Decision-Useful Carbon Information

Gunther Glenk*
Harvard Business School, Harvard University
Business School, University of Mannheim
gglenk@hbs.edu

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Abstract

Current carbon accounting practices often obscure firms' actual emissions and abatement progress. This paper builds on financial accounting standards to propose how to characterize the quality of reported emissions and how companies should account for their emissions to achieve a certain reporting quality. In particular, I first propose that the objective of corporate carbon reporting is to provide carbon information about the reporting firm that is useful to managers, investors, and other stakeholders in making decisions related to the firm. Carbon information qualifies as *decision-useful* if and only if it satisfies a comprehensive system of qualitative characteristics adapted from generally accepted financial accounting principles. I then develop procedures for accounting for corporate emissions and show that firms adhering to these procedures will produce outcome variables that are relevant and faithfully represent the actual emissions embodied in their economic activities. Overall, the paper shows how standard-setters could revise recent carbon disclosure regulations to improve the quality of reported emissions.

Keywords: carbon accounting, information quality, sustainability reporting
JEL Classifications: G18, M14, M41, Q54, Q56

1 Introduction

In the global effort to mitigate climate change, companies around the world have begun reporting their annual greenhouse gas (GHG) emissions. Thousands of companies have also pledged to reduce their emissions, many to net zero by 2050 (Net Zero Tracker, 2023). Some companies have even begun marketing individual products as being already neutral to the global climate. While such efforts have been recognized as crucial for a timely transition toward a decarbonized economy (IPCC, 2023), analysts have argued that current carbon accounting practices obscure firms' actual emissions and abatement progress.[1] This paper proposes how to characterize the quality of reported emissions and how companies should account for their emissions to achieve a particular reporting quality.

The standard framework for accounting and reporting corporate emissions today is the *GHG Protocol*.[2] Similar to financial accounting standards, the GHG Protocol includes an objective, principles for conceptual guidance, and procedures for determining key outcome variables. These variables include three measures (or scopes) of a firm's periodic emissions, covering direct emissions from its operations (Scope 1), indirect emissions from the generation of the energy it consumed (Scope 2), and other indirect emissions generated by upstream suppliers and downstream customers (Scope 3). In addition to these measures of corporate emissions, the GHG Protocol defines a measure of the direct and indirect emissions associated with the life cycle of a given product. Companies typically determine their direct emissions based on physical quantities (e.g., liters of fuel consumed) and the chemical composition of the substances consumed in the emission process, while they estimate their indirect emissions based on exemplary production processes and industry averages.

Common concerns about the GHG Protocol include that its current objective, principles, and procedures are incoherent and vague. In particular, the GHG Protocol establishes no clear attribution of emissions to firms, resulting in firms along a value chain estimating and reporting the same emissions multiple times. In addition, the GHG Protocol does not distinguish between actual and estimated, past and future emissions, leading companies to

[1] "It's accounting tricks," industry analysts have commented on Apple's claim that its new Watch Series 9 is "carbon-neutral" (Bryan, 2023). In the United States, companies such as Delta Airlines have been sued for making misleading climate claims. In Europe, the European Commission (2023b) has adopted a directive aimed at preventing unfounded claims about the environmental merits of products.

[2] The GHG Protocol has been adopted by public and private organizations worldwide for voluntary and mandatory carbon disclosure. In line with common practice, I will refer to the collection of standards and guidelines issued by the organization called the GHG Protocol simply as *the* GHG Protocol.

aggregate different emission measures. Furthermore, companies have considerable discretion in selecting parameters for their calculations, often resulting in reported emissions that are biased, incomplete, difficult to verify, and fragmented across periods and firms.[3] Analysts have argued that these methodological issues undermine the decisions of a firm's managers, investors, and other stakeholders, and ultimately affect the firm's environmental and financial performance.[4]

In analogy to financial accounting standards, I first propose in this paper that the objective of corporate carbon reporting is to provide carbon information about the reporting firm that is useful to the users of the information in making decisions related to the firm. Users of carbon information include internal and external stakeholders of the firm who may be concerned with the firm's environmental impact, the firm's financial performance, or both. Decisions, and thus information needs, can be diverse. This paper focuses on decisions that require information on the firm's actual contribution to climate change, measured in terms of the atmospheric GHGs embodied in the firm's economic activity.[5] Carbon information is then said to be *decision-useful* if and only if it satisfies a comprehensive system of qualitative characteristics adapted from generally accepted financial accounting principles.

I then develop procedures for accounting for corporate emissions and show that firms adhering to these procedures will produce outcome variables that are decision-useful. Central to these procedures is the recording of the stock of actual atmospheric GHGs controlled by the reporting firm as a result of events and transactions in the firm's economic activity. Events refer to direct emissions from the firm's operations. Transactions refer to the firm (i) obtaining the indirect emissions embodied in the inputs purchased from suppliers and (ii) transferring the direct and indirect emissions embodied in the products sold to customers. Thus, the firm's control of a stock of atmospheric GHGs arises and expires in parallel with the firm's use and trade of the underlying economic assets.[6] Decision-useful outcome variables then result from a combination of measurement approaches from the GHG Protocol and

[3] See, for instance, Bjørn et al. (2022); Busch et al. (2022); Klaaßen and Stoll (2021); Wagenhofer (2024).

[4] In particular, analysts have argued that the current quality of reported emissions limits managers and investors in their ability to assess a firm's climate impact and climate-related financial risks, and thus to act according to their impact and risk preferences (SEC, 2024; European Union, 2023).

[5] Examples include decisions by managers about decarbonizing the firm's operations and decisions by investors about providing financial resources based on the firm's realized climate impact. Other decisions may require other information (e.g., downstream emissions), which should be disclosed separately to avoid obfuscation.

[6] As such, emissions are transferred along the value chain with the underlying goods and services. Each firm in the value chain can focus on measuring their direct emissions and use the information provided by its immediate suppliers for the emissions embodied in its procurement Kaplan and Ramanna (2021, 2022).

accounting rules from historical cost accounting that facilitate the faithful representation of the actual atmospheric GHGs embodied in individual events and transactions.

The outcome variables developed in this paper include four measures of corporate emissions. The first is a stock measure that captures the actual atmospheric GHGs controlled by the reporting firm at the end of a reporting period. This stock of atmospheric GHGs has effectively remained embodied in the firm's operating assets. The other three are flow measures that capture the changes in this stock incurred during the reporting period and the net addition of actual atmospheric GHGs embodied in the firm's periodic economic activity. These measures of corporate net emissions effectively include variants of the firm's Scope 1, 2, and upstream 3 emissions. When combined, they also reflect the carbon accounting analog of the firm's cash flow statement, showing the sources of the firm's periodic emissions and how they are managed. In addition to the measures of corporate emissions, the outcome variables include a measure of the actual atmospheric GHGs embodied in a product due to the use of economic resources in its provision.

Compared to the GHG Protocol, the proposed framework is more coherent and specific. In particular, the notion of control uniquely links a stock of atmospheric GHGs to a firm, resolving the ambiguity of responsibility across firms and thus the double counting of emissions in a value chain. In addition, accounting for the stock of actual atmospheric GHGs controlled by the reporting firm facilitates the distinction between different emission measures. Furthermore, companies have limited discretion in their carbon accounting, as the few parameters they can choose should be generally accepted as neutral. As a result, the outcome variables in this paper allow a firm's managers, investors, and other stakeholders to make informed decisions regarding the actual emissions embodied in the firm's economic activity and the progress made toward a reduction target. Managers are also incentivized to set more realistic emission targets and implement decarbonization measures that lead to actual reductions in atmospheric GHGs (Chen and Pfeiffer, 2024).[7]

Recognizing the potential of carbon information, standard-setters worldwide have recently introduced regulations for corporate carbon accounting and reporting.[8] These regulations

[7]Such incentives are lacking in current carbon accounting practices, where managers have considerable discretion in determining their emissions and upstream emissions are estimated based on industry averages.

[8]See, for instance, the Corporate Sustainability Reporting Directive by the European Union (European Union, 2023), the climate-related disclosure rule by the Securities and Exchange Commission in the United States (SEC, 2024), and the sustainability-related disclosure standards by the International Sustainability Standards Board (ISSB, 2023b,a).

require firms to disclose information on their corporate emissions that is *decision-useful* and to obtain at least limited assurance on their disclosures from external auditors. At the same time, the standard-setters have also largely adopted the procedures of the GHG Protocol for how firms should determine and report their emissions. The analysis in this paper shows that these regulations will improve the quality of reported carbon information by reducing the discretion companies have in choosing parameters for calculating their emissions. Yet, it also shows how the standard-setters could revise their regulations to facilitate that reported information on corporate emissions will indeed be decision-useful. The transactional design of the proposed framework should further enable firms to obtain reasonable assurance on their carbon disclosures, the level expected for financial audits (Distler et al., 2024).

While much of the proposed framework mirrors financial accounting, there are significant differences. In financial accounting, the primary users of reported information are existing and potential investors making decisions about providing resources to the reporting firm (FASB, 2021; IASB, 2018). A central reporting element is the firm's assets, defined prospectively as the present rights of an entity to economic benefits and often valued via financial assessments. And the firm's events and transactions are typically recorded at the associated prices, which may or may not reflect the underlying costs. In the proposed framework, the users of reported information include internal and external stakeholders making decisions related to the firm's actual contribution to climate change. The central reporting element is the stock of actual atmospheric GHGs controlled by the reporting firm, which is determined retrospectively by the physical quantity of atmospheric GHGs. And the firm's events and transactions are recorded based on the embodied atmospheric GHGs, which must be faithfully represented for the reported carbon information to be decision-useful.

