CO_{2e}}{Energy}$$

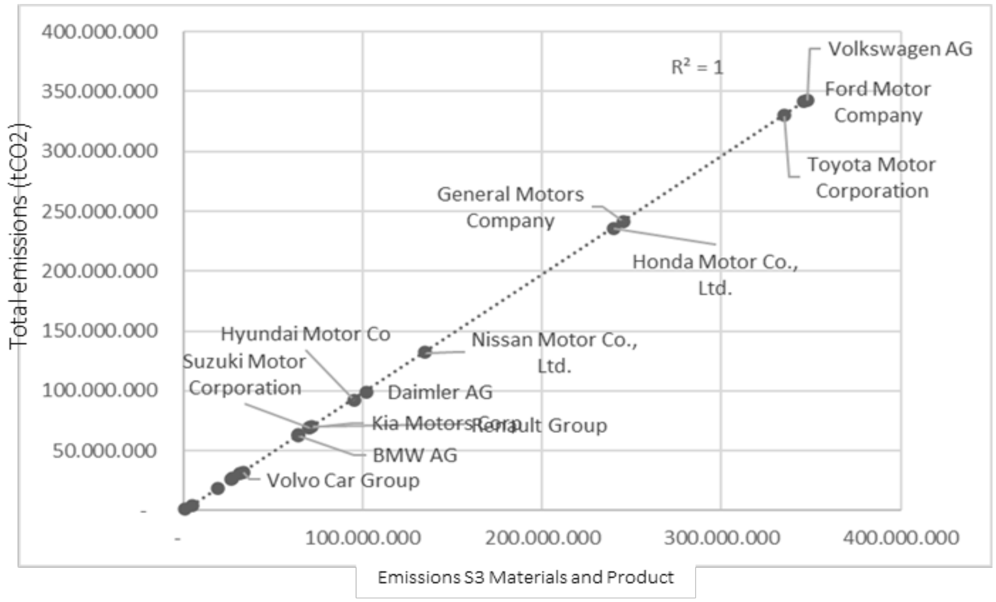
Considering process emissions factor non-material $\boldsymbol{f(P)} \rightarrow \mathbf{0}$

$$f(rm)\frac{Energy}{Input}x\frac{CO_{2e}}{Energy} \quad x\ \ f(p)\frac{Energy}{Input}x\frac{CO_{2e}}{Energy}$$

$$f(rm,p) = \ t\ steel\ \frac{CO2e}{t\ steel}\ x\ \ km\ \frac{CO_{2e}}{km}$$

These two factors *f(rm)* and *f(p)*, *Purchased goods* (raw materials) and *Use of sold products* (the use of vehicles), drive the materiality of companies' emissions. Just by considering these two and focusing efforts on having good strategic metrics related and good information, it would be enough to currently consider in the models of analysis of climate transition risk.

Graph 1: Total emissions compared with the Purchased goods and Use of sold products emissions reported by NAuto (2021).



As vehicles become electrified, new material identities will have to be included:

$$F(vt) = \ t\,\text{steel}\ \frac{CO2e}{t\ steel}\text{x}\ \boldsymbol{kwh}\ \ \frac{\boldsymbol{CO2e}}{\boldsymbol{kwh}}\ x\ Units\ km\ \frac{CO_{2e}}{km}x\ \boldsymbol{Energy}\ \frac{\boldsymbol{CO_{2e}}}{\boldsymbol{Energy}}$$

Battery emisión factor:

$$\boldsymbol{kwh}\ \frac{\boldsymbol{CO2e}}{\boldsymbol{kwh}}$$

Energy emisión factor from vehicle consumption:

