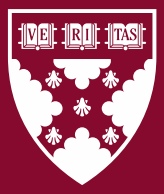
Working Paper 24-026

Toward Decision-Useful Carbon Information

Gunther Glenk



Harvard Business School

Toward Decision-Useful Carbon Information

Gunther Glenk
Harvard Business School

Working Paper 24-026

Funding for this research was provided in part by Harvard Business School.

Toward Decision-Useful Carbon Information

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

September 2023

*I am grateful to David Bokern, Matthew Brander, Shira Cohen, Jody Grewal, Jimmy Jia, Lena Klaaßen, Shirley Lu, Karthik Ramanna, Stefan Reichelstein, Anna Rohlfing-Bastian, Simone Ruiz-Vergote, Thorsten Sellhorn, Christian Stoll, colleagues at the University of Mannheim, and seminar participants at Goethe University, Stanford University, and the Alliance for Research on Corporate Sustainability for helpful discussions and comments. I also thank Levis Lerner for valuable research assistance. Financial support for this study was provided by the German Research Foundation (Project-ID 403041268, TRR 266) and the Joachim Herz Foundation.

Abstract

Companies are increasingly viewed as crucial drivers for timely decarbonization. Current accounting practices for greenhouse gas (GHG) emissions, however, often leave corporate carbon disclosures and abatement obscured. Here I introduce a taxonomy for assuring the quality of corporate carbon information. Analog to financial accounting standards, information on a firm's GHG emissions is to be *decision-useful* to stakeholders. That is, it is relevant and faithfully represents the actual changes in atmospheric GHGs associated with a firm's economic activity. Applying the taxonomy, I show that information prepared under the widely used *Greenhouse Gas Protocol* generally fails to represent a firm's GHG emissions faithfully. Yet, if firms complying with the GHG Protocol adopted the taxonomy, they could directly improve their disclosures by faithfully representing some of their emissions. My findings highlight the need to revise the GHG Protocol, as well as recently proposed carbon disclosure mandates that seek to produce *decision-useful* information but have also adopted the GHG Protocol.

Keywords: carbon accounting, carbon emissions, decarbonization, net-zero pledges
JEL Classifications: G18, M41, M48, Q54, Q56

1 Introduction

In the global effort to mitigate climate change, companies are increasingly viewed as crucial drivers of a timely transition toward a decarbonized economy[1–3]. Accordingly, over fifteen thousand firms worldwide have pledged to reduce their greenhouse gas (GHG) emissions[4]. Current carbon accounting practices, however, often leave reported emissions and reduction efforts obscured[5;6]. To improve the acceptance of their disclosures, companies have been seeking assurance from independent auditors and accreditation from voluntary reporting initiatives[7;8]. The reliability of corporate carbon disclosures has nonetheless remained debated among investors as much as climate advocates[9].

Today's most widely used framework for accounting and reporting corporate emissions is the *Greenhouse Gas Protocol*[10]. This framework defines principles and procedures to ensure that reported information represents a faithful, true, and fair account of a company's GHG emissions. The principles are intended to provide conceptual guidance, while the procedures describe specific steps for arriving at different measures of corporate emissions. Since its introduction in 1998, the GHG Protocol has been adopted by public and private organizations worldwide. It has also been incorporated into leading voluntary reporting initiatives, including the Carbon Disclosure Project, the Global Reporting Initiative, the Science Based Target Initiative, and the Task Force on Climate-Related Financial Disclosures.

Common concerns about the GHG Protocol include that emissions are counted multiple times by different firms along the value chain and that the reported information is frequently biased[11], incomplete[12;13], incomparable[14;15], intransparent[16], and inaccurate[17]. Recent studies have suggested different changes to improve individual aspects of corporate carbon disclosure[16;18;19]. In particular, some studies have proposed that firms adopt a "reality principle" to report emissions when and where they occur[20;21]. Other studies have argued that carbon reporting is more comparable and consistent over time if firms provide initial forecasts of their emissions, periodic revisions of earlier forecasts, and updates on emissions reductions achieved[22;23]. Furthermore, several studies have suggested that firms transfer the emissions embedded in their products along the value chain[24–26]. Each firm would then rely on primary information from its immediate suppliers, enabling it to compile a more reliable measure of the upstream emissions associated with its business.