This paper contributes to several lines of research. One line of recent work has proposed methodological changes to current carbon accounting practices.[9] For example, Kaplan and Ramanna (2021, 2022) have proposed that companies transfer the emissions embodied in products along the value chain, arguing that this approach could make reported emissions more reliable. Reichelstein (2024) and Penman (2024) have introduced accrual accounting systems for corporate emissions and argued that such systems offer more information about a firm's emissions performance over time. Other studies have proposed improvements in individual aspects of corporate carbon disclosures, including the accuracy (Brander et al.,

[9]In contrast, Berg et al. (2024) and Gipper et al. (2024b) examine the role of assurance in addressing issues arising from the implementation of the GHG Protocol.

2021), temporal consistency (Comello et al., 2023), and comparability (Jia et al., 2023) of reported emissions and the credibility of net-zero targets (Fankhauser et al., 2022; Bjørn et al., 2021). I complement this literature by proposing a comprehensive framework for how to characterize the quality of reported emissions and how companies should account for their emissions to produce decision-useful information. My analysis shows why some earlier suggestions, such as the transfer of emissions across firms, are necessary but insufficient on their own for companies to faithfully represent the actual atmospheric GHGs embodied in their economic activity, and how they must be combined with other methodological changes to be sufficient in combination.

A second line of work has empirically examined the drivers of corporate carbon reporting and performance. Cohen et al. (2023a) and Reid and Toffel (2009) have found that investors are increasingly demanding information on corporate emissions. Other studies have shown that companies reduce their direct (Scope 1) emissions when they adopt or become subject to targeted initiatives, such as executive compensation (Cohen et al., 2023b), management targets (Ioannou et al., 2016), shareholder engagement (Azar et al., 2021; Dyck et al., 2019), and mandatory disclosure regulation (Downar et al., 2021; Tomar, 2023; Christensen et al., 2021). This paper contributes to this research by proposing a framework that enables managers to provide decision-useful information on product and corporate emissions. In addition, the framework enables investors and other stakeholders to monitor companies' decarbonization efforts and hold them accountable for their climate claims and pledges.

A third line of related work has focused on the quality of corporate reporting. One topic of long-standing discussion is how to conceptually define information quality and how to achieve a particular quality (Schnackenberg and Tomlinson, 2016).[10] Financial accounting standards boards have continuously refined both aspects for financial reporting over the past decades. Yet, there has also been a proliferation of non-financial reporting in recent years, with carbon reporting based on the GHG Protocol being a case in point. This paper extends the advances made for financial information to non-financial information by first adapting the current conceptual framework of financial accounting standards to corporate emissions. It then combines measurement approaches from the GHG Protocol with accounting rules from financial accounting standards to provide specific steps for arriving at decision-useful

[10] Another topic is the impact of precision in sustainability reporting on investors and firm value (Friedman et al., 2021; Mahieux et al., 2023; Xue, 2023). In this context, the proposed framework demonstrates how companies can enhance the precision of their carbon reporting.

outcome variables.

The remainder of the paper proceeds as follows. Section 2 reviews the main methodology of the GHG Protocol and addresses common concerns about it. Section 3 formally introduces the proposed framework, starting with the objectives and principles of decision-useful carbon information. I then develop the accounting procedures, identify measures of a firm's emissions performance, and examine the treatment of trade across the boundary of the framework, that is, between companies that have adopted the framework and those that have not. Section 4 discusses the advantages of the proposed framework over the GHG Protocol, its contribution to previous research on corporate carbon accounting, and its implications for policymakers. Section 5 concludes the paper.

2 The Greenhouse Gas Protocol

2.1 Main Methodology

Like financial accounting standards, the GHG Protocol includes three key elements. An objective seeks to describe the purpose of accounting and reporting corporate emissions. Principles aim to provide conceptual guidance for accounting and reporting emissions by defining qualitative characteristics of reported information. And procedures generate the information by describing steps for arriving at different measures of emissions. Common to these elements is the substance of the reported information, which emerges implicitly in the guidelines as the emissions associated with the reporting company.

The main objective of the GHG Protocol can be read as the goal "*to help companies prepare a GHG inventory that represents a true and fair account of their emissions, through the use of standardized approaches and principles*" (GHG Protocol, 2004). This objective is stated in several documents of the GHG Protocol, usually along with other reasons for developing the guidelines. The principles of the GHG Protocol include five qualitative characteristics: *relevance*, *completeness*, *consistency*, *transparency*, and *accuracy*. Table 1 provides their verbal definitions as given in the GHG Protocol (2004). For both the objective and the principles, the GHG Protocol leaves somewhat open how they should be interpreted and how they relate to each other.

The procedures of the GHG Protocol can be summarized in three main steps. The first step is to choose the organizational boundary regarding the entities and other assets that

are to be included in the reporting. This step is somewhat similar to the consolidation processes used in financial reporting but may result in a different organizational boundary for carbon reporting than for financial reporting. The second step is to choose the operational boundary in terms of three scopes of emissions. Scope 1 emissions are direct emissions from sources within a company's organizational boundary. Scope 2 emissions are indirect emissions resulting from the generation of energy (i.e., electricity, steam, heat, or cooling) consumed by sources within the company's organizational boundary. Scope 3 emissions are all other indirect emissions generated by the company's upstream suppliers and downstream customers. The GHG Protocol requires companies to disclose their Scope 1 and 2 emissions, while reporting Scope 3 emissions is optional.

Table 1. Principles of the GHG Protocol.

Principle	**Definition**
Relevance	Ensure the GHG inventory appropriately reflects the GHG emissions of the company and serves the decision-making needs of users – both internal and external to the company.
Completeness	Account for and report on all GHG emission sources and activities within the chosen inventory boundary. Disclose and justify any specific exclusions.
Consistency	Use consistent methodologies to allow for meaningful comparisons of emissions over time. Transparently document any changes to the data, inventory boundary, methods, or any other relevant factors in the time series.
Transparency	Address all relevant issues in a factual and coherent manner, based on a clear audit trail. Disclose any relevant assumptions and make appropriate references to the accounting and calculation methodologies and data sources used.
Accuracy	Ensure that the quantification of GHG emissions is systematically neither over nor under actual emissions, as far as can be judged, and that uncertainties are reduced as far as practicable. Achieve sufficient accuracy to enable users to make decisions with reasonable assurance as to the integrity of the reported information.

The final step is to calculate emissions. For corporate emissions, the common procedure is to identify all emission sources within the chosen boundaries, multiply an activity measure by a corresponding emission factor for each emission source, and aggregate the resulting estimates. While the GHG Protocol describes this calculation mostly verbally, it will be useful to express it formally. Let q_i denote the measure of activity for emission source $i \in I_s$. The set I_s captures all emission sources of Scope s for $s \in \{1, 2, 3\}$ in a given reporting period within the chosen boundaries. Let e_i denote the emission factor corresponding to emission source i. Suppose that e_i is expressed in kilograms of carbon dioxide equivalents

(CO_2e) per unit of activity. That is, e_i measures the aggregate value of the major GHGs, with the contribution of each gas converted based on the global warming potential of the gases (IPCC, 2023).[11] The total Scope s emissions in a given reporting period of a company with no subsidiaries are then given by:

$$\sum_{i \in I_s} q_i \cdot e_i. \tag{1}$$

For product emissions, the process begins with identifying the emission sources in each scope that are connected to the provision, use, and end-of-life treatment of the product (GHG Protocol, 2011b). Examples include consumable items, product components, packaging, and potential recycling activities. Emissions associated with resources such as capital goods, overhead operations, and corporate services, are considered "non-attributable" and typically excluded. For a given product, the company then multiplies the calculated emissions from each source by the share attributed to the product. Let $\alpha_i^o \in [0, 1]$ denote the share of emission source i the company chooses to attribute to a given product, where $\alpha_i^o = 0$ for $i \in I_s$ not attributed to the product. The cradle-to-grave emissions of the product produced in a given reporting period are then given by:

$$\sum_{s=1}^{3} \sum_{i \in I_s} \alpha_i^o \cdot q_i \cdot e_i. \tag{2}$$

The data used in the above calculations vary depending on the scope of emissions. For Scope 1 emissions, activity measures are typically physical quantities, such as liters of fuel consumed. Emission factors are determined by the chemical composition of the substances consumed in the emission process. The physical quantities can be obtained from company records, and the emission factors from public databases. Examples of recognized sources of emission factors include the EU Emissions Trading System (European Commission, 2023a), the US Environmental Protection Agency (U.S. EPA, 2023), the UK Department of Food and Rural Affairs (U.K. Defra, 2023), and the International Energy Agency (IEA, 2023).

For Scope 2 emissions, activity measures are the kilowatt-hours of the different types of energy consumed. Emission factors can be determined in two ways: (i) based on the average emission intensity of the grid where the energy is consumed (location-based method) and

[11] The calculation can be easily expanded based on a vector of emission factors that captures the major GHGs and their aggregate value as separate entries.

(ii) based on contractual instruments of energy supply that companies may have obtained (market-based method) (GHG Protocol, 2015). Companies may find the necessary information for both methods on their energy bills. Alternatively, they can use average emission factors from public databases such as those referenced above.

