Corporate Carbon Accounting: Current Practices and Opportunities for Research

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February 2025

*I am grateful to Stefan Reichelstein, Thorsten Sellhorn, Christian Stoll, colleagues at the University of Mannheim, and seminar participants at the TRR 266 Annual Meeting for helpful discussions and comments. Financial support for this study was provided by the German Research Foundation (Project-ID 403041268, TRR 266).

Abstract

This article reviews current practices in corporate carbon accounting and highlights opportunities for future research. The common framework for determining and reporting corporate greenhouse gas (GHG) emissions today is the GHG Protocol. Like financial accounting standards, this framework includes overarching objectives, principles for conceptual guidance, and procedures for determining key outcome variables. Their design and implementation, however, often result in disclosures that obscure firms' actual emissions and decarbonization progress. Recognizing the growing demand for transparency, standard-setters worldwide have recently introduced regulations for carbon accounting and reporting. These regulations require companies to disclose decision-useful information on their emissions. Yet, they have also largely adopted the GHG Protocol for how companies should determine and report their emissions. Accounting scholars now have the opportunity to develop solutions that will make corporate carbon accounting an effective tool in combating climate change.

Keywords: carbon accounting, corporate emissions, sustainability reporting
JEL Classifications: M41, M48, Q54, Q56

1 Introduction

"It's accounting tricks," industry analysts have commented on Apple's claim that its Watch Series 9 is "carbon neutral" (Bryan, 2023). Like Apple, companies around the world have pledged to reduce their greenhouse gas (GHG) emissions to net zero and begun reporting on their progress toward these pledges (Net Zero Tracker, 2023). While such efforts have been recognized as crucial in the global effort to mitigate climate change (IPCC, 2023), analysts have argued that current practices in corporate carbon accounting obscure firms' actual emissions.[1] This lack of transparency, in turn, undermines decision-making by managers, investors, and other stakeholders and ultimately impairs the environmental and financial performance of firms (SEC, 2024; European Union, 2023).

This paper reviews current practices in corporate carbon accounting, synthesizes observations from a financial accounting perspective, and highlights opportunities for research. The common framework for determining and reporting corporate emissions today is the GHG Protocol (2004). Like financial accounting standards, this framework includes overarching objectives, 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 are recommended to 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 can estimate their indirect emissions based on industry averages.

Observations on the methodology of the GHG Protocol mainly pertain to the lack of core features of an accounting system. In particular, the GHG Protocol lacks proper definitions of the purpose and elements of corporate carbon reporting, resulting in the objectives, principles, and procedures being somewhat vague and incoherent. It also establishes no clear attribution of emissions to firms, leading firms along a value chain to estimate and report the same emissions multiple times. It further does not distinguish between actual and estimated

[1] In the United States, companies such as Delta Airlines have been sued for making misleading climate claims. In Europe, the European Commission (2023) has passed a directive aimed at preventing unsubstantiated claims about the environmental benefits of products.

or past and future emissions, causing companies to aggregate different emission measures. In addition, it grants companies considerable discretion in selecting parameters for calculating their emissions, often resulting in reported emissions that are biased, incomplete, and difficult to compare (e.g., Bjørn et al. (2022); Klaaßen and Stoll (2021)).

Observations on the implementation of the GHG Protocol stem from the fact that most companies lack robust information systems for carbon accounting. As a result, they often face gaps in the data needed to calculate their emissions, while their information processing is prone to errors, manipulation, and inconsistencies (Gipper et al., 2024b). Overall, current practices in corporate carbon accounting lead to a fragmented reporting landscape, with carbon disclosures varying in form and content across firms, periods, and reporting channels (Jia et al., 2023; Depoers et al., 2016). They also limit the assurance level companies obtain for their carbon disclosures, as auditors most often provide only *limited assurance*, meaning that no evidence of misreporting has come to their attention (Gipper et al., 2024a; Berg et al., 2024a). They further distort incentives for real decarbonization, mainly because they restrict managers from taking credit for actual emissions reductions and limit investors and other stakeholders in holding firms accountable for their climate pledges (Mahieux et al., 2024; Xue, 2024).

In response to growing calls for transparency, standard-setters worldwide have recently introduced regulations for corporate carbon accounting and reporting.[2] These regulations require firms to disclose decision-useful information on their emissions. 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 suggests that these regulations will improve the quality of carbon disclosures, mainly by reducing the discretion companies have in calculating their emissions and by requiring companies to obtain external assurance. Yet, it also shows how standard-setters could revise their regulations to facilitate that reported information on corporate emissions will indeed become decision-useful.