This Perspective introduces a taxonomy for assuring the quality of corporate carbon information. In direct analogy to financial accounting standards[27;28], the pervasive criterion

for carbon disclosures is to be *useful* to a firm's stakeholders in making decisions related to the firm. Such decisions may be related to the firm's financial or environmental performance. The pervasive criterion is defined by a comprehensive system of qualitative characteristics that are adapted from generally accepted financial accounting principles. Crucially, reported information is considered *decision-useful* if and only if it is relevant and faithfully represents the actual changes in atmospheric GHGs associated with the firm's economic activity. Such changes include direct and indirect emissions of GHGs to the atmosphere as well as direct and indirect removals from it.

I then apply the taxonomy to examine the information resulting from the GHG Protocol when firms fully comply with it. This analysis identifies the causes and gravity of different flaws of the GHG Protocol by showing how its principles and procedures impede individual qualitative characteristics of decision-useful carbon information. Overall, my analysis shows that both the principles and procedures of the GHG Protocol generally fail to produce information that faithfully represents a firm's emissions. Critical deficiencies include that the GHG Protocol establishes no unique attribution of emissions to firms and makes no distinction between a firm's realized, estimated, and expected emissions. In addition, it allows companies to choose the scope, approach, and data for determining their emissions, enabling them to (unintentionally) understate emissions and overstate reductions.

Recognizing the potential of standardization, regulators and standard-setters worldwide, including the European Union (EU), the United States Securities and Exchange Commission (US SEC), and the International Sustainability Standards Board (ISSB), have recently announced mandates and standards for corporate carbon disclosure. These directives seek to ensure that the carbon information reported by companies will be *decision-useful*[29–31]. Like their voluntary counterparts, however, they have also adopted most of the procedures of the GHG Protocol. The analysis in this paper shows that the mandates, as currently conceptualized, will improve the quality of carbon disclosures by confining the room for companies to choose parameters favorably. Yet, they cannot ensure that the reported information will be decision-useful due to deficiencies inherited from the GHG Protocol.

Finally, I argue that if companies were to adopt the taxonomy, they could directly improve their disclosures by faithfully representing a share of their emissions. Specifically, they could build on elements of the GHG Protocol to provide verifiable, neutral, and complete depictions of the direct emissions emanating from their own operations as well as the indirect

emissions obtained from upstream suppliers that have also adopted the taxonomy. Since the taxonomy is derived from financial accounting standards, companies should also be able to adapt existing software solutions to process carbon information. In addition, external auditors should be able to verify corporate carbon disclosures, which will be required for regulatory compliance with the disclosure mandates[29;30].

The taxonomy introduced in this paper complements and extends earlier suggestions for improving corporate carbon disclosure. In particular, the taxonomy effectively embodies a reality principle[20;21] without imposing a location requirement, as changes in atmospheric GHGs will be recognized by the responsible firm once they occur. In addition, companies adhering to the taxonomy will produce decision-useful carbon information that is not only comparable and consistent over time but also across firms[22;23]. Finally, the taxonomy enables the transfer of reliable product emissions along corporate value chains[24–26], as suppliers adhering to the taxonomy would provide not merely an estimate of emissions but a faithful representation of the actual changes in atmospheric GHGs embedded in the products.

2 The Greenhouse Gas Protocol

By defining principles and procedures, the GHG Protocol seeks to ensure that companies report a faithful, true, and fair account of their GHG emissions. The five principles stated in the GHG Protocol with no particular hierarchy are *relevance*, *completeness*, *consistency*, *transparency*, and *accuracy* (see Table 1 for their definitions). These principles are intended to provide conceptual guidance for accounting and reporting corporate emissions, especially in situations where the procedures are ambiguous.