For Scope 3 emissions, the GHG Protocol recommends that companies use activity and emissions data determined by the respective emitter in the value chain (GHG Protocol, 2011a). To comply with this, companies would need to collect the information from their multiple-tier suppliers and customers. Recognizing the practical challenges of such collection efforts, the GHG Protocol allows firms to estimate emissions based on exemplary production processes and industry averages. Activity measures then vary widely, including the quantity of items procured, the square meters of space occupied, or the amount of money spent on a purchase. Emission factors are typically estimated based on life-cycle assessments of the underlying activity and third-party data sources.[12]

2.2 Common Concerns

Figure 1 highlights six common concerns with the current methodology of the GHG Protocol. *Ambiguous Responsibility* means that the GHG Protocol establishes no unique attribution of emissions to firms. Instead, emissions are estimated and reported multiple times by different companies along the value chain. To illustrate, the Scope 1 emissions of one company reflect the Scope 2 and 3 emissions of other companies. The GHG Protocol recognizes double counting as an attempt to capture the collective responsibility within the supply chain (GHG Protocol, 2004). Yet, shared responsibility can blur accountability and even lead to omissions. For example, industrial producers of steel, cement, and other basic materials regularly ignore emissions from burning waste as an alternative fuel, arguing that these emissions would have occurred in nearby waste incinerators (ECRA, 2022). But the operators of such incinerators note that they no longer burn the waste.

Obscuring Aggregation describes that the GHG Protocol makes no distinction between actual and estimated, past and future emissions. Instead, companies aggregate emissions that have occurred with those that are expected to occur sometimes far in the future (Brander et al., 2021). For example, Scope 3 emissions aggregate past with future emissions by

[12] A prominent example of such data sources is the life-cycle assessment data provided by *sphera*. Many consulting and software companies have also developed their own proprietary data sets for Scope 3 emissions.

construction. Such aggregation obscures actual changes in the stock of atmospheric GHGs and a firm's actual contribution to climate change. It can also obscure a firm's financial risks and opportunities resulting from its emissions, such as the financial impact of (higher) carbon prices or the abatement cost of different decarbonization initiatives.

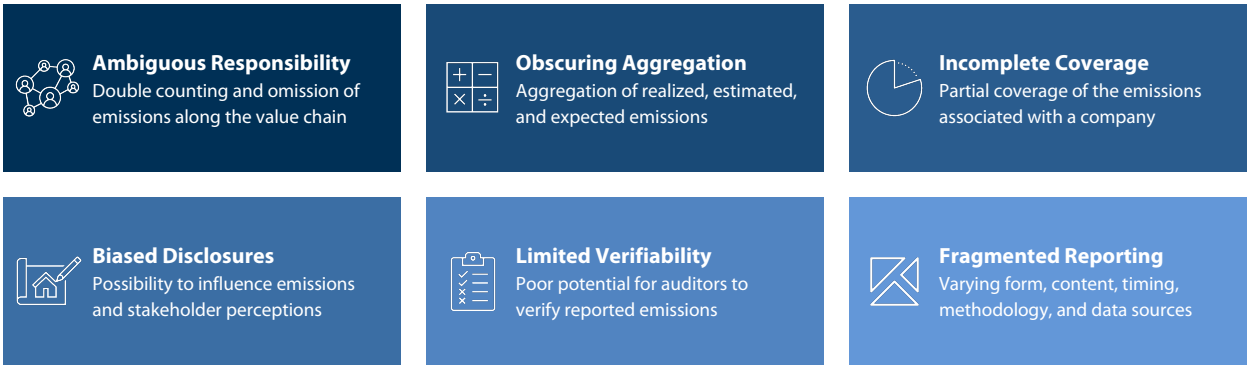

Figure 1. Common concerns about the GHG Protocol.

Incomplete Coverage captures the fact that companies can choose their organizational and operational boundaries and thus the range of emissions they report. As a result, they can understate their emissions by strategically choosing the boundaries while still complying with the GHG Protocol. For example, multinational firms often omit emissions from overseas operations for which emissions data are hard to obtain (Gipper et al., 2024b). Many firms also report emissions for only a fraction of upstream Scope 3 emissions, such as those related to energy consumption, business travel, or material production inputs (Depoers et al., 2016). Such underreporting can account for a significant portion of a company's total emissions. Klaaßen and Stoll (2021) estimate that technology companies omitted about half of their total emissions in their 2019 corporate reports.

Biased Disclosures describes the latitude companies have to choose the approach and data to estimate their emissions. As a consequence, companies can shape emission metrics and stakeholder perceptions by choosing favorable input parameters, yet comply with the GHG Protocol. Previous research has found that firms have systematically reported lower emissions in corporate sustainability reports published on their websites than through the Carbon Disclosure Project, a platform for corporate carbon disclosure (Klaaßen and Stoll, 2021; Depoers et al., 2016). However, evidence of managers manipulating emission metrics, for example by cherry-picking methodologies or emission factors, has not been documented (Bingler et al., 2022; Downie and Stubbs, 2012).

Limited Verifiability refers to the poor potential for auditors to verify reported emissions. This is primarily due to the preceding issues. In particular, the latitude companies have in choosing the parameters for calculating emissions generally limits the ability of auditors to verify reported emissions to the extent that the calculations performed are appropriate and without error. Yet, such verification is much weaker than the assurance that a firm's emissions are fairly represented, which would be similar to the level of assurance required for financial information. Over the past decade, more than 50% of S&P 500 companies that have disclosed corporate emissions have requested verification by external auditors (Gipper et al., 2024a). In about 90% of the cases, however, the auditors could only provide limited assurance, meaning that no evidence of misreporting has come to their attention.

Finally, *Fragmented Reporting* describes the fragmented landscape of corporate carbon reporting. For example, the form and content of carbon disclosures prepared under the GHG Protocol vary widely across firms and time periods, making it difficult to compare the disclosures (Jia et al., 2023). In addition, companies disclose their emissions at different times of the year and typically much later than their financial statements (Bajic et al., 2021). They also often disclose only partial information about the methodology, data sources, and assumptions used to determine their emissions, making the reported information difficult to understand (Depoers et al., 2016). This fragmentation is also driven by the discretion companies have under the GHG Protocol.

3 Decision-Useful Carbon Information

3.1 Objective and Principles

In analogy to financial accounting standards (FASB, 2021; IASB, 2018), I propose that the objective of corporate carbon reporting is to provide carbon information about the reporting firm that is useful to the users of the information in making decisions related to the firm. Users of carbon information include internal and external stakeholders of the firm, such as managers, investors, regulators, and customers. These users may be concerned with the firm's environmental impact, the firm's financial performance, or both.

Decisions, and thus information needs, can be diverse. This paper focuses on decisions that require information on the firm's actual contribution to climate change, measured in terms of the atmospheric GHGs embodied in the firm's economic activity. Examples include

decisions by managers about decarbonizing the firm's operations, decisions by investors about providing financial resources based on the firm's realized climate impact or the financial risk of the firm's realized emissions, decisions by regulators about setting incentives for climate action, and decisions by customers seeking to buy products with low embodied emissions. Other decisions may require different information.[13] Yet, such disclosures should be made separately so as not to obscure information through aggregation.

Carbon information in this paper therefore refers to information on the present stock of atmospheric GHGs controlled by the reporting firm as a result of past events and transactions and the changes in this stock that have occurred in the reporting period. A present stock of atmospheric GHGs is any quantity of the major GHGs, measured in metric tons, that exists in the atmosphere at the reporting date. This stock results from GHGs that have actually been emitted or removed from the atmosphere. Removals can be achieved through technological or nature-based solutions, such as direct air capture facilities or reforestation projects. They are considered additional to the natural carbon cycle and permanent in the sense that the GHGs removed are not released back into the atmosphere.[14] Examples of such permanent removals include the mineralization of CO_2 in volcanic rock and the geologic sequestration of biomass (Allen et al., 2024).

Control uniquely links a stock of atmospheric GHGs to a firm to resolve the ambiguity of responsibility. A firm's control results from events and transactions in the firm's economic activity. Events refer to direct emissions and removals in the firm's operations, such as driving an internal combustion engine vehicle or operating a direct air capture facility for some time. Transactions refer to the firm obtaining the indirect emissions and removals embodied in the inputs purchased from suppliers. Transactions also refer to the firm transferring the direct and indirect emissions and removals embodied in the products sold to customers. Thus, a firm's control of a present stock of atmospheric GHGs arises and expires in parallel with the firm's use and trade of the underlying economic assets.

Like financial information, carbon information will be called *decision-useful* if and only if it is *relevant* and *faithfully represents* what it purports to represent. Table 2 provides the definitions of these qualitative characteristics. Accordingly, relevant carbon information is

[13] Examples include information on the emissions expected to result from the use of the firm's products, the emissions expected to occur in the economy as a result of a particular action by the firm, the physical impact of a changing climate on the firm's financial performance, and the firm's plans to decarbonize.

[14] Removals that will be partially reversed within a foreseeable time frame can also be recognized by firms, provided that any reversals are also recognized in future disclosures.

capable of making a difference in the decisions made by users. Information may have this capacity even if some users choose not to use it or are already aware of it. As such, relevance describes what type of carbon information is useful to users.

Table 2. Fundamental characteristics of decision-useful carbon information.

Characteristic	Definition
Relevance	Relevant carbon information is capable of making a difference in the decisions made by users. Carbon information has this capacity if it has predictive value, confirmatory value, or both.
◦ Predictive Value	Carbon information can be used to predict future outcomes.
◦ Confirmatory Value	Carbon information confirms or changes previous evaluations.
Faithful Representation	Carbon information is complete, neutral, and free from error.
◦ Completeness	A complete depiction includes all information necessary for a user to understand the depicted phenomenon, including all necessary descriptions and explanations.
◦ Neutrality	A neutral depiction is without bias in the selection or presentation of carbon information.
◦ Free from error	A depiction is free from error if there are no errors or omissions in the description of the phenomenon, and the process used to produce the reported information has been selected and applied with no errors in the process.