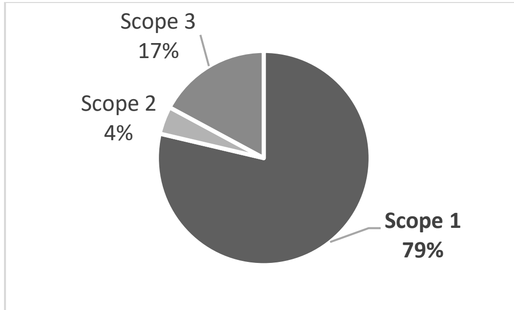
$$\boldsymbol{Energy}\ \frac{\boldsymbol{CO_{2e}}}{\boldsymbol{Energy}}$$

With this high correlation, it can be determined that the exposure of companies in the sector can be monitored by considering a few factors: the type of steel used for manufacturing the car and the emissions of the vehicles that are manufactured. In the case of electric vehicles, battery emissions are also significant.

b. Cement Sector

The intensity of direct CO_2 emissions from cement production has remained relatively stable over the last five years, and it is estimated to have slightly increased (by 1%) in 2022 (IEA, 2023a). However, annual decreases in CO_2 intensity of 4% are required until 2030 for the sector to be on the pathway to the Net Zero Emissions by 2050 Scenario (NZE) (IEA, 2023a).

Graph 2: Distribution of emissions by scopes from NCem (2021)



Scope 1 emissions emerge from thermal processes (i.e., the combustion of fuel for high temperature) and scope 2 emissions arise through the production of electricity consumed in the manufacturing of cement. Approximately 40% of its scope 1 emissions come from fuel consumption and the rest from the calcination of raw material (Marmier, 2023).

The production of carbon dioxide (CO_2) occurs as a byproduct of the chemical conversion process used in the production of clinker, in which limestone ($CaCO3$) is converted into lime (CaO) (52%) as well as by the combustion of fossil fuels (35%).

Thus, emissions come from two production factors:

- The use of fossil fuels in the combustion furnace
- The percentage of clinker in the cement mix.

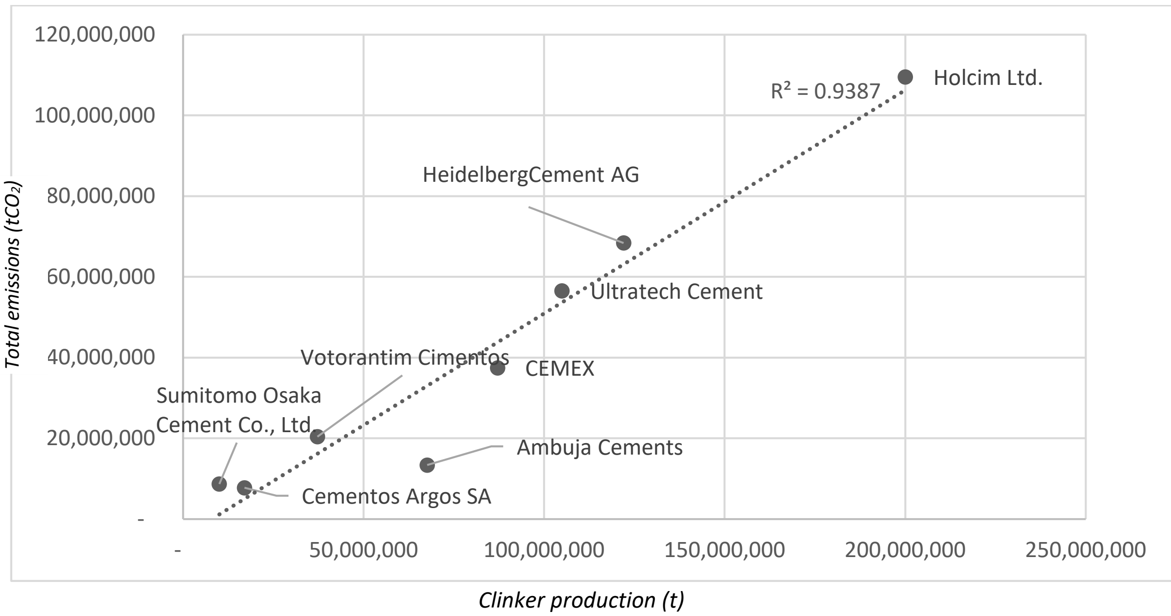
$$f(rm, P, p)\frac{Energy}{Input} x \frac{CO_{2e}}{Energy}$$