The procedures of the GHG Protocol can be divided into the four main steps illustrated in Figure 1. First, companies choose their organizational boundary regarding the entities, operations, and other assets within their organization. Then, they choose their operational boundary in terms of three emission scopes. Scope 1 emissions refer to direct emissions from a company's operations within its organizational boundary. Scope 2 emissions are indirect emissions associated with the energy (i.e., electricity, steam, heat, or cooling) consumed by the company. Scope 3 emissions are all other indirect emissions generated by the company's upstream suppliers and downstream customers.

In the third step, companies calculate the GHG emissions for each included entity and emission scope. The general procedure is to first identify all emission sources within the

chosen boundaries. Then, firms multiply a measure of activity at each emission source by a corresponding emission intensity factor, which quantifies the GHGs emitted per unit of activity. For Scope 1 emissions, activity measures are typically physical quantities, such as liters of fuel consumed. Emission factors are then 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.

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.

For Scope 2 emissions, companies can refer to their energy bills or use average emission intensity factors from public databases if energy suppliers provide no emissions information. For Scope 3 emissions, the GHG Protocol recommends companies to use primary information on all production steps and collect the corresponding activity and emissions data from their multiple-tier suppliers and customers. Recognizing the practical challenges of collecting such data, the GHG Protocol allows firms to estimate emissions based on exemplary production processes and industry averages[32]. Activity measures then obtain various quantities, such as the number of items procured 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.

In the final step, companies can account for carbon offsets purchased on the voluntary carbon market. Carbon offsets are certificates of the avoidance or removal of GHGs through

mitigation projects. Common examples include afforestation, forest protection, the deployment of renewable energy sources, or the installation of direct air capture facilities[33]. The amount of GHGs compensated through such projects is calculated as the difference between the emissions associated with a project and a baseline representing a hypothetical scenario of what emissions would have been without the project. Central to this calculation is the ability of project developers to demonstrate that their project is additional and not the baseline itself. This additionality was originally intended to ensure the integrity of a fixed emissions cap under a GHG emissions program, such as the European Emissions Trading System, for which the offset might be used.

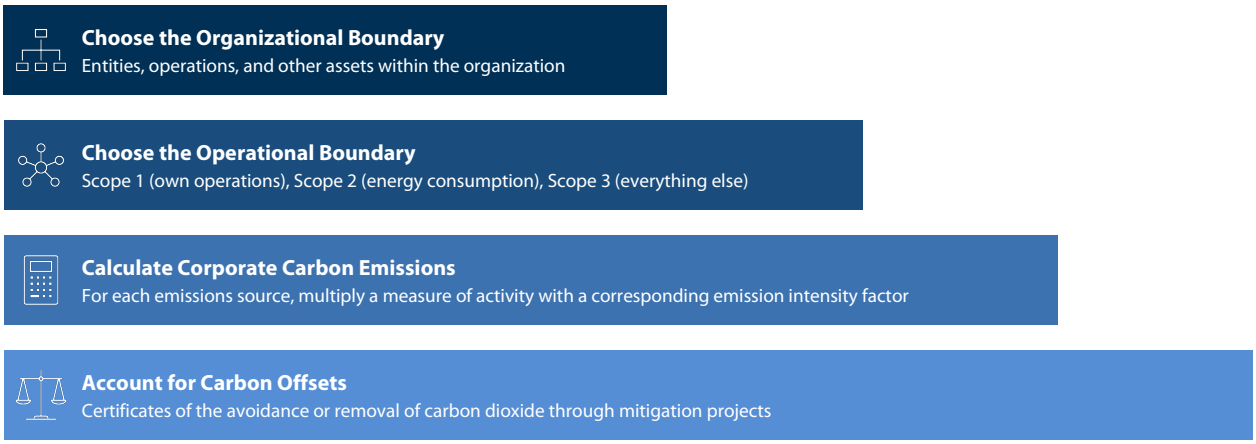


Figure 1. Procedures of the GHG Protocol. This figure illustrates the four main steps of the GHG Protocol for determining corporate carbon emissions.