A firm-specific aspect of relevance is materiality. Carbon information will be *material* if omitting, misstating, or obscuring it could reasonably be expected to influence decisions. Materiality depends on the nature and magnitude of the depicted phenomenon and the circumstances in which the materiality judgment has to be made. It is often argued that a uniform quantitative threshold for materiality would help companies decide which emissions to include in their report (GHG Protocol, 2023a). But such a threshold would substitute a generalized collective judgment for specific individual judgments. In particular, it would ignore the potential difference in the materiality of a phenomenon when evaluated from the perspective of a firm's environmental impact or financial performance. For example, the flaring and venting of natural gas may be environmentally material but financially immaterial to an oil and gas producer.

A faithful representation requires information to be *complete*, *neutral*, and *free from error*. As defined in Table 2, completeness means that no material amount of the present stock of atmospheric GHGs controlled by the reporting firm, nor any material change in that stock, is omitted. Central to completeness is the organizational boundary of a company.

For financial reporting, companies set their organizational boundaries according to existing standards. A faithful representation requires that a firm's organizational boundary contains no arbitrary or incomplete set of economic activities. Since the present stock of atmospheric GHGs controlled by a firm results from its economic activities, the activities reflected in its carbon reporting should align with those reflected in its financial reporting. This alignment also helps users analyze performance measures that depend on both carbon and financial information, such as measures of a firm's carbon intensity.

Neutrality requires that companies do not color the image they communicate, that is, bias their disclosures by, say, understating emissions or overstating removals. In the draft *Land Sector and Removals Guidance* (GHG Protocol, 2023b), the GHG Protocol proposes that firms use conservative assumptions, values, and procedures to determine emissions and removals. Such conservatism would introduce bias into carbon information, which would be inconsistent with neutrality (FASB, 2021). Free from error requires that reported carbon information be without errors or omissions. Yet, free from error does not mean accurate in all respects. For example, an estimate of an unobservable emission cannot be determined to be accurate or inaccurate. A representation of that estimate can be faithful if the amount is identified as an estimate, the estimation process is explained, and no errors have been made in the selection and application of the estimation process.

As for financial information, the decision-usefulness of carbon information is enhanced if the information is *comparable*, *verifiable*, *timely*, and *understandable*. Comparability allows users to identify and understand similarities and differences between phenomena. Consistency facilitates comparability by requiring the same methods for the same phenomena, from period to period within a firm and in a single period across firms. Verifiability requires that different knowledgeable and independent observers can reach consensus that a particular depiction is a faithful representation. Thus, verifiability helps assure the quality of reported carbon information. Timeliness means that information is available to users in time to be capable of influencing decisions. Understandability requires that information is clear and concise. Understandable information enables users with reasonable knowledge of corporate emissions to comprehend its meaning.

Figure 2 illustrates the relationships between the proposed objective and principles of corporate carbon reporting. Decision-usefulness requires that carbon information is relevant and faithfully represents what it purports to represent. Either irrelevance or unfaithful

representation results in information that is not decision-useful. Enhancing characteristics improve the usefulness of carbon information. But they cannot make information relevant or representationally faithful.

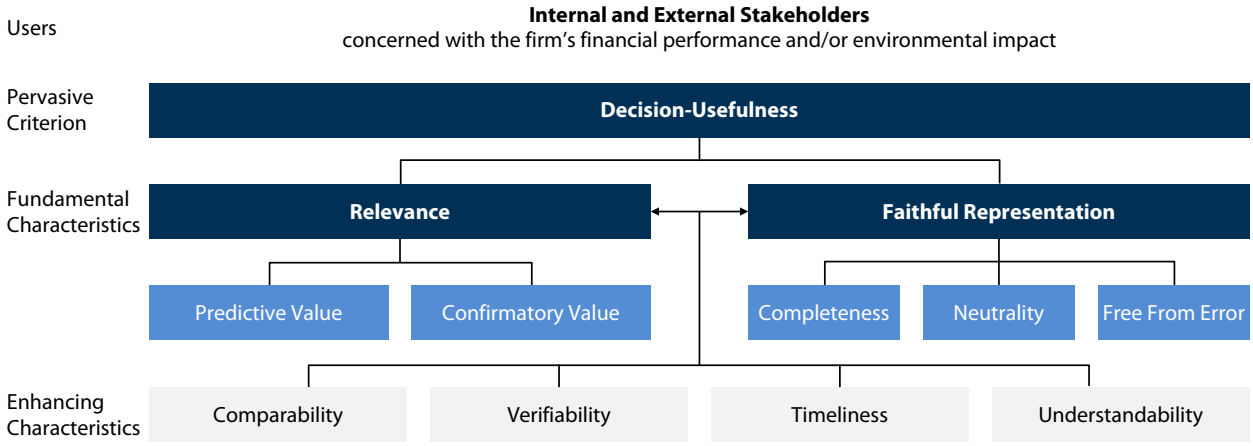

Figure 2. Taxonomy of decision-useful carbon information.

3.2 Main Procedures

Consider now a set of firms that seek to report decision-useful carbon information. This set, denoted by F_r in reporting period r, may arise from a voluntary climate alliance or a mandate for corporate carbon disclosure. All firms in F_r are separate entities, adhere to the following procedures, and have their resulting carbon information verified by third-party auditors. In addition, they all exhibit direct and indirect emissions in their economic activity. Some firms also exhibit direct or indirect removals. Suppose initially that the firms in F_r only trade with each other.

Carbon information about a firm $f \in F_r$ can be considered relevant. This is because carbon information, as defined above, has both predictive and confirmatory value, and thus the capacity to influence decisions related to the firm. For example, the total direct emissions of the firm in the current period can be used to predict the total direct emissions in the next period. At the same time, the total direct emissions in the current period can also be used to confirm or change a prediction about them made in previous periods. Besides, information about the emissions of firms and their products is already influencing decisions today. For example, public and private organizations worldwide have made the emissions of suppliers a criterion for purchasing from them (see, for instance, Lu et al. (2022); The White House

(2022)). Similarly, consumers have been shown to change their purchasing decisions when companies disclose an estimate of the emissions embodied in the goods and services they sell (Floyd et al., 2023; Beyer et al., 2024).

The faithful representation of carbon information about firm f depends on the recording of individual events and transactions. For events, let x_i capture the kilograms of CO_2e emitted or removed by firm f due to event $i \in D_{f,r}$, where the set $D_{f,r}$ captures all material events firm f incurs in period r. Direct emissions and removals can be quantified by multiplying the underlying physical quantity q_i by the corresponding emission factor e_i. Thus, $x_i = q_i \cdot e_i$ for event $i \in D_{f,r}$, where $e_i > 0$ for emissions and $e_i < 0$ for removals. This quantification is conceptually the same as for Scope 1 emissions. Yet, it requires specific input data to be complete, neutral, and free from error. Completeness requires that the physical quantity q_i captures the entire event. Neutrality requires the use of standard emission factors e_i, such as those provided by governmental databases mentioned above. And the free-from-error property requires that the firm measures the physical quantity q_i correctly and selects the emission factor e_i that is specific to event i.[15]

For transactions, let y_i capture the present stock of atmospheric GHGs in kilograms CO_2e firm f obtains due to transaction $i \in O_{f,r}$. The set $O_{f,r}$ captures all material transactions with suppliers firm f conducts in period r. The parameter y_i can be interpreted as the sum of indirect emissions and removals embodied in all goods and services purchased with transaction $i \in O_{f,r}$. Thus, $y_i > 0$ if the emissions outweigh the removals, while $y_i < 0$ if the purchase primarily involves removals.[16]

Similarly, let z_i capture the present stock of atmospheric GHGs in kilograms CO_2e firm f transfers due to transaction $i \in T_{f,r}$. The set $T_{f,r}$ captures all transactions with customers firm f conducts in period r. The parameter z_i can be interpreted as the sum of direct and indirect emissions and removals embodied in all goods and services sold with transaction $i \in T_{f,r}$. Thus, $z_i < 0$ if the emissions outweigh the removals, while $z_i > 0$ if the sale primarily involves removals. By construction, there is one $i \in T_{f,r}$ for each $j \in O_{g,r}$ for some $f, g \in F_r$ with $f \neq g$, where $z_i = y_j$. Firms in F_r disclose z_i to their customers. Such bilateral disclosure is similar to an energy supplier today providing their customers information on their Scope 2 emissions. Key to the bilateral disclosure, however, is that the measure of a

[15] For example, companies with global operations should use emission factors that are specific to the time, geographic location, and production technology used in a given event (GHG Protocol, 2023a).

[16] This assumes that firms have discretion in attributing removals that are not inherently linked to any product. To mitigate greenwashing concerns, firms could disaggregate y_i into emissions and removals.

product's carbon footprint faithfully represents the embodied stock of atmospheric GHGs.

Determining the carbon footprint of a product is conceptually similar to historical cost accounting (Kaplan et al., 2023). Some direct and obtained emissions are fully attributable to the product due to the use of the underlying economic resources in the provision of the product. Others are partially attributable due to resources that are shared across multiple products or periods, such as operating assets or general management. Unlike cost allocations, however, carbon allocations require additional rules to be complete, neutral, and free from error. Completeness requires that all x_i and y_i causally related to the product are included in the allocation. The free-from-error property requires that the allocation be made without errors or omissions. And neutrality requires intertemporal and cross-sectional allocation rules that are generally accepted as neutral. Without such allocation rules, firms could arbitrarily set the emissions embodied in their products. For example, firms could market their primary product as emission-free by allocating all incurred emissions to by-products.