Accounting scholars now have the opportunity to make corporate carbon accounting an effective tool for mitigating climate change. In particular, they could contribute to the development and emergence of generally accepted carbon accounting principles. They could study the adoption of such principles and their impact on corporate practices, reported

[2]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).

emissions, and stakeholder responses. And they could examine the interaction between corporate carbon accounting and climate regulation, such as carbon pricing. For corporate carbon accounting to become effective fast enough to have a material impact on climate change, accounting scholars could work with other actors in the field. For example, they could collaborate with environmental scientists to ensure the rigor of the accounting principles, work with businesses to develop practical solutions, and engage with standard-setters to keep standards aligned with the latest research. In particular, they could contribute to the ongoing revision of the GHG Protocol.

This paper contributes to the emerging literature on corporate carbon accounting. One line of work has proposed methodological changes to current practices.[3] For example, Kaplan and Ramanna (2021, 2022) have proposed that companies transfer the emissions embodied in products along the value chain to make reported emissions more reliable. Reichelstein (2024) and Penman (2024) have introduced accrual accounting systems that provide more information about a firm's emissions performance over time. Other studies have proposed improvements to individual aspects of corporate carbon disclosure, including the accuracy (Brander et al., 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). This paper adds to this research by providing a systematic review of limitations in current practices that could be addressed in future research.

Another 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), and mandatory disclosure regulation (Downar et al., 2021; Tomar, 2023). This paper contributes to this research by highlighting limitations in the quality of the emissions data used in most empirical studies on the topic. It also offers several opportunities for more detailed analysis of corporate carbon accounting, reporting, and management.

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

2 The GHG Protocol

Greenhouse Gas Protocol is an initiative managed by the World Resources Institute and the World Business Council for Sustainable Development that seeks to provide standards for measuring and managing the emissions of public and private organizations. Since its launch in the late 1990s, the initiative has published a range of guidance documents that have been widely adopted by organizations around the world.[4] For private organizations, these documents describe how firms should determine and report the emissions associated with their operations, products, and supply chain, as well as the emissions avoided or removed through mitigation projects. My analysis will focus on these corporate guidelines and, in keeping with common practice, will refer to them as *the* GHG Protocol.[5]

The GHG Protocol includes several components. One key component is the definition of overarching objectives. These objectives are stated in several documents, usually without detail as to their interpretation or relationship to other components. While the objectives vary slightly across documents, the most comprehensive are arguably those in the so-called *Corporate Standard* (GHG Protocol, 2004). These objectives are:

- *"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,*
- *To simplify and reduce the costs of compiling a GHG inventory,*
- *To provide business with information that can be used to build an effective strategy to manage and reduce GHG emissions,*
- *To provide information that facilitates participation in voluntary and mandatory GHG programs,*
- *To increase consistency and transparency in GHG accounting and reporting among various companies and GHG programs."*

Another central component is the definition of principles. Similar to generally accepted financial accounting principles, the principles of the GHG Protocol are intended to provide conceptual guidance for the accounting and reporting of emissions by defining qualitative

[4]For example, 92% of the Fortune 500 companies that reported their emissions through the Carbon Disclosure Project in 2016 determined their emissions based on the GHG Protocol (GHG Protocol, 2024).
[5]Much of this paper is based on Glenk (2024).

characteristics of reported information. 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). Similar to the objectives, the GHG Protocol leaves somewhat open how the principles should be interpreted, how they relate to each other, and how they relate to the other components.

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.

A third and extensive component is the description of procedures for determining and reporting emissions. These procedures 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. 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.[6] The GHG Protocol requires companies to disclose

[6]Scope 3 emissions are divided into eight categories of upstream emissions (i.e., purchased goods and services, capital goods, fuel- and energy-related activities, transportation and distribution, waste generated in

their Scope 1 and 2 emissions, while reporting Scope 3 emissions is optional.

The third step is to calculate emissions. For corporate emissions, companies should first identify all emission sources within the chosen boundaries, then multiply an activity measure by a corresponding emission factor for each emission source, and finally aggregate the resulting estimates. While the GHG Protocol describes this calculation mostly verbally and through examples, it will be helpful 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, where 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).[7] The total Scope s emissions in a given reporting period of a company with no subsidiaries, denoted by CE_s, are then given by:

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

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, a company should then multiply the calculated emissions from each source by the share attributed to the product. Let $\alpha_{i,p} \in [0, 1]$ denote the share of emission source i the company chooses to attribute to product $p \in P$, where P reflects the set of final products the firm produces in a given period. The cradle-to-grave emissions of product p produced in a particular reporting period, denoted by PE_p, are then given by:

$$PE_p \equiv \sum_{s=1}^{3} \sum_{i \in I_s} \alpha_{i,p} \cdot q_i \cdot e_i. \tag{2}$$

operations, business travel, employee commuting, and leased assets) and seven categories of downstream emissions (i.e., transportation and distribution, processing of sold products, use of sold products, end-of-life treatment of sold products, leased assets, franchises, and investments) (GHG Protocol, 2011a).