Regarding reporting, the GHG Protocol requires companies to disclose their chosen organizational boundary and their Scope 1 and 2 emissions, while reporting Scope 3 emissions and carbon offsets is optional. Companies reporting carbon offsets are encouraged to identify those that have been verified and approved by an external GHG program. For each reported emissions scope, companies are required to disclose the total amount of all seven major GHGs separately in metric tons and the overall aggregate in tons of carbon dioxide (CO_2) equivalent based on the gases' global warming potential, in both cases excluding the impact of carbon offsets.

3 Common Concerns

Current carbon accounting and reporting practices have been criticized in many regards. This criticism can be summarized into the six key concerns illustrated in Figure 2. One of the most common concerns is double counting, in the sense that emissions are counted and reported multiple times by different firms along the value chain. Double counting of emissions is intended to reflect the shared responsibility of companies along the value chain[10]. However, shared responsibility often obscures the sense of ownership and can even lead to the multiple omission of emissions. For instance, industrial manufacturers of products such as steel or cement regularly ignore emissions from burning waste as an alternative fuel, arguing that these emissions would have occurred in nearby waste incinerators[34]. But operators of such incinerators note that they no longer burn the waste.

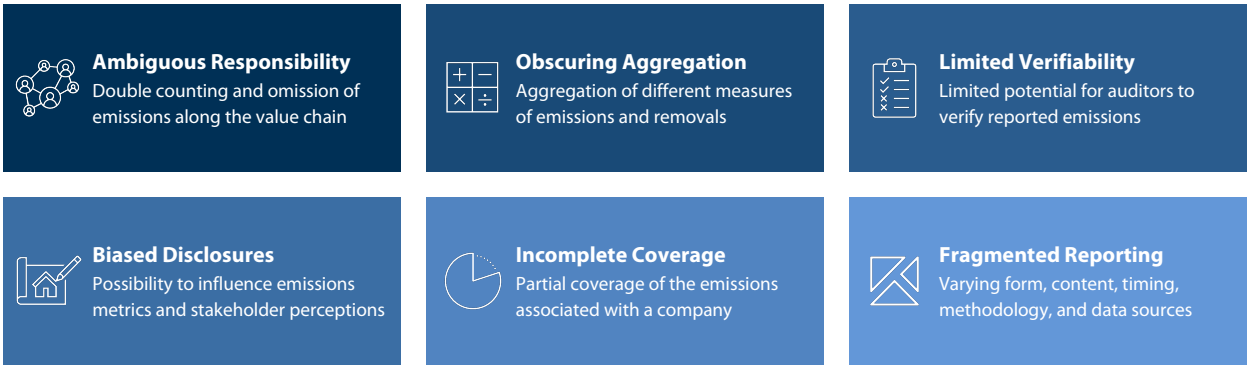


Figure 2. Concerns about corporate carbon accounting and reporting. This figure illustrates the six key concerns about current carbon accounting and reporting practices.

Another concern is that companies commonly aggregate different measures of changes in atmospheric GHGs. In particular, they typically aggregate emissions that have occurred with those expected to occur going forward[20]. Some companies even count CO_2 removals pledged to be attained in the future against emissions that have already materialized[35;36]. Such aggregation obscures actual changes in atmospheric GHGs and a firm's contribution to climate change. It also obscures a firm's climate-related risks and opportunities, such as the financial impact of (higher) carbon prices or the abatement potential of different decarbonization initiatives.

Limited verifiability refers to the poor potential for independent auditors to verify reported emissions. Verifiable disclosures allow auditors to identify errors reporting firms may make in determining and reporting their emissions. Errors may result from the correct application of

an inappropriate methodology, the incorrect application of an appropriate methodology, or both. Over the past decade, over 50% of S&P 500 companies that have disclosed corporate emissions have requested verification from external auditors[7]. For about 90% of the reported emissions figures, however, auditors were unable to verify the disclosures, primarily due to missing information. As a result, the auditors could only issue "limited" assurances, meaning that no evidence of misreporting had come to their attention.