Regulators may at some point define acceptable carbon allocation rules, similar to financial depreciation rules for tax purposes. Absent such regulation, the neutrality of product carbon footprints depends on firms choosing allocation rules without bias. One way for firms to demonstrate this is by adopting a verifiable hierarchy of allocation rules that capture, with decreasing generality, the causal relationship between resource use and product delivery.[17] Established product costing rules, such as activity-based costing, could thereby serve as proxies for the resources consumed and the associated stock of atmospheric GHGs. Yet, just as companies adapt their cost allocation rules, they may also adapt their carbon allocation rules to the specifics of their production processes.

Companies and industry associations have recently developed industry-specific hierarchies of carbon allocation rules.[18] For example, the *Strategic CO_2 Transparency Tool* by the global chemical company BASF (2022) is an automated tool that first tries to directly attribute emissions to products based on the consumption of the underlying resources. If this is not applicable, it tries to allocate emissions based on industry standards per product category, then tries to use common physical or economic allocation bases, and finally resorts to specific rules for waste products or minor by-products. Automated systems entail the additional benefits of being consistent over time and preventing manual interference.

[17] For example, utilities should allocate emissions based on the temporal and spatial matching of power generation and consumption, using smart meter data or representative demand profiles.

[18] See Together for Sustainability (2022) and Catena-X (2023) for examples from the chemicals and automotive industries.

To formally define the carbon footprint of a product, let $p \in P_{f,r}$ uniquely identify a single product, where the set $P_{f,r}$ captures all finished products firm f produces in period r. Examples of a unique identifier include a product's serial number or, for bulk products or continuous services, a sufficiently specific time frame. Suppose that all firms in F_r adopt carbon allocation rules that are generally accepted as neutral. Let $\alpha_{i,p} \in [0,1]$ denote the resulting neutral share of the stock of atmospheric GHGs associated with event or transaction i that is attributed to product p. The *Product Carbon Footprint*, $PCF_{f,p}$, of product $p \in P_{f,r}$ is then given by the weighted sum of the stock of atmospheric GHGs associated with all events and transactions attributed to the product:[19]

$$PCF_{f,p} \equiv \sum_{t=1}^{r} \Bigg[\sum_{i \in D_{f,t}} \alpha_{i,p} \cdot x_i + \sum_{i \in O_{f,t}} \alpha_{i,p} \cdot y_i \Bigg]. \tag{3}$$

Note in passing that $z_i = PCF_{f,p}$ if firm f sells product p in transaction $i \in T_{f,r}$.

Observation 1. *The Product Carbon Footprint, $PCF_{f,p}$, of product $p \in P_{f,r}$ of firm $f \in F_r$ is relevant information and faithfully represents the present stock of atmospheric GHGs embodied in the product as a result of past events and transactions.*

Observation 1 follows from the recursive, decentralized calculation of product carbon footprints along the value chain. To see this, consider initially a single firm $f \in F_r$. Each of the firm's x_i faithfully represents the kilograms of CO_2e emitted or removed due to event $i \in D_{f,r}$. Suppose initially that the firm's suppliers faithfully represent the present stock of atmospheric GHGs embodied in the goods and services they supply. That is, each of the firm's y_i is assumed to be a faithful representation. The $PCF_{f,p}$ of product $p \in P_{f,r}$ of firm f then faithfully represents the present stock of atmospheric GHGs embodied in the product, given that the weights $\alpha_{i,p}$ are neutral. Since this consideration holds for any product $p \in P_{f,r}$ of any firm $f \in F_r$, all firms in F_r faithfully represent the present stock of atmospheric GHGs embodied in their products. Thus, every y_i of every firm in F_r is indeed a faithful representation.

It is important to recognize that firms in F_r will have discretion in determining the carbon footprints of their products if multiple carbon allocation rules are accepted as neutral for given economic resources. That is, the carbon footprints of identical products produced by

[19] The framework can be readily adapted to account for the time value of changes in the stock of atmospheric GHGs by including an appropriate factor similar to a financial interest rate (Levasseur et al., 2012).

different firms in identical production processes may differ but still faithfully represent the present stock of atmospheric GHGs embodied in the products. At the firm level, however, emissions are generally robust to the choice of a carbon allocation system. This is because individual allocations balance out across products and time periods.

To formally describe the emissions of firms, let the *Emission Stock*, $ES_{f,r}$, capture the present stock of atmospheric GHGs controlled by firm f at the end of reporting period r as a result of events and transactions. This stock metric is given by the cumulative sum of all direct, obtained, and transferred emissions and removals the firm has incurred until the end of period r. As such, the metric reflects the present stock of atmospheric GHGs embodied in the firm's operating assets.[20] In addition, let the *Controlled Net Emissions*, $CNE_{f,r}$, capture the change in the present stock of atmospheric GHGs controlled by firm f as a result of events and transactions in reporting period r. This flow metric is given by the sum of all direct, obtained, and transferred emissions and removals the firm has incurred in period r. Thus:

$$ES_{f,r} \equiv \sum_{t=1}^{r} \Bigg[\sum_{i \in D_{f,t}} x_i + \sum_{i \in O_{f,t}} y_i + \sum_{i \in T_{f,t}} z_i \Bigg], \tag{4}$$

$$CNE_{f,r} \equiv \sum_{i \in D_{f,r}} x_i + \sum_{i \in O_{f,r}} y_i + \sum_{i \in T_{f,r}} z_i, \tag{5}$$

or, equivalently, $ES_{f,r} = ES_{f,r-1} + CNE_{f,r}$, where $ES_{f,r=0} = 0$ by definition.[21]

Observation 2. *(i) The Emission Stock, $ES_{f,r}$, of firm $f \in F_r$ is relevant information and faithfully represents the present stock of atmospheric GHGs controlled by the firm at the end of reporting period r as a result of past events and transactions.*
(ii) The Controlled Net Emissions, $CNE_{f,r}$, of firm $f \in F_r$ is relevant information and faithfully represents the change in the present stock of atmospheric GHGs controlled by the firm as a result of events and transactions in reporting period r.

Observation 2 follows directly from the faithful representation of individual events and transactions. An immediate implication of Observation 2 is that $\sum_{f \in F_r} CNE_{f,r}$ faithfully represents the total net addition of GHGs to the atmosphere controlled by firms in F_r as a

[20] A firm's Emission Stock also reflects a lower bound on the present stock of atmospheric GHGs that will be embodied in future sales products throgh intertemporal accruals (Reichelstein, 2024).
[21] Companies seeking to report emissions from periods before $r = 0$ could provide separate estimates of the accumulated emissions until $r = 0$. See Section 3.4 for a broader discussion about estimated emissions.

result of events and transactions in period r. This is because each ton of CO_2e emitted or removed by firms in F_r is counted and reported only once and all transactions between firms in F_r cancel each other out by design. As a consequence, $\sum_{f \in F_r} CNE_{f,r}$ is exactly equal to the sum of all direct emissions and removals by firms in F_r, provided that firms in F_r only trade with each other.[22]

In closing this section, recall that the usefulness of carbon information about firm f is enhanced if it is comparable, verifiable, timely, and understandable. Comparability arises primarily because the unit of measurement is a ton of CO_2e actually emitted or removed. Verifiability obtains because the information is based on individual events and transactions, which, in turn, are verifiable through company records, site visits, and employee interviews. Timeliness should come from the firm's ability to build its carbon accounting on its financial accounting, and therefore maintain both sets of books in parallel. Finally, understandability obtains as the users of the firm's carbon information can directly see the present stock of atmospheric GHGs controlled by the firm at a given point in time and any changes that have occurred during the reporting period.

3.3 Performance Measurement

Companies worldwide have recently articulated net-zero pledges, in which they promise to achieve zero net emissions by some year in the future (Net Zero Tracker, 2023). Yet, the credibility of such pledges has remained controversial, in part due to the quality of the underlying measures of net emissions. Note that a firm's Controlled Net Emissions, $CNE_{f,r}$, will be equal to zero by construction if the firm transfers an equivalent amount of emissions to customers as it incurs in its operations and procurement in a given period. This condition arises, for example, if the firm has no emissions in its operating assets and sells all of its periodic output.

A common measure of corporate net emissions today is based on a firm's direct emissions. To introduce a corresponding metric in the context of the proposed framework, let the *Direct Net Emissions*, $DNE_{f,r}$, capture the change in the present stock of atmospheric GHGs

[22] Similarly, $\sum_{f \in F_r} ES_{f,r}$ faithfully represents the total net addition of GHGs to the atmosphere controlled by firms in F_r since reporting period $r = 0$. If furthermore firms in F_r only trade with each other, then $\sum_{f \in F_r} ES_{f,r}$ is exactly equal to the sum of all direct emissions and removals by firms in F_r since $r = 0$.

controlled by firm f as a result of events in period r. Formally:

$$DNE_{f,r} \equiv \sum_{i \in D_{f,r}} x_i. \tag{6}$$

This metric shows the progress firm f has made in decarbonizing its operations. Accordingly, $DNE_{f,r}$ will be equal to zero if the firm has been able to either reduce its direct emissions to zero in period r or generate removals at an amount equivalent to any remaining emissions.