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

In the calculations above, the GHG Protocol recommends different data inputs depending on the emissions scope. For Scope 1 emissions, activity measures are recommended to be physical quantities, such as liters of fuel consumed. Emission factors can then be determined by the chemical composition of the substances consumed in the emission process. The physical quantities should be obtained from company records, and the emission factors from public databases. Examples of recognized sources of emission factors include the European Emissions Trading System, the US Environmental Protection Agency, the UK Department of Food and Rural Affairs, and the International Energy Agency.

For Scope 2 emissions, activity measures should be the kilowatt-hours of the different types of energy consumed. Emission factors should be determined in two ways: (i) based on the average emission intensity of the grid where the energy is consumed (location-based method) and (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 in 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 can 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 estimated based on life-cycle assessments of the underlying activity and third-party data sources.[8]

While this paper focuses on the preceding components, the GHG Protocol also provides guidance on other topics. For example, to track emissions over time, companies are required to select a base year against which their future emissions will be compared. Whenever significant changes occur, such as acquisitions and divestments, they are to recalculate their historical emissions since the base year to reflect these changes. This approach is intended to maintain consistency over time (GHG Protocol, 2004). Another example is the compensation of emissions through carbon offsets purchased on the voluntary carbon market. Carbon

[8] 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.

offsets are certificates of the avoidance or removal of GHGs through mitigation projects, such as reforestation, prevented deforestation, deployment of renewable energy, or installation of direct air capture technologies (Allen et al., 2024). The GHGs compensated through a project are calculated as the difference between the emissions associated with the project and a hypothetical baseline of what the emissions would have been without the project. In this calculation, project developers need to make a compelling argument that their project is additional and not the baseline itself (GHG Protocol, 2005, 2023).

Information on the implementation of the GHG Protocol at companies remains scarce, but there are some patterns. For example, larger companies often have dedicated sustainability teams to collect data from different business units and prepare emissions reports. These teams have often been located in the firms' marketing departments but are now increasingly located in finance and accounting departments. Smaller companies typically hire external consultants to determine their emissions and prepare their emissions reports. Most firms still rely primarily on Microsoft Excel and surveys to collect the data, make the necessary calculations, and prepare the emissions reports. Yet, recent years have seen a proliferation of new software solutions, often provided by early-stage companies, that promise a highly automated estimation of corporate emissions.

3 Observations on the GHG Protocol

Stakeholders of many global companies are calling for better information about the firms' emissions. A key concern is that current practices for determining and reporting emissions often obscure a firm's actual emissions and abatement progress. This lack of transparency is argued to undermine decision-making by limiting managers, investors, and other stakeholders 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). This section synthesizes observations on the GHG Protocol from a financial accounting perspective, focusing on ways in which its methodology and implementation contribute to this lack of transparency.

3.1 Observations on the Methodology

Perhaps the first point to note is that the GHG Protocol lacks a proper definition of the purpose of corporate carbon reporting. While the GHG Protocol outlines objectives, these are more reflective of the initiative's rationale for providing the guidelines than the purpose of reporting itself. In contrast, the purpose of financial reporting is to provide financial information about the reporting firm that is *useful* to investors in making decisions about providing resources to the firm.[9] The authors of the GHG Protocol may have sought to avoid *decision-usefulness* as the pervasive criterion due to the challenge of identifying the different users of carbon information, the decisions they make, and the information needs they have. But this omission leads to the problem observable today that stakeholders of many companies are demanding more useful information about the firms' emissions.

Another gap in the GHG Protocol is the lack of a definition of the elements of corporate carbon reporting. Core to financial accounting standards is the detailed definition of assets and liabilities. Changes in these stock variables over the reporting period further lead to the definitions of the flow variables revenues, expenses, gains, and losses. The GHG Protocol effectively focuses on the flows of GHGs into or out of the atmosphere associated with the reporting firm in the reporting period. These flows may have occurred in the past or may be expected to occur in the future. However, some past emissions may be embodied in the firm's operating assets and could therefore be better represented by stock variables (Reichelstein, 2024). Other past emissions may be embodied in goods and services purchased by the firm in one period but received in another. Such emissions could be better represented by different flow variables. The lack of distinction between different stock and flow variables obscures the causal and temporal relationship between the firm's emissions and its underlying economic activity and thus limits the depiction of the firm's periodic carbon performance.[10]

A central aspect of the definition of assets and liabilities in financial accounting standards is a notion of control that establishes a unique attribution of an asset or liability to the reporting firm and no other party. The GHG Protocol lacks such a notion of control, which

[9] The third objective of the GHG Protocol quoted in Section 2 goes in the direction of decision-usefulness, while the first objective includes that companies provide a *true and fair account* of their emissions. In financial accounting, a *true and fair account* is generally considered equivalent to a *faithful representation*, which together with *relevance* constitutes *decision-usefulness* (FASB, 2021; IASB, 2018).