The concern of biased disclosures describes the leeway companies have to shape emissions metrics and stakeholder perceptions. In particular, companies can choose the methodology and data used to calculate their emissions. Accordingly, early evidence suggests that firms may have cherry-picked favorable methodologies[11] or emission intensity factors[17] to determine their emissions. In addition, companies 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[12;13].

Another concern is that companies can choose the range of emissions they report. As a result, companies frequently provide an incomplete coverage of the emissions associated with their economic activity. In particular, companies often report emissions for only a fraction of upstream indirect emissions, such as those related to energy consumption, business travel, or material production inputs[13;37]. Such underreporting can account for a substantial portion of a company's total emissions. For instance, a recent study estimates that technology companies omitted about half of their total emissions in their 2019 corporate reports[12].

Finally, the landscape of corporate carbon reporting is highly fragmented. For instance, companies disclose their GHG emissions at different times of the year and typically much later than their financial statements, arguing that current accounting procedures are complex and laborious[15]. In addition, the form and content of carbon disclosures vary substantially across firms and time periods, making it difficult to compare the disclosures[14;15]. This variance is primarily due to firms preparing their disclosures based on different third-party frameworks[30], choosing their organizational boundaries according to alternative rules[13], or changing the scope of reported emissions between periods[12]. Furthermore, companies often disclose only partial information about the methodology, data sources, and assumptions used to determine their emissions, which makes the reported information difficult to understand[13]. The recent proliferation of voluntary carbon disclosure frameworks has further contributed to the reporting fragmentation[30;38].

4 Decision-Useful Carbon Information

4.1 Introducing the Taxonomy

In direct analogy to financial accounting standards[27;28], the taxonomy seeks to ensure that reported information on a firm's atmospheric phenomena is useful to the users of carbon information in making decisions related to the firm. Atmospheric phenomena refer to changes in atmospheric GHGs associated with the firm's economic activity. They include direct emissions of GHGs to the atmosphere from the firm's operations and indirect emissions embedded in trade with suppliers and customers whenever direct emissions occur up or down the value chain. They also include direct or indirect removals of CO_2 from the atmosphere attained via technological or nature-based solutions.

Users of carbon information include internal and external stakeholders of the firm, such as managers, investors, regulators, customers, and other stakeholders. These users may be concerned with the impact of the firm's atmospheric phenomena on the environment, the firm's financial performance, or both. Decisions related to the firm are diverse, including risk assessments, resource allocations, purchasing decisions, and policy choices. Importantly, the taxonomy focuses on the information required to understand the atmospheric phenomena, leaving their interpretation in the specific context of a decision to the user.

Like financial information, information on a firm's atmospheric phenomena will be called *decision-useful* if and only if it is *relevant* and *faithfully represents* what it purports to represent. Relevance results from the information having the capacity to make a difference in decisions even if some users choose not to use it. Faithful representation obtains if and only if the information is a *verifiable*, *neutral*, and *complete* depiction of the *real-world atmospheric phenomena* the reporting firm *controls*. Table 2 provides detailed definitions for these qualitative characteristics.

Consistent with the definitions in Table 2, carbon information is becoming increasingly relevant to business decisions. For instance, investors use emissions data to assess climate-related risks and opportunities in capital allocation decisions[30]. Companies and public institutions such as Apple[39], BMW[40], and the US Federal Government[41], have made quantitative carbon information a criterion for selecting suppliers. In addition, many consumer-oriented firms in Europe and the US provide (qualitative or quantitative) carbon information in the marketing of their products.