$DNE_{f,r}$ is a crucial measure at the aggregate level, because $\sum_{f \in F_r} DNE_{f,r}$ effectively reflects the current damage, measured in tons of CO_2e, all reporting firms have contributed to the global climate.[23] When assessed over time, this sum also indicates the rate at which these companies are progressing toward a net-zero position.Yet, $DNE_{f,r}$ provides an incomplete picture of abatement progress at the level of individual firms. This is primarily because firms might reduce their direct emissions by outsourcing production processes and thus claim emission reductions without real changes to atmospheric GHGs.[24]

To introduce a more comprehensive metric, let the *Operating Net Emissions*, $ONE_{f,r}$, capture the total net addition of GHGs to the atmosphere embodied in the business operations of firm f in period r. This metric includes the firm's $DNE_{f,r}$ and all periodic obtained emissions and removals, less any transferred removals:

$$ONE_{f,r} \equiv DNE_{f,r} + \sum_{i \in O_{f,r}} y_i + \sum_{i \in T_{f,r}} \max\{z_i, 0\}. \tag{7}$$

$ONE_{f,r}$ shows the extend to which firm f has decarbonized its operations and procurement. As such, $ONE_{f,r}$ will be equal to zero if the firm has been able to either reduce its direct and obtained emissions to zero in period r or balance any remaining emissions with an equivalent amount of direct or obtained removals.

In addition to outsourcing, the definition in (7) also addresses the issue that removals are typically not causally linked to the provision of a firm's products. Such missing links leave firms with discretion in how they use removals. Some firms may primarily trade removals, that is, obtain and transfer removals without matching them to their emissions. The sum of all periodic direct and obtained emissions and removals, i.e., $\sum_{i \in D_{f,r}} x_i + \sum_{i \in O_{f,r}} y_i$ could

[23] Greenstone et al. (2023) estimate the damage to society from corporate emissions by multiplying companies' periodic direct emissions by different estimates of the social cost of carbon.

[24] Berg et al. (2023) find that large emitters have reduced emissions mainly by divesting from polluting assets.

then be zero and suggest that the firm has balanced its emissions with removals. Concerns about such greenwashing have led to calls for restrictive accounting treatments for removals. The metric defined in (7) offers an alternative to such restrictions by showing the extent to which firms actually use removals to balance their periodic emissions.

A firm's Operating Net Emissions are linked to its Controlled Net Emissions through the emissions transferred to customers. That is, $CNE_{f,r} = ONE_{f,r} + \sum_{i \in T_{f,r}} \min\{z_i, 0\}$. Given that a firm's $CNE_{f,r}$ is equal to zero if all periodic emissions are transferred, $CNE_{f,r}$ reflects the least stringent measure of the three measures of corporate net emissions. In contrast, $ONE_{f,r}$ is the most stringent and comprehensive measure. Companies serious about decarbonizing their businesses could thus substantiate their net-zero pledges by adopting $ONE_{f,r}$ as the measure of their periodic net additions of GHGs to the atmosphere.

Table 3 combines the three measures of corporate net emissions into one statement, where the mathematical operators indicate the directional impact of the line items on the cumulative sum across the table entries. This statement can be interpreted as the carbon accounting analog of a firm's cash flow statement. It shows the sources of the firm's periodic emissions and removals and how the firm manages them. Periodic disclosure of the carbon flow statement shows the progress made toward a particular target. Companies seeking to provide further detail can differentiate the line items in Table 3 by business unit, cost account, product line, or some other category. In particular, the side-by-side reporting of the statement by business unit with the line items differentiated by cost account would provide an overview of the distribution of emissions and removals across a firm.

Table 3. Corporate Net Emissions.

+	Direct Emissions
−	Direct Removals
=	**Direct Net Emissions**
+	Obtained Emissions
−	Obtained Removals
+	Transferred Removals
=	**Operating Net Emissions**
−	Transferred Emissions
=	**Controlled Net Emissions**

As part of the net-zero movement, many companies claim to be *carbon-neutral*, and some companies pledge to become *climate-neutral*. While different definitions of these terms cir-

culate, carbon neutrality typically describes the condition when all emissions from a firm's business operations in a particular reporting period are balanced by an equivalent amount of removals. In contrast, climate neutrality is increasingly used to describe the condition when all emissions from a firm's business operations since a reference date in the past, typically the firm's inception, are balanced by an equivalent amount of removals.[25]

Based on the preceding definitions, companies can back up their claims with specific disclosures. In particular, the business operations of firm f can be considered to have been *carbon-neutral* in period r if $ONE_{f,r} = 0$. Similarly, the business operations of firm f can be considered to have been *climate-neutral* since a reference period $\hat{r}$ for $1 \leq \hat{r} \leq r$ if $\sum_{t=\hat{r}}^{r} ONE_{f,t} = 0$. Clearly, climate neutrality emerges if the firm's business operations have been carbon-neutral in all respective periods. If the firm has exhibited positive $ONE_{f,r}$ in some periods, however, it can only achieve climate neutrality by attaining an equivalent cumulative amount of negative $ONE_{f,r}$ in other years.

Along with corporate climate pledges, companies are increasingly marketing their products as beneficial to the global climate. As a cumulative measure, the notion of climate neutrality readily applies to goods and services. The provision of product $p \in P_{f,r}$ of firm f can thus be considered to have been *climate-neutral* if $PCF_{f,p} = 0$. Note that a product line is climate-neutral if each product has a carbon footprint of zero. If the firm has either continuous emissions or emissions in operating assets used for the provision of this product line, then the firm will have to repeatedly direct or obtain an equivalent amount of removals.

3.4 Cross-boundary Trade

A central assumption in the preceding procedures has been that firms in F_r trade only with each other. As firms adopt the framework, however, most firms that have adopted the framework will, at least initially, trade mainly with firms that have not adopted the framework. Small firms and private individuals may potentially never adopt the framework. Some firms in F_r may even attempt to evade the stringency of the framework by engaging in trade with firms outside the set. This section considers the treatment and implications of trade across the boundary of the set, that is, between firms that have adopted the framework and those that have not.

[25] For example, technology companies like Microsoft (2023) and Google (2023) have set the more ambitious goal to remove all of their historical emissions from the atmosphere.

Consider first the case where firm $f \in F_r$ sells products to customers not in F_r. The same procedures and performance measurement then apply as described above for trading with customers in F_r. In particular, firm f transfers the control of the present stock of atmospheric GHGs embodied in the traded goods and services to its customers. Accordingly, the firm's Emission Stock, $ES_{f,r}$, and Controlled Net Emissions, $CNE_{f,r}$, decline (increase) whenever the aggregate carbon footprint of the traded goods and services is positive (negative). A key difference to before is that at the aggregate level $\sum_{f \in F_r} DNE_{f,r} - \sum_{f \in F_r} CNE_{f,r}$ now gives the total net addition of atmospheric GHGs caused by internal firms for products sold to external firms.

Suppose now that firm $f \in F_r$ purchases goods and services from external suppliers. The firm can then not rely on the carbon footprints of the resources, if provided by the suppliers, to faithfully represent the embodied present stock of atmospheric GHGs (Hafstead et al., 2022). At the same time, the firm is exposed to and shares responsibility for the incurred emissions. To account for this, the firm should estimate the present stock of atmospheric GHGs embodied in the procured goods and services. This estimation is conceptually the same as for upstream Scope 3 emissions described in Section 2. Yet, it requires additional guidelines to be complete, neutral, and free from error. Completeness requires the firm to account for all material steps of the exemplary production process assumed for the procured resources. Neutrality requires the firm to select input parameters without bias, for example, by using generally accepted activity measures and emission factors where available. And the free-from-error property requires the firm to assume an applicable exemplary production process and to select the corresponding activity measures and emission factors.[26]

The procedures for accounting for estimated atmospheric GHGs are entirely symmetric to those for actual atmospheric GHGs. In particular, firm f allocates estimated atmospheric GHGs to products based on the use of the underlying resources in the provision of the products. Upon selling these products, the firm transfers the control of the present stock of estimated atmospheric GHGs embodied in the traded products to its customers. The present stock of estimated atmospheric GHGs controlled by firm f as a result of past transactions thus increases and decreases in accordance with the firm's procurement and sale of the underlying economic resources.

[26]For example, carbon accounting software providers such as *Normative*, *Watershed*, and *Persefoni* have developed tools for estimating upstream Scope 3 emissions in different industries with decreasing specificity depending on the information a reporting company can provide.

Key to reporting estimated atmospheric GHGs is to identify them as such, because the difference between estimated and actual atmospheric GHGs has the capacity to influence decisions. For example, consider the possibility that the estimated carbon footprint of an input from an external supplier is lower than the actual carbon footprint of an otherwise equivalent input from an internal supplier. Some firms in F_r may then prefer to purchase the input from the external supplier in order to obtain lower emissions. Others may prefer to buy it from the internal supplier to signal a sense of trustworthiness to their stakeholders. Omitting the difference between actual and estimated atmospheric GHGs would therefore obscure material information.[27]

The separate accounting for actual and estimated atmospheric GHGs raises the question of when firms in F_r would achieve zero net emissions. Note that net-zero positions based on Direct Net Emissions would be unaffected by firms obtaining estimated atmospheric GHGs, because direct emissions and removals always reflect changes in the present stock of actual atmospheric GHGs. For the other performance measures above, firms in F_r would have to achieve net-zero positions in both books, that is, for actual and estimated atmospheric GHGs. To mitigate potential greenwashing concerns about any removals firms in F_r estimate to have obtained, the firms could limit themselves to obtaining only actual removals from suppliers in F_r. The firms would then achieve zero net emissions if they have been able to either reduce both actual and estimated emissions to zero in a given period or balance any remaining actual and estimated emissions with an equivalent amount of actual removals.