[10] Because of this lack of distinction, analysts have argued that the GHG Protocol reflects more a classification than an accounting framework, where reporting firms estimate the emissions associated with their economic activity in a given period and merely classify them into three scopes.

uniquely links emissions to the reporting firm. Instead, emissions are estimated separately and reported multiple times by different companies along the value chain. The GHG Protocol recognizes double counting as an attempt to capture the shared responsibility within the supply chain (GHG Protocol, 2004). But shared responsibility can often lead to collective irresponsibility in the form of inaction or omissions of emissions. 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 operators of such incinerators note that they no longer burn the waste.

The principles of the GHG Protocol also fall short of their potential. In financial accounting, a comprehensive system of qualitative characteristics constitutes the pervasive criterion of reported information and provides conceptual guidance for the accounting of individual economic phenomena. As such, the characteristics serve as a link between the purpose of financial reporting and the procedures producing the reported information. In particular, for financial information to be *decision-useful*, it must be *relevant* and *faithfully represent* what it purports to represent, where a *faithful representation* requires information to be *complete*, *neutral*, and *free from error* (FASB, 2021; IASB, 2018). Either irrelevance or unfaithful representation results in information that is not *decision-useful*. The usefulness of financial information is enhanced if it is *comparable*, *verifiable*, *timely*, and *understandable*. These characteristics improve the usefulness of information, but they cannot make information *relevant* or a *faithful representation*.

In the GHG Protocol, the principles are detached from a purpose of corporate carbon reporting. By way of their selection and definition, they can also provide only limited guidance for the procedures of the GHG Protocol. For example, the qualitative characteristics lack *faithful representation*, though the definition of *relevance* is more descriptive of a *faithful representation* than of what constitutes *relevant* information. Meanwhile, the qualitative characteristics include *completeness*, typically a component of *faithful representation*, yet its definition allows companies to choose their organizational and operational boundaries, enabling them to (inadvertently) omit emissions. *Transparency* and *accuracy* are generally considered redundant as they follow from characteristics such as *completeness*, *neutrality*, *free from error*, and *understandability* (FASB, 2021). The definition of *transparency* then includes aspects of *verifiability* and *understandability*, while the definition of *accuracy* in-

cludes aspects of *neutrality*. Yet, neither of these definitions can be considered equivalent to the respective ones in financial accounting (FASB, 2021; IASB, 2018).

The procedures for determining and reporting emissions under the GHG Protocol give rise to several observations. First, they allow companies to choose their organizational and operational boundaries and thus the set of emission sources I_s they consider. As a result, companies can provide an incomplete depiction of their emissions by strategically choosing the boundaries. 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.

Second, the procedures grant companies considerable discretion in choosing the activity measures q_i and emission factors e_i used to estimate their emissions. As a consequence, companies can bias the depiction of their emissions and shape stakeholder perceptions by choosing favorable input parameters. Previous research has found that firms have systematically reported lower emissions in corporate sustainability reports than through the Carbon Disclosure Project (Klaaßen and Stoll, 2021; Depoers et al., 2016). However, evidence of managers manipulating emissions, for example by cherry-picking emission factors, has not been documented (Bingler et al., 2022; Downie and Stubbs, 2012).

Third, the procedures do not distinguish between actual and estimated emissions. Yet, Scope 1 emissions identified based on the physical quantities and chemical composition of the substances consumed in the emission process arguably reflect the actual addition of GHGs to the atmosphere that has occurred. Scope 2 and upstream Scope 3 emissions calculated based on exemplary production processes and industry averages can only reflect an estimate of the actual emissions embodied in the procured goods and services.[11] Downstream Scope 3 emissions, by construction, reflect an estimate of the emissions that are expected to occur in the future. This lack of distinction makes it difficult to assess whether reported emissions are free from error. It also obscures a firm's actual contribution to climate change, as well

[11] In principle, Scope 2 and upstream Scope 3 emissions identified recursively based on the direct emissions of suppliers in the value chain could reflect the actual cradle-to-gate emissions embodied in the procured goods and services (Kaplan and Ramanna, 2021; Reichelstein, 2024).

as financial risks and opportunities resulting from the firm's emissions.[12]

3.2 Observations on the Implementation

Unlike for financial accounting, most companies lack robust information systems for carbon accounting. As a result, they often face gaps in the data needed to determine their emissions (Gipper et al., 2024b). Data gaps often arise because physical quantities of production inputs are either not recorded or not provided when requested through surveys. A common approach to addressing data gaps is to approximate emissions based on the monetary values of samples of production inputs. For example, direct emissions from vehicles are often approximated by dividing fuel expenditures from representative business days by the average fuel price and multiplying the result by the carbon intensity of the fuel. It is, therefore, not uncommon for direct emissions to be estimated when they could be calculated to reflect actual emissions if firms had robust information systems in place.