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

Characteristic	Definition
Relevance	Information can make a difference in decisions even if some users choose not to use it. The capacity to make a difference relies on the information having predictive value, confirmatory value, or both.
◦ Predictive Value	Information enables the estimation of future outcomes.
◦ Confirmatory Value	Information enables the evaluation of earlier outcomes.
Faithful Representation	Information is a verifiable, neutral, and complete depiction of the real-world atmospheric phenomena the reporting firm controls.
◦ Real-world phenomena	Changes in atmospheric GHGs have occurred in the past. Such changes do not include emissions and removals that are estimated to have occurred or those that are likely to occur in the future.
◦ Control	The reporting firm has legal rights associated with an event or a transaction, or other means of ensuring that it, and no other party, directed the event or transaction that has led to the change in atmospheric GHGs.
◦ Verifiability	Knowledgeable and independent observers can reach a consensus that the depiction of an atmospheric phenomenon is without errors and omissions, and the process used to arrive at the depiction has been selected and applied without errors.
◦ Neutrality	Information is prepared without bias intended to attain a predetermined result or to induce a particular behavior.
◦ Completeness	Information includes all real-world atmospheric phenomena a firm controls and all descriptions and explanations necessary for users to understand the depicted phenomena.

Real-world atmospheric phenomena only include changes in atmospheric GHGs that have occurred in the past to measure a firm's actual contribution to climate change so far. Firms can, of course, provide estimates of expected future emissions, yet such disclosures would have to be separate so as not to obscure information. Control establishes a unique attribution of atmospheric phenomena to firms, which is essential for resolving the frequent responsibility disputes over emissions today[42]. Importantly, control over atmospheric phenomena embedded in goods and services will be transferred from suppliers to customers as part of the underlying economic transactions. Such transfer of control is consistent with the transfer of financial claims and obligations associated with an economic good[43].

Verifiability ensures that the reported carbon information is free from error. Verification can be direct, by checking a depicted phenomenon, or indirect, by checking the inputs and recalculating the outputs. Neutrality implies that companies do not color the image they communicate, for instance, by understating emissions or overstating removals. Completeness

means that no emissions and removals are omitted. Central to completeness is a firm's organizational boundary. Firms preparing financial reports determine their organizational boundary pursuant to existing standards. Faithful representation requires that a firm's organizational boundary contains no arbitrary or incomplete set of economic activities. Since a firm's atmospheric phenomena mainly originate from its economic activity, completeness requires that the activities included for reporting atmospheric phenomena are consistent with those for reporting economic phenomena[30].

As for financial information, the decision-usefulness of carbon information is enhanced if the information is *timely*, *comparable*, and *understandable*. Timeliness describes that the information must be available to users in time to be capable of influencing their decisions. Timeliness cannot make information relevant, but untimely information can lose the relevance it might otherwise have had. Comparability means that users can identify similarities and differences between two sets of real-world atmospheric phenomena. Consistency facilitates comparability by requiring the same principles and procedures from period to period within a firm and in a single period across firms. Understandability requires that users with reasonable knowledge of atmospheric phenomena who study the information with reasonable diligence can comprehend its meaning. Comparability enhances understandability.

Meanwhile, the provision of decision-useful information is constrained by *materiality* and benefits that need to justify costs. Carbon information will be called *material* if its omission or misstatement can influence decisions. Materiality depends on the type and magnitude of changes in atmospheric GHGs judged in the particular circumstances of their omission or misstatement. For instance, the omission of indirect emissions associated with some procurement is more likely to be material if it amounts to 10% of the emissions associated with all procured goods and services than if it amounts to 1%. Studies in the finance and accounting literature have examined the financial materiality of corporate GHG emissions in monetary terms[44–47]. For carbon information to be useful in financial and environmental impact assessments, concerns about whether the omission or misstatement of particular atmospheric phenomena can influence decisions will have to be evaluated in tons of GHGs.

The benefits of decision-useful carbon information are potentially extensive. Examples include understanding a firm's climate-related risks and opportunities, identifying leaders and laggards in climate action, and informed decision-making by investors, managers, customers, policymakers, and other stakeholders[29;30]. Meanwhile, the costs of carbon disclosure

include collecting, processing, and analyzing emissions data, as well as preparing, verifying, and disseminating the disclosures. They also include the costs of revealing climate-related risks and potentially experiencing adverse reactions by the firm's stakeholders[48;49]. Cost-benefit assessments are inherently subjective and will need to be conducted by the company, regulator, or standard-setter adopting the taxonomy. It is widely agreed that the issues of current practices described in Section 3 impede the benefits of carbon information while imposing significant costs[30;38].