$$f(rm)\frac{Energy}{Input} x \frac{CO_{2e}}{Energy} \quad x \; \boldsymbol{f(P)\frac{Energy}{Input} x \frac{CO_{2e}}{Energy}} \quad x \; \boldsymbol{f(p)\frac{Energy}{Input} x \frac{CO_{2e}}{Energy}}$$

Considering process emissions factor non material $\boldsymbol{f(rm)} \to \boldsymbol{0}$ and $\boldsymbol{f(p)} \to \boldsymbol{0}$

$$F(vt) = F(cement) x \frac{CO2a1}{Output} = F(cement) x \frac{Clinker}{cement}$$

<u>Graph 3:</u> Total emissions (S1+S2+S3) vs Clinker production. NCem (2021).



As can be observed from the graph, it can be considered that the strategic metric lies in the abilities of cement companies to decouple their revenue from Clinker production.

$$\overset{\Delta}{\rightarrow} CO_{2e} = f(output)\frac{Clinker}{output}$$

c. Steel Sector

Between 2002 and 2012, the volume of steel production increased by 72% worldwide, and emissions increased by 75% (Xylia et al., 2018). It is a significant source of CO_2 emissions, being responsible for 2.8 gigatonnes of annual CO_2 emissions, which represents 8% of global emissions (IEA, 2023b), accounting for approximately 25% of global industrial emissions. This industry heavily depends on coal for the production of new steel and is part of complex and globalized value chains.

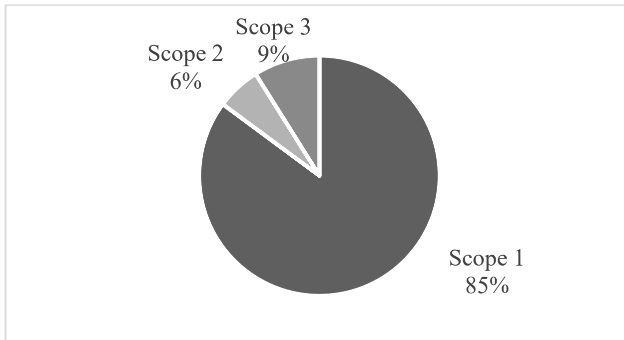
However, there are large variations in emissions depending on the production route, product portfolios, and the carbon intensity of the fuel mix. Many efforts are being made to reduce the energy intensity and emissions in the steel sector. In fact, these efforts have resulted in a 50% decrease in specific energy consumption in iron and steel production over the last 30 years (Xylia et al., 2018).

Steel production is primarily carried out in two ways: the first is carried out in integrated plants that use iron ore as raw material, and the second in secondary facilities that mainly recycle steel scrap.

Integrated plants typically encompass coke production, blast furnace operation, and the use of *basic oxygen furnaces* (BOF) or, in some cases, *open hearth furnaces* (OHF) although their use has been decreasing over time. In BOFs, crude steel is made from pig iron (formed from iron ore), obtained from the blast furnace, and then converted into finished steel products.

Secondary steel production is commonly carried out in *electric arc furnaces (*EAF) by melting recycled steel scrap in electric arc furnaces, emitting only a fraction of the CO_2 compared to integrated plants.

<u>Graph 4:</u> *Distribution of emissions by scopes sample NSteel (2021)*



Changes in the process are the main contributor, and this is only possible by establishing a moratorium on the most emitting technologies, ensuring that new installations use the most modern and electrified ones.

The primary energy consumption of the steel sector will change considerably as the sector decarbonizes. The decrease in the total energy intensity of steel manufacturing occurs in the early stages, mainly due to the increased use of scrap (EAF archetype), which requires much less energy than producing steel from iron or through the average BOF process.