In addition to the data gaps, information processing is prone to errors, manipulation, and inconsistencies. Errors easily result from manual data entry and aggregation, incorrect Excel formulas, and incorrect or outdated emission factors (Gipper et al., 2024b). Manipulation may arise when managers exploit the discretion granted in the GHG Protocol in choosing boundaries and input parameters for determining emissions. Inconsistencies often occur when different people within a company work on different emissions using different Excel files. For example, a firm's total periodic emissions calculated as the sum of all emission scopes resulting from equation (1) should be exactly equal to the sum of all product emissions calculated according to equation (2), provided that any overhead emissions are attributed to products. That is:

$$\sum_{s=1}^{3} \sum_{i \in I_s} q_i \cdot e_i = \sum_{p \in P} \sum_{s=1}^{3} \sum_{i \in I_s} \alpha_{i,p} \cdot q_i \cdot e_i, \tag{3}$$

because for each emission source i, the allocation shares $\alpha_{i,p}$ should add up to one across all products (i.e., $\sum_{p \in P} \alpha_{i,p} = 1$ for every $i \in I_s$). Yet, this identity rarely holds in practice, because corporate and product emissions are often calculated in separate workflows.

The preceding issues have several implications. First, they lead to a fragmented landscape of corporate carbon reporting. For example, the form and content of carbon disclosures prepared under the GHG Protocol vary widely across firms, periods, and reporting channels,

[12] To mitigate these issues, industry associations such as Catena-X (2023) require their member companies to disclose the share of supplier-specific data included in their product or company emissions.

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).

Second, the issues limit the assurance level companies obtain for their carbon disclosures. Like financial audits, carbon audits involve external auditors checking samples of reported data against source data, interviewing personnel, performing site visits, and reviewing the reporting firm's information systems. Over the past decade, more than 50% of S&P 500 companies disclosing corporate emissions have sought verification from external auditors (Gipper et al., 2024a). In about 90% of the cases, however, auditors could only provide *limited assurance*, meaning that no evidence of misreporting has come to their attention. Such verification is much weaker than *reasonable assurance*, which confirms that a firm's emissions are fairly represented and reflects the assurance level required for financial information. Nonetheless, even if audits result in limited assurance, they have helped companies improve the quality of their carbon disclosures by reducing omissions and correcting errors (Gipper et al., 2024b; Berg et al., 2024a).

Third, the issues distort incentives for real decarbonization. The general rationale for corporate carbon reporting is that stakeholder responses to the reported information curb the polluting behavior of the reporting firms. Yet, this mechanism hinges on the reliability or precision of the reported information (Mahieux et al., 2024; Xue, 2024). In particular, less precise information limits investors and other stakeholders in their ability to assess firms' carbon performance and hold them accountable for their climate claims and pledges. This stimulates managers to set less realistic emissions targets and implement decarbonization measures that are less effective in reducing actual atmospheric GHGs (Berg et al., 2024b), because they expect that the chosen targets will only be compared to imprecise estimates of their emissions in future periods. In addition, less precise information limits managers in taking credit for emissions reductions and pressuring suppliers to reduce the carbon footprint of the goods and services they provide. This is because managers have considerable discretion in determining their emissions, and upstream emissions are typically estimated based on industry averages.

4 Carbon Disclosure Regulation

Recognizing the growing demand for transparency, 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, requiring companies, beginning in fiscal year 2024, to provide information on corporate emissions and other sustainability matters that is *relevant* and *faithfully represents* the underlying phenomena (European Union, 2023). The definitions of these qualitative characteristics are generally consistent with those in financial accounting standards. Yet, the EU has avoided specifying the users of the reported information, their decisions, and their information needs. Accordingly, the scope of information to be reported is broad and covers 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 their financial reporting, 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) issued a reporting standard, according to which companies should provide sustainability-related information, including information on corporate emissions, that is *decision-useful* to investors (ISSB, 2023b,a). The objective and the system of qualitative characteristics in the standard are generally consistent with those in financial accounting standards. Yet, similar to the EU, the ISSB has largely adopted the procedures of the GHG Protocol. In particular, the ISSB leaves companies full discretion 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 detailed what constitutes decision-useful information on corporate emissions, it has adopted most procedures of the GHG Protocol. In particular, the SEC leaves companies full discretion 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 suggests that the regulations will improve the availability and quality of corporate carbon disclosures. Quality improvements should partly result from methodological changes such as limiting the discretion of firms to choose their organizational boundary or the emission factors for calculating their Scope 1 and 2 emissions. Improvements should also result from better implementation of the GHG Protocol. In particular, both the EU and the SEC require companies to obtain at least limited assurance on their carbon disclosures from external auditors (European Union, 2023; SEC, 2024).[13] External verification should help companies reduce gaps, errors, and inconsistencies in their data and calculations. In addition, the implementation should become more harmonized across firms with respect to the form, timing, and supplementary information of the disclosures. This should make the reported emissions more comparable, timely, and understandable, at least within the jurisdiction in which a given regulation applies.