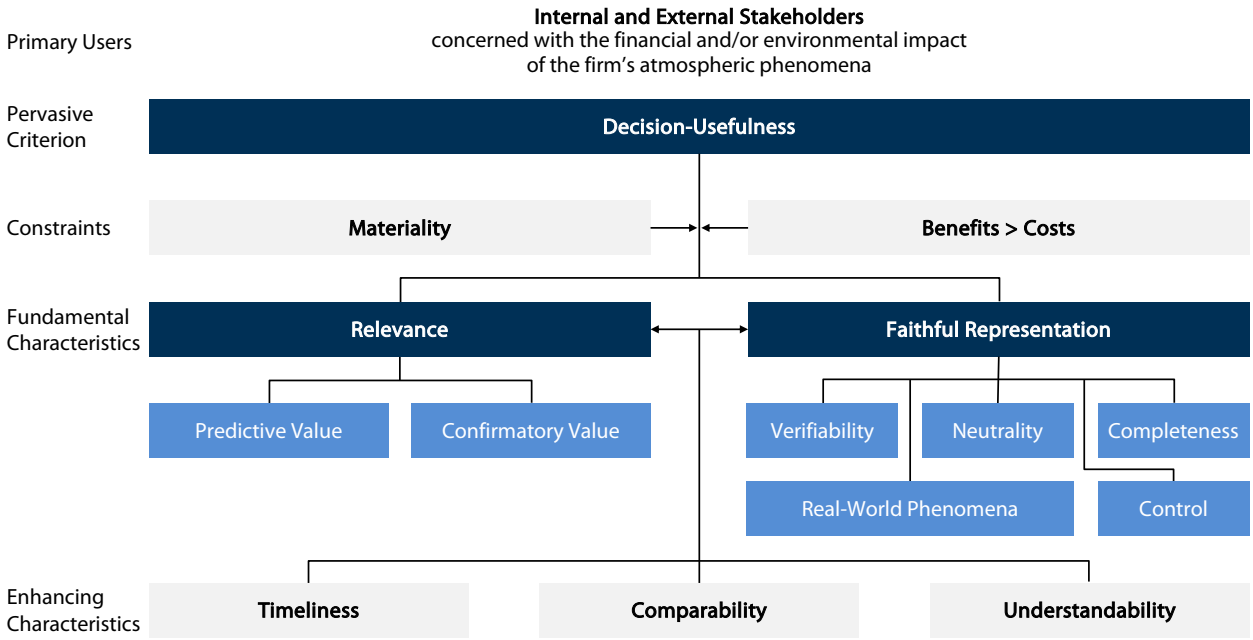


Figure 3. Taxonomy of decision-useful carbon information. This figure illustrates the relationships between the qualitative characteristics of decision-useful carbon information in resemblance to the hierarchy of generally accepted financial accounting principles.

Figure 3 illustrates the taxonomy of decision-useful carbon information. Accordingly, decision-usefulness requires that information is relevant and faithfully represents what it purports to represent. Either irrelevance or unfaithful representation leads to information that is not decision-useful. Enhancing characteristics improve while constraints limit the decision-usefulness of carbon information, but neither can make information relevant or representationally faithful. Importantly, users of carbon information are not only present and potential investors concerned with the firm's financial performance, as in financial accounting standards. Instead, they include all stakeholders interested in the financial and/or environmental impact of the firm's atmospheric phenomena.