A common concern with regulatory programs, such as the European Emissions Trading System, is carbon leakage. Such leakage can occur when firms shift their production to jurisdictions outside the program.[28] In contrast, the proposed framework captures all direct and obtained emissions firms in F_r have controlled, regardless of jurisdiction. Some firms in F_r may outsource parts of their production to external firms to reduce the actual emissions they direct. Some firms in F_r may also loop purchases from suppliers in F_r through external firms to reduce the actual emissions they obtain. Either way, the firms in F_r will need to estimate the emissions embodied in the goods and services they purchase from external firms. While these estimates may be lower than the actual emissions in the procurement, their

[27] In line with this, the industry association Catena-X (2023) requires its members to disclose the share of primary, that is, supplier-specific data underlying their product or company emissions.

[28] To mitigate such leakage, the European Union has introduced the Carbon Border Adjustment Mechanism (European Union, 2024). This mechanism will charge companies for emissions embodied in the goods and services imported into the European Union, requiring reliable measures of product carbon footprints.

calculation is costly, and stakeholders may increasingly hold firms accountable by demanding reliable information on actual emissions.[29]

4 Discussion

4.1 Advantages of the Proposed Framework

The proposed framework offers several advantages over the current methodology of the GHG Protocol, particularly in its objective, substance, principles, and procedures. The objective for information reported under the proposed framework is to be *useful* to users in making decisions related to the firm. In contrast, the pervasive criterion for information reported under the GHG Protocol is to be a *true and fair account*. This criterion leaves unclear who the intended users are, what decisions they make, and what information they need to be able to make those decisions. Furthermore, a true and fair account is generally considered equivalent to a faithful representation as it results from information that is complete, neutral, and free from error (FASB, 2021; IASB, 2018). Yet, a faithful representation is inferior to decision-usefulness since information can be representationally faithful but irrelevant.

The substance of carbon information reported under the proposed framework is given as the present stock of atmospheric GHGs controlled by the reporting firm as a result of past events and transactions and the changes in this stock that have occurred in the reporting period. This stock is uniquely linked to the reporting firm and results from GHGs that have been emitted or removed. Under the GHG Protocol, the substance of information emerges implicitly as the emissions associated with the reporting firm. This substance focuses on the periodic flow of GHGs into the atmosphere that is somehow associated with the reporting firm. It ignores the stock of atmospheric GHGs that exists as a result of past flows into or out of the atmosphere. It also makes no distinction between past and future flows and lacks the notion of control that links a stock of atmospheric GHGs to the reporting firm.

The principles of the proposed framework reflect a comprehensive system of qualitative characteristics. Fundamental characteristics constitute the pervasive criterion, while enhancing characteristics improve the usefulness of carbon information. For the principles of the

[29] Some analysts have suggested that companies should be required to estimate emissions obtained from external suppliers based on the most carbon-intensive companies in the industry. While this approach could incentivize firms to buy from internal suppliers, it would conflict with the neutral depiction of embodied emissions.

GHG Protocol, it remains unclear how they constitute the pervasive criterion, how they relate to each other, and how they guide the procedures. The five principles also miss qualitative characteristics necessary for a faithful representation (i.e., neutrality and free from error), while they include characteristics that are not components of a faithful representation. In particular, relevance constitutes decision-usefulness together with a faithful representation. Consistency contributes to comparability, which enhances decision-usefulness. Transparency and accuracy are considered redundant as they follow from the qualitative characteristics completeness, neutrality, free from error, and understandability (FASB, 2021; IASB, 2018).

The definitions of the principles in the GHG Protocol are also somewhat mixed. The definition of relevance describes a faithful representation but not what constitutes relevant information. Completeness allows firms to choose their organizational and operational boundaries, enabling them to (unintentionally) omit emissions. The definition of consistency describes steps to improve understandability but not what constitutes consistency. Finally, the definition of transparency describes elements of verifiability and understandability, while the definition of accuracy includes aspects of neutrality. Yet, neither can be considered equivalent to the respective definitions in Section 3.1.

In terms of the main procedures, recall that under the GHG Protocol companies first choose their organizational and operational boundaries and then quantify both direct and indirect emissions. Companies have considerable discretion in selecting emission sources, activity measures, emission factors, and carbon allocation rules. Under the proposed framework, in contrast, organizational boundaries are set by existing financial accounting standards and operational boundaries are determined by the events and transactions in the economic activities of companies. To calculate corporate and product emissions, companies quantify direct emissions and removals, while they use information provided by their suppliers for obtained emissions and removals. Companies have limited discretion in these calculations because the parameters they can choose (i.e., emission factors and carbon allocation rules) should be generally accepted as neutral.

Advantages also show in the outcome variables. In the proposed framework, Product Carbon Footprints represent the total actual emissions and removals that products have accumulated from cradle to gate. These values include a share of the emissions and removals embodied in the operating assets and other shared resources used in the provision of the products. A firm's Emission Stock captures the present stock of atmospheric GHGs embodied

in the firm's operating assets. Three flow measures of corporate net emissions further capture the periodic net addition of GHGs to the atmosphere embodied in the firm's economic activity. Under the GHG Protocol, in contrast, companies estimate the life-cycle emissions of a product from cradle to grave. These values include estimates of potential downstream emissions but exclude emissions embodied in shared resources such as capital goods, overhead operations, and corporate services.[30] At the corporate level, companies estimate three types of periodic emissions (Scope 1–3). The GHG Protocol has not introduced a stock measure for atmospheric GHGs.

Despite the preceding differences, the outcome variables also share similarities that could support the adoption of the proposed framework. The total periodic direct emissions in a firm's corporate net emissions effectively reflect the firm's Scope 1 emissions (see Table 3). Similarly, the total periodic obtained emissions from procured energy include the firm's (market-based) Scope 2 emissions. With the help of their energy suppliers, companies could disaggregate these obtained emissions into their constituent components: emissions from generation (Scope 2) and emissions embodied in operating assets and general management. The remaining obtained emissions capture the firm's upstream Scope 3 emissions, which could also be disaggregated into the different categories of upstream Scope 3 emissions.[31] Initially, most obtained emissions will also likely be based on estimates by the reporting firm, similar to current practices. Yet, as more companies adopt the framework, reporting firms will increasingly be able to obtain reliable information on the actual emissions embodied in the goods and services procured from their suppliers.

From an incentive perspective, the proposed framework also creates incentives for real and continuous decarbonization. In particular, decision-useful carbon information enables investors and other stakeholders to monitor companies' emissions performance and hold them accountable for their climate claims and pledges. This stimulates managers to set more realistic emissions targets and to implement decarbonization measures that lead to actual reductions in atmospheric GHGs, because they can expect that the actual emissions achieved

[30] For example, alternative fuels like biomass are often credited with an emissions factor of zero because emissions from combustion are assumed to have been absorbed during plant growth. Yet, this ignores value chain emissions and has incentivized deforestation (Schlesinger, 2018). The proposed framework accounts for all removals from plant growth and all emissions embodied in the fuel, including those from harvesting, processing, transporting, and burning the biomass.

[31] The GHG Protocol differentiates upstream Scope 3 emissions into eight categories: purchased goods and services, capital goods, fuel and energy related activities, transportation and distribution, waste generated in operations, business travel, employee commuting, and leased assets (GHG Protocol, 2011a).

in each subsequent period will be compared to the chosen targets.[32] In addition, decision-useful carbon accounting allows managers to take full credit for any emission reductions they have achieved and to pressure suppliers to reduce the carbon footprint of the goods and services they provide (Chen and Pfeiffer, 2024). This is because every ton of atmospheric GHG avoided by a firm or its suppliers reduces the firm's reported net emissions and the carbon footprint of its products. Such incentives are lacking in current carbon accounting and reporting practices, where managers have considerable discretion in determining their emissions and upstream emissions are estimated based on industry averages.

A central concern of reporting frameworks is that the resulting benefits justify the costs. How the benefits of decision-useful carbon information relate to the costs of reporting that information will be an empirical question. Compared to the GHG Protocol, however, the proposed framework should result in greater benefits and lower costs. Greater benefits should result from a better understanding of a firm's emissions-related risks and opportunities, identifying leaders and laggards in climate action, and generally enabling stakeholders to make more informed decisions (SEC, 2024; European Union, 2023). For reporting firms, lower costs should result primarily from quantifying only direct emissions and from being able to build on financial accounting systems to process, verify, and disseminate carbon information. For stakeholders, lower costs should mainly result from the improved quality of the reported information (Esty et al., 2020).

4.2 Contributions to Earlier Work

Recent studies have proposed various methodological changes to current carbon accounting practices. For example, the *E-liability* approach of Kaplan and Ramanna (2021, 2022) argues that the transfer of emissions embodied in goods and services along the value chain could make reported emissions more reliable. I complement this work by proposing a comprehensive framework for how to characterize the quality of reported emissions and how companies should account for their emissions to produce decision-useful information. My analysis shows why the transfer of emissions along the value chain is necessary but insufficient for companies to faithfully represent the present stock of actual atmospheric GHGs embodied in their economic activity. Other necessary elements pertain to the measurement of direct emissions

[32] In other words, more precise carbon information enables investors and other stakeholders to act according to their impact and risk preferences (Friedman et al., 2021; Mahieux et al., 2023; Xue, 2023).

and the allocation of emissions to products. My analysis also suggests specific procedures for the treatment of trade across the boundary of the framework, which is critical to maintaining the quality of information as companies adopt the framework.

Reichelstein (2024) and Penman (2024) have introduced accrual accounting systems for corporate emissions, arguing that such systems provide more information about a firm's emissions performance over time. As with financial accounting, accrual accounting for corporate emissions and decision-useful carbon accounting are essentially different, interdependent parts of the same machine. Core to both is the separation of corporate emissions into stock and flow variables. Reichelstein (2024) focuses on the preparation of emission statements (i.e., a balance sheet and a flow statement) and the flow of emissions within a firm, facilitating the intertemporal and cross-sectional allocation of emissions to products. This paper focuses on the quality of reported emissions and the flow of emissions between firms, facilitating that carbon allocations and other procedures faithfully represent what they purport to represent.