At the same time, the analysis shows that all three standard-setters could revise their regulations to facilitate that corporate carbon disclosures will indeed become decision-useful. To begin with, they could clarify the primary users of carbon information, the decisions they make, and the information on corporate emissions they need to make these decisions. They could also clarify the elements of corporate carbon reporting and adopt a double-entry accounting system for corporate emissions that distinguishes between different stock and flow variables. Such an accounting system could also introduce a notion of control, linking atmospheric GHGs uniquely to firms, and differentiate between actual and estimated, as well as past and future emissions. In addition, both the SEC and the ISSB could facilitate the completeness of reported emissions by aligning the setting of organizational boundaries with financial reporting standards. The ISSB could further facilitate the neutrality of direct emissions by specifying acceptable emission factors.

[13]This minimum is set to rise to reasonable assurance in the coming years, which is widely expected to be challenging for most companies given the current practices for determining and reporting emissions.

5 Opportunities for Accounting Research

Accounting researchers now have the opportunity to make corporate carbon accounting an effective tool for combating climate change. First and foremost, they could contribute to the emergence of generally accepted carbon accounting principles. As for financial accounting, such principles will not only be crucial for the external reporting of emissions and, thus, for firms' compliance with carbon disclosure regulations (Mahieux et al., 2024). They will also be useful for the internal reporting of emissions and, thus, for the steering of decarbonization pathways (Glenk et al., 2024). Accounting researchers could develop such principles by building on measurement approaches from environmental science and accounting rules from financial accounting.[14] They could also study the adoption of such principles and their impact on corporate practices, reported emissions, and stakeholder responses.

Central to the development of carbon accounting principles will be the dual objectives of faithfully representing corporate emissions and providing incentives for decarbonization. In particular, carbon accounting systems should be designed with checks and balances to facilitate the recording of the actual emissions embodied in firms' economic activities without omissions or double counting.[15] At the same time, they should be designed to incentivize real decarbonization by allowing a firm to take credit for every ton of atmospheric GHGs avoided or removed by the firm or its suppliers. In this line of inquiry, it will be critical to examine how companies can account for the removal of GHGs from the atmosphere in a reliable manner. It will also be instructive to study how alternative rules for the intertemporal and cross-sectional allocation of emissions to products affect the incentives for customers to purchase, and thus for producers to supply, low-carbon products (Sunar and Plambeck, 2016). It will further be insightful to examine whether, how, and why managers engage in activities akin to earnings management, where they shape reported emissions without addressing actual emissions (Downie and Stubbs, 2012).

Accounting scholars could further examine the real effects of corporate carbon disclosure. Much of the literature on this topic has focused on the effect of voluntary or mandatory

[14] For example, Kaplan and Ramanna (2021, 2022) have proposed that all firms in a supply chain determine the carbon footprints of their products in a way similar to historical cost accounting for operating assets and pass them on to their customers. The resulting cradle-to-gate product carbon footprints would then reflect an allocated share of the actual direct emissions of the producing firm and all of its suppliers.

[15] For example, Reichelstein (2024) has proposed balance sheets and flow statements for corporate emissions that should allow for the assessment of the actual carbon performance of companies, similar to financial statement analysis.

disclosure on the direct emissions of reporting firms (e.g., Azar et al. (2021); Downar et al. (2021); Tomar (2023)). As firms and regulators adopt more comprehensive carbon reporting, future research could examine the extent to which firms merely outsource direct emissions to suppliers and the effectiveness of more comprehensive disclosure in mitigating such behavior (Berg et al., 2024b; Mahieux et al., 2024). Along these lines, future research could also examine the incremental effect of more comprehensive disclosure relative to carbon pricing regulations focused on firms' direct emissions. For example, European firms that are charged for their direct emissions under the European Emissions Trading System will also need to report their indirect emissions under the Corporate Sustainability Reporting Directive.

Finally, accounting researchers could explore the interplay between corporate carbon accounting and climate regulation, such as carbon pricing or subsidies for climate technologies. For example, the EU has recently introduced the Carbon Border Adjustment Mechanism. This mechanism will impose charges on the direct emissions embodied in select materials imported into the EU, where importers will be able to claim credits for emissions charges already paid in the country of origin (European Union, 2024). Corporate carbon accounting could not only provide reliable measures of product carbon footprints, which the mechanism will need. It could also serve as an effective link between different carbon pricing systems. Another example is that both the EU and the United States have introduced subsidies for electrolytic hydrogen production, where the subsidy level depends on the carbon intensity of the hydrogen produced (European Commission, 2022; U.S. Congress, 2022). These subsidies will also require reliable measures of the indirect emissions embodied in the electricity converted to hydrogen (Giovanniello et al., 2024).