According to this, emissions would be determined by the energy intensity of the production process, and related in this case to the percentage of BOF production process plants.

$$f(rm,P,p)\frac{Energy}{Input}x\frac{CO_{2e}}{Energy}$$

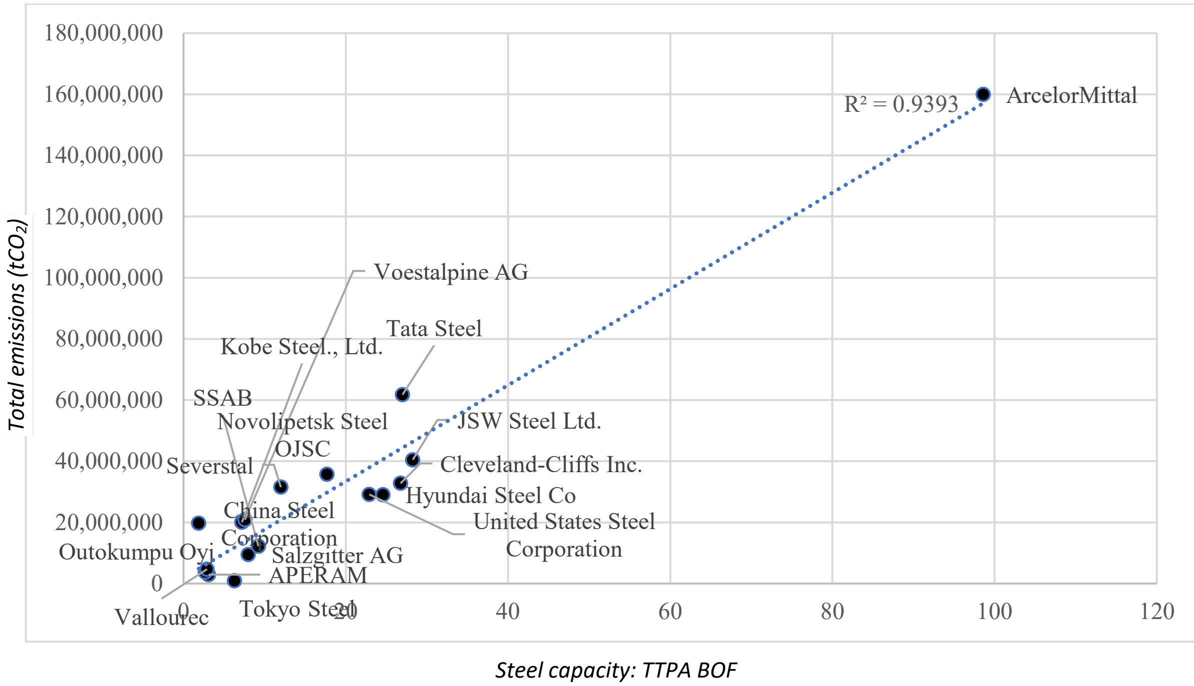
$$f(rm)\frac{Energy}{Input}x\frac{CO_{2e}}{Energy}\quad x\ f(P)\frac{Energy}{Input}x\frac{CO_{2e}}{Energy}\quad x\ f(p)\frac{Energy}{Input}x\frac{CO_{2e}}{Energy}$$

In this case *rm* and *P*

$$Input\ x\left(\frac{Energy}{Input}\right)\mathrm{x}\ \left(\frac{CO_{2e}}{Energy}\right)$$

In this case, the strategic metric is defined as (Energy/Input), which depends on the type of furnace used and its energy consumption. According to IEEFA (IEEFA, 2022), the difference in energy efficiency between a *Basic Oxygen Furnace (BOF)* and an *Electric Arc Furnace (EAF)* is significant, amounting to 120%. Furthermore, when the input material is scrap metal, the EAF's efficiency advantage dramatically increases, resulting in emissions that are 30 times lower than those of a BOF.