As a result of the complementarity, outcome variables in Reichelstein (2024) and this paper are also conceptually related. For example, Reichelstein (2024) has introduced a metric called *Carbon Emissions in Goods Sold* to capture the total emissions and removals embodied in a firm's products sold in a given period. In the context of the proposed framework, the Carbon Emissions in Goods Sold by firm f in period r, denoted by $CEGS_{f,r}$, are given by the sum of all transferred emissions and removals:

$$CEGS_{f,r} \equiv \sum_{i \in T_{f,r}} z_i, \tag{8}$$

where $\sum_{i \in T_{f,r}} z_i = \sum_{p \in P_{f,r}} PCF_{f,p}$ if the firm sells all products in $P_{f,r}$ in period r. The main difference between a firm's $CEGS_{f,r}$ and $ONE_{f,r}$ is that $CEGS_{f,r}$ is an accrual measure of the emissions and removals attributed to the products sold in a period. In contrast, $ONE_{f,r}$ is a flow measure of the firm's periodic direct and obtained emissions and removals less transferred removals. The two measures are linked by the firm's Emission Stock, $ES_{f,r}$. Accordingly, it may be that $CEGS_{f,r} = 0$ while $ONE_{f,r} > 0$ if the firm's $ES_{f,r}$ is increasing ($CNE_{f,r} > 0$), for example due to inventory build-up. Alternatively, the two measures are identical if the firm has no removals and no emissions embodied in operating assets.

Other studies have suggested improvements to individual aspects of corporate carbon disclosures. Brander et al. (2021) have suggested that companies adopt a "reality principle"

to report emissions when and where they occur. Comello et al. (2023) have argued that corporate carbon reporting will be more comparable and consistent over time if companies provide initial forecasts of their emissions, periodic revisions of earlier forecasts, and updates on emissions reductions achieved. Distler et al. (2024) have suggested adding emissions to financial transactions and using the same accounting rules for financial and emission information. Fankhauser et al. (2022) and Bjørn et al. (2021) have proposed different ways to make net-zero targets more credible. This paper unifies and extends these earlier proposals by offering a comprehensive framework of carbon accounting rules derived from generally accepted financial accounting standards. This framework incorporates a reality principle without imposing a location requirement, as changes in atmospheric GHGs will be recognized by the controlling firm as they occur. Companies adhering to the framework will also produce information that is comparable and consistent not only over time but also across firms.

Finally, some previous research has argued for reporting only direct emissions to keep the associated costs low and encourage more companies to report (Bolton et al., 2021). Furthermore, if every company in the world were to report its direct emissions, all corporate emissions would be accounted for. Critics of this approach point out that far from all companies worldwide are likely to report their emissions in the near future. This, in turn, creates incentives for reporting firms to outsource emission-intensive production activities. Consistent with these concerns, both companies and regulators have been moving toward more comprehensive carbon reporting in recent years. Yet, much of the proposed framework would still be applicable if the focus of reporting were to shift to direct emissions only.

4.3 Policy Implications

Recognizing the potential of carbon information, standard-setters worldwide have recently introduced regulations for corporate carbon accounting and reporting. In January 2023, the European Union (EU) enacted the Corporate Sustainability Reporting Directive, which requires companies, beginning in fiscal year 2024, to provide sustainability disclosures, including information on corporate emissions, that are *relevant* and *faithfully represent* the underlying sustainability matters (European Union, 2023). The definitions of these principles are generally consistent with those in Section 3.1. Yet, the substance of the reported information is much broader, covering any emissions associated with the reporting firm. In terms of how companies should determine and report their emissions, the EU has largely

adopted the procedures of the GHG Protocol. Yet, the EU requires companies to set their organizational boundaries according to financial reporting standards, disclose their Scope 3 emissions, and use emission factors from the European Emissions Trading System to calculate their Scope 1 and 2 emissions.

In June 2023, the International Sustainability Standards Board (ISSB) published two standards, according to which companies should provide sustainability-related information, including information on corporate emissions, that is *decision-useful* to investors (ISSB, 2023b,a). The principles constituting decision-useful information are broadly consistent with those in Section 3.1. Yet, the primary focus of the reported information is to facilitate investment decisions, and the substance of the information includes any emissions associated with the reporting firm. Similar to the EU, the ISSB has largely adopted the procedures of the GHG Protocol. In particular, the ISSB allows companies to choose their organizational boundaries and the emission factors used to determine their emissions, whereby companies are required to disaggregate their Scope 1 and 2 emissions into those referable to the consolidated financial accounting group and those referable to other portfolio companies. The ISSB also requires companies to disclose their Scope 3 emissions.

In March 2024, the Securities and Exchange Commission (SEC) in the United States issued a final rule requiring companies, beginning in fiscal year 2025, to provide climate-related disclosures, including information on corporate emissions, that are *decision-useful* to investors (SEC, 2024). While the SEC has not specified what constitutes decision-useful information on corporate emissions, it has adopted most procedures of the GHG Protocol. In particular, the SEC allows companies to choose their organizational boundaries and whether to disclose their Scope 3 emissions. Similar to the EU, the SEC requires companies to use emission factors from the U.S. Environmental Protection Agency to calculate their Scope 1 and 2 emissions.

The analysis in this paper shows that all three organizations could adopt the proposed framework to facilitate that reported information on corporate emissions will indeed be decision-useful. In particular, the SEC could specify what constitutes decision-useful carbon information. The EU and the ISSB could improve the quality of reported information by including the notion of control that links atmospheric GHGs to a firm and distinguishing between past and future, actual and estimated atmospheric GHGs. The SEC and the ISSB could facilitate the completeness of reported emissions by aligning the setting of organiza-

tional boundaries with financial reporting standards. All three organizations could adopt the approach of accounting for emissions and removals embodied in goods and services firms obtain through trade. They could also work with industry associations to define acceptable carbon allocation rules for different industries. Finally, the ISSB could facilitate the neutrality of direct emissions by specifying acceptable emission factors.

In addition to the Corporate Sustainability Reporting Directive, the EU has adopted a Directive on Green Claims that seeks to prevent companies from making misleading claims about environmental merits of their products (European Commission, 2023b). In particular, the regulation seeks to ensure that companies wishing to market environmental benefits of their products substantiate their claims with *reliable*, *comparable*, and *verifiable* information, based as far as possible on company-specific data. Companies seeking to comply with this regulation regarding their GHG emissions could use the framework proposed in this paper to faithfully represent the emissions and removals embodied in their goods and services. This could be particularly useful for substantiating explicit claims, such as the climate-neutral provision of individual products.

Central to the above regulations is the requirement that climate-related claims and disclosures be verified by third-party auditors. In particular, the EU and the SEC require companies to obtain at least limited assurance on their corporate carbon disclosures from external auditors (European Union, 2023; SEC, 2024). This lower bound is scheduled to rise to reasonable assurance, the level expected for financial audits, over the coming years. Because the carbon accounting framework in this paper is based on financial accounting standards, auditors should be able to verify both product and corporate carbon disclosures. The transactional design of the framework should also allow auditors to provide reasonable assurance, even for upstream emissions companies obtain through trade (Distler et al., 2024).

5 Concluding Remarks

Companies worldwide are increasingly striving to mitigate their climate impacts and risks by lowering their greenhouse gas emissions. Current carbon accounting practices specified in the GHG Protocol, however, often obscure firms' actual emissions and abatement progress, limiting firms and their stakeholders in making decisions according to their impact and risk preferences. This paper has first used the conceptual framework of financial accounting standards as a template for characterizing the quality of corporate carbon information. It

has then combined measurement approaches from the GHG Protocol with accounting rules from historical cost accounting to show how companies should account for their emissions to produce outcome variables that are relevant and faithfully represent the actual emissions embodied in their economic activities.

Aware of methodological issues, the GHG Protocol organization has recently initiated a revision of its standards and guidelines that is to conclude in 2026 (GHG Protocol, 2024a). It has also launched a partnership with the IFRS Foundation that aims to guide collaboration between the GHG Protocol and the ISSB and ensure that reported information meets the needs of capital markets (GHG Protocol, 2024b). This paper has shown how standard-setters could revise carbon disclosure regulations to facilitate that reported information will be decision-useful to investors and other stakeholders of reporting firms. Since the proposed framework builds on the GHG Protocol and financial accounting standards, reporting firms should face no significant conceptual barriers in adopting the framework. Moreover, because the proposed framework also enables firms to faithfully represent their Scope 1, 2, and upstream 3 emissions, their carbon reporting could remain compliant with current carbon disclosure regulations during a general transition period.

This paper offers several avenues for further research.[33] One promising extension is to broaden the range of decisions made by users of carbon information to include emissions associated with the use of a firm's products. Firms can often influence the rate at which such downstream emissions occur through product design, though they can only estimate the future materialization of these emissions. It would also be instructive to extend the accounting rules in this paper to the consolidation of emissions across a firm's subsidiaries. Such consolidation would need to address the risk of omission or double counting of emissions from entities jointly owned by multiple parent companies. Finally, future work in this line of research could develop accounting rules for carbon offsets that only avoid emissions or temporarily remove GHGs from the atmosphere. Companies could still recognize removals that are partially reversed within a foreseeable time frame, provided that any reversal or replacement with new removals would also also be included in subsequent disclosures.

[33]Future work could also coordinate the alignment between carbon and financial accounting standards as both evolve.

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