2024 has been the hottest year on record, with global average temperatures for the first time exceeding 1.5°C above pre-industrial levels, the lower threshold of the 1.5–2.0°C long-term goal set by the Paris Agreement. For corporate carbon accounting to become effective soon enough, accounting scholars could collaborate with other actors in the field. In particular, they could work with environmental scientists to ensure that carbon accounting principles accurately reflect the climate impact of greenhouse gas emissions and removals. They could also work with businesses and industry associations to develop practical solutions that are scientifically sound yet ready for widespread adoption. Finally, they could work with standard-setters to keep standards aligned with the latest research. In particular, they could contribute to the ongoing revision of the GHG Protocol, which is due to be completed in

2027.

References

Myles Allen, Kaya Axelsson, Ben Caldecott, Thomas Hale, Cameron Hepburn, Conor Hickey, Eli Mitchell-Larson, Yadvinder Malhi, Friederike Otto, Nathalie Seddon, and Steve Smith. The Oxford Principles for Net Zero Aligned Carbon Offsetting, 2024.

José Azar, Miguel Duro, Igor Kadach, and Gaizka Ormazabal. The Big Three and corporate carbon emissions around the world. *Journal of Financial Economics*, 142(2):674–696, 2021.

Andrej Bajic, Ruediger Kiesel, and Martin Hellmich. Handle with Care: Challenges and Opportunities of using Company-Level Emissions Data for Assessing Financial Risks from Climate Change. 2021. URL `https://dx.doi.org/10.2139/ssrn.3789928`.

Florian Berg, Jaime Oliver Huidobro, and Roberto Rigobon. On the Importance of Assurance in Carbon Accounting. 2024a. URL `https://dx.doi.org/10.2139/ssrn.4734240`.

Tobias Berg, Lin Ma, and Daniel Streitz. Out of sight, out of mind: Divestments and the Global Reallocation of Pollutive Assets. 2024b. URL `https://dx.doi.org/10.2139/ssrn.4368113`.

Julia Anna Bingler, Mathias Kraus, Markus Leippold, and Nicolas Webersinke. Cheap talk and cherry-picking: What ClimateBert has to say on corporate climate risk disclosures. *Finance Research Letters*, 47(PB):102776, 2022.

Anders Bjørn, Shannon Lloyd, Matthew Brander, and Damon Matthews. Renewable energy certificates threaten the integrity of corporate science-based targets. *Nature Climate Change*, 12 (6):539–546, 2022.

Matthew Brander, Francisco Ascui, Vivian Scott, and Simon Tett. Carbon accounting for negative emissions technologies. *Climate Policy*, 21(5):699–717, 2021.

Kenza Bryan. Apple's 'carbon neutral' claims come under scrutiny, oct 2023. URL `https://on.ft.com/4cZizxu`.

Catena-X. Catena-X Product Carbon Footprint Rulebook, 2023. URL `https://bit.ly/3MJUXBR`.

Shira Cohen, Igor Kadach, and Gaizka Ormazabal. Institutional Investors, Climate Disclosure, and Carbon Emissions. *Journal of Accounting and Economics*, 76(2-3):101640, 2023a.

Shira Cohen, Igor Kadach, Gaizka Ormazabal, and Stefan Reichelstein. Executive Compensation Tied to ESG Performance: International Evidence. *Journal of Accounting Research*, 61(3):805–853, 2023b.

Stephen Comello, Julia Reichelstein, and Stefan Reichelstein. Corporate carbon reporting: Improving transparency and accountability. *One Earth*, 6(7):803–810, 2023.

Florence Depoers, Thomas Jeanjean, and Tiphaine Jérôme. Voluntary Disclosure of Greenhouse Gas Emissions: Contrasting the Carbon Disclosure Project and Corporate Reports. *Journal of Business Ethics*, 134(3):445–461, 2016.

Benedikt Downar, Jürgen Ernstberger, Stefan Reichelstein, Sebastian Schwenen, and Aleksandar Zaklan. The impact of carbon disclosure mandates on emissions and financial operating performance. *Review of Accounting Studies*, 26:1137–1175, 2021.

John Downie and Wendy Stubbs. Corporate Carbon Strategies and Greenhouse Gas Emission Assessments: The Implications of Scope 3 Emission Factor Selection. *Business Strategy and the Environment*, 21(6):412–422, 2012.

ECRA. State of the Art Cement Manufacturing: Current technologies and their future development, 2022. URL `http://bit.ly/3m5TKdE`.

European Commission. European Hydrogen Bank, 2022. URL `https://bit.ly/3O8niSR`.

European Commission. Green Claims, 2023. URL `https://bit.ly/3EvPA56`.