Graph 5: Total emissions (S1+S2+S3) by company vs BOF Steel production (TTPA) by company NSteel (2021)



In this case, steel production using *BOF technology* clearly determines emissions and therefore exposure to transition risk. This is a clear case where incorporating location into the metric provides relevant information, as the amounts of emissions contributed by each facility can have very different financial impacts depending on the climate policies of different jurisdictions.

5. Discussion and concluding comments

The corporate Greenhouse Gas (GHG) inventory is central element for understanding the climate-related transition risks that companies encounter. While global sustainability reporting standards depend on the GHG Protocol, introduced in 2004 to address a different era's challenges, today's users face difficulties accessing comprehensive and trustworthy information.

In this regard, this paper has problematized key aspects of the GHG Protocol that may hinder creating comparable, consistent, and useful decision-making in climate-related financial risks, as we summarize below:

First, its current structure, aiming to standardize emission classification and measurement, inadvertently hinders the comparability of companies' emissions inventories. This is due to various factors, such as differing baselines and consolidation approaches (financial versus operational control), selective reporting of Kyoto Protocol gases, and the choice between location-based or market-based methods for scope 2 emissions, among others. Furthermore, the extensive yet poor-quality information on scope 3 emissions and the issue of emission factor (in)commensurability compound these challenges.

Second, the inherent complexity and the extensive knowledge and resources required for emission measurement discourage companies from developing comprehensive GHG inventories, especially since significant emissions often stem from specific parts of the value chain, not always material in term of emissions.

Third, the financial impact of transition risks (including regulatory, technological, market, and reputational risks) heavily depends on the operational jurisdictions of a company. Detailing emissions information by country could significantly enhance its utility in credit risk models, valuations, and transition planning. This granularity could facilitate the alignment of corporate emissions inventories with national inventories and sector-specific decarbonization pathways, a crucial reference for company transition plans.

The second part of this paper proposes an alternative approach to the GHG Protocol, based on the Kaya identity (Kaya & Yokobori, 1997), to identify the main driving forces of GHG emissions across the value chain. Building on a sample of 70 companies from the EuroSTOXX 100 and within the automotive, cement, and steel sectors, our findings show that emissions arising in automakers, cement, and steel sectors are linked to a few emissions drivers. In the case of the automakers' sector, emissions are concentrated within purchased goods (steel and batteries) and the use of sold products (vehicle emissions). In the cement sector, the main forces of emissions emerge from fossil fuels in combustion furnaces and the percentage of clinker in the cement mix. Finally, iron and basic oxygen furnaces are the primary determinants of emissions in the steel sector. Therefore, the model proposed allows focusing information efforts on a limited number of decarbonization levers, reducing the costs of data collection and assurance and, even more importantly, creating a robust model with climate metrics that help in decision-making for credit risk assessment.

Driven by the necessity for more advanced decarbonization metrics (Bjørn et al., 2021), this article addresses the academic call for advancements in technical accounting methods (He et al., 2022; Hazaea et al., 2023). These metrics are essential for assessing systemic climate risks and encouraging the private sector's decarbonization efforts. However, current challenges in corporate climate metrics, affecting their credibility and utility, underscore the urgency of this issue. Therefore, this study contributes to previous literature by providing initial insights to enhance decision-making in climate-related credit risks. This academic contribution aims to expand to the regulatory and practitioner setting by providing key considerations for regulators crafting climate reporting frameworks to support a transition to a low-carbon economy.

We acknowledge two limitations from our analysis. Firstly, the findings are preliminary and not as comprehensive as some other studies. Yet, the data collected is sufficient to pinpoint decarbonization drivers in three crucial sectors. Secondly, the study's quantitative approach has not yet engaged stakeholders, including companies, regulators, and financial institutions, in evaluating the effectiveness of these methodologies. In this regard, further research could also explore the application of strategic climate metrics in financial auditing and a more detailed approach in sectoral decarbonization planning.

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