European Union. Commission Delegated Regulation (EU) 2023/2772, 2023.

European Union. Carbon Border Adjustment Mechanism, 2024. URL `https://bit.ly/4bYnjCg`.

Sam Fankhauser, Stephen M. Smith, Myles Allen, Kaya Axelsson, Thomas Hale, Cameron Hepburn, J. Michael Kendall, Radhika Khosla, Javier Lezaun, Eli Mitchell-Larson, Michael Obersteiner, Lavanya Rajamani, Rosalind Rickaby, Nathalie Seddon, and Thom Wetzer. The meaning of net zero and how to get it right. *Nature Climate Change*, 12(January):15–21, 2022.

FASB. Conceptual Framework for Financial Reporting, 2021.

GHG Protocol. A Corporate Accounting and Reporting Standard, 2004.

GHG Protocol. The GHG Protocol for Project Accounting, 2005.

GHG Protocol. Corporate Value Chain (Scope 3) Accounting and Reporting Standard, 2011a.

GHG Protocol. Product Life Cycle Accounting and Reporting Standard, 2011b.

GHG Protocol. Scope 2 Guidance, 2015.

GHG Protocol. Land Sector and Removals Guidance, 2023.

GHG Protocol. Greenhouse Gas Protocol, 2024. URL `https://ghgprotocol.org/`.

Michael A. Giovanniello, Anna N. Cybulsky, Tim Schittekatte, and Dharik S. Mallapragada. The influence of additionality and time-matching requirements on the emissions from grid-connected hydrogen production. *Nature Energy*, 9(2):197–207, 2024.

Brandon Gipper, Samantha Ross, and Shawn X Shi. ESG Assurance in the United States. *Review of Accounting Studies*, 2024a.

Brandon Gipper, Fiona Sequeira, and Shawn Shi. Carbon Accounting Quality: Measurement and the Role of Assurance. 2024b. URL `https://dx.doi.org/10.2139/ssrn.4627783`.

Gunther Glenk. Decision-Useful Carbon Information. 2024. URL `https://dx.doi.org/10.2139/ssrn.4444037`.

Gunther Glenk, Rebecca Meier, and Stefan Reichelstein. Assessing the Cost of Industrial Decarbonization. 2024.

IASB. Conceptual Framework for Financial Reporting, 2018.

Ioannis Ioannou, Shelley Xin Li, and George Serafeim. The effect of target difficulty on target completion: The case of reducing carbon emissions. *The Accounting Review*, 91(5):1467–1492, 2016.

IPCC. Summary for Policymakers, 2023.

ISSB. IFRS S2 Climate-Related Disclosures, 2023a.

ISSB. IFRS S1 General Requirements for Disclosure of Sustainability-Related Financial Information, 2023b.

Jimmy Jia, Nicola Ranger, and Abrar Chaudhury. Designing for Comparability: A foundational principle of analysis missing in climate reporting systems. 2023. URL `https://dx.doi.org/10.2139/ssrn.4258460`.

Robert Kaplan and Karthik Ramanna. Accounting for Climate Change. *Harvard Business Review*, 2021.

Robert Kaplan and Karthik Ramanna. We Need Better Carbon Accounting. Here's How to Get There. *Harvard Business Review*, 2022.

Lena Klaaßen and Christian Stoll. Harmonizing corporate carbon footprints. *Nature Communications*, 12(1):6149, 2021.

Lucas Mahieux, Haresh Sapra, and Gaoqing Zhang. Measuring Scope 3 Emissions: What are the Costs and Benefits? 2024. URL `https://dx.doi.org/10.2139/ssrn.4507526`.

Net Zero Tracker. Net Zero Tracker, 2023. URL https://zerotracker.net/.

Stephen Penman. Accounting for Carbon. 2024. URL https://dx.doi.org/10.2139/ssrn.4721974.

Stefan Reichelstein. Corporate carbon accounting: balance sheets and flow statements. *Review of Accounting Studies*, 29(3):2125–2156, 2024.

Erin Reid and Michael Toffel. Responding to Public and Private Politics: Corporate Disclosure of Climate Change Strategies. *Strategic Management Journal*, 30:1157–1178, 2009.

SEC. The Enhancement and Standardization of Climate-Related Disclosures for Investors, 2024.

Nur Sunar and Erica Plambeck. Allocating emissions among Co-Products: Implications for procurement and climate policy. *Manufacturing and Service Operations Management*, 18(3):414–428, 2016.

Sorabh Tomar. Greenhouse Gas Disclosure and Emissions Benchmarking. *Journal of Accounting Research*, 61(2):451–492, 2023.

U.S. Congress. H.R. 5376 - Inflation Reduction Act of 2022, 2022.

Hao Xue. ESG Disclosure, Market Forces, and Firm Investment. 2024. URL https://ssrn.com/abstract=4685129.