Financial accounting standards are themselves subject to continuous revision. A long-

standing debate in the accounting literature has addressed the question of whether different or additional qualitative characteristics should be included to describe the quality of financial information[50;51]. Examples include *reliability*, *transparency*, *accuracy*, *true and fair view*, *credibility*, and *high quality*. So far, the Financial Accounting Standards Board in the US and the International Accounting Standards Board in Europe have settled on the consensus that these characteristics are generally equivalent to or follow from a faithful representation and its constituent characteristics of verifiability, neutrality, and completeness[27;28]. These considerations are directly applicable to carbon information.

4.2 Current Information Quality

I now apply the preceding taxonomy to examine the information that results from the GHG Protocol when companies fully adhere to it. As stated in Section 2, the GHG Protocol seeks to ensure that the reported information represents a faithful, true, and fair account of a company's GHG emissions. This objective is focused on emissions and ignores removals, though removals are included in the procedures of the GHG Protocol. In addition, a true and fair account is generally considered equivalent to a faithful representation as it results from information that is verifiable, neutral, and complete[27;28]. Furthermore, a faithful representation is inferior to the criterion of decision-usefulness since information can be representationally faithful but irrelevant.

Observation 1. *The GHG Protocol does not seek to ensure that the reported information on a firm's atmospheric phenomena is decision-useful. Instead, it seeks to ensure that the reported information faithfully represents a firm's GHG emissions.*

The principles and procedures of the GHG Protocol are intended to ensure that compliant companies achieve the overall objective. In light of the taxonomy, however, the principles suffer from two major deficiencies. First, the selection of principles is unfavorable as it lacks qualitative characteristics necessary for a faithful representation (i.e., verifiability, neutrality, control, and real-world phenomena). At the same time, it includes principles that are not components of a faithful representation. Specifically, relevance constitutes decision-usefulness together with a faithful representation. Consistency contributes to comparability, which, in turn, enhances decision-usefulness. Transparency and accuracy are redundant as they result from the qualitative characteristics verifiability, neutrality, completeness, and understandability[27;28].

Second, the definitions of the principles are mixed and vague. In particular, the definition of relevance describes a faithful representation but not what constitutes relevant information. Completeness allows firms to choose their organizational and operational boundaries, which enables them to (unintentionally) omit emissions. The definition of consistency describes steps for improving understandability but not what constitutes consistency. Furthermore, the definition of transparency describes elements of verifiability and understandability, while the one for accuracy includes aspects of neutrality. Yet, neither can be considered equivalent to the respective definitions in subsection 4.1. Finally, the definitions in Table 1 do not include equivalent specifications for the criteria of control, real-world phenomena, and timeliness.

Observation 2. *The principles of the GHG Protocol cannot ensure that the reported information on a firm's atmospheric phenomena is decision-useful. They also cannot ensure that the reported information faithfully represents a firm's GHG emissions.*

The procedures of the GHG Protocol also have two major deficiencies. First, they produce inherently fuzzy information. Scope 2 and upstream Scope 3 emissions seek to capture the real-world emissions the firm has obtained from suppliers. Based on exemplary production processes and industry averages, however, the calculations by the reporting firm can only return an estimate of these emissions. Downstream Scope 3 emissions seek to capture expected emissions the firm's customers will incur. These emissions reflect no real-world phenomena, and their realization is beyond the firm's control. Carbon offsets seek to capture the GHG avoided or removed by a mitigation project. Calculated relative to a hypothetical baseline, they can only reflect estimates of potential GHG avoidance or removal.

Second, the procedures of the GHG Protocol deliberately leave room for firms to choose parameters. In particular, they allow firms to choose their organizational and operational boundaries, which impedes the completeness of reported information. They also allow firms to choose the activity data for calculating Scope 3 emissions and the emission intensity data for calculating all emissions, which inhibits the neutrality of reported information. Together, the two deficiencies impair the comparability and understandability of reported information. They also increase the cost of preparing the information.

Observation 3. *The procedures of the GHG Protocol cannot ensure that the reported information on a firm's atmospheric phenomena is decision-useful. They also cannot ensure that the reported information faithfully represents a firm's GHG emissions.*

The information resulting from the GHG Protocol is today widely treated as if it faithfully represented real-world phenomena a firm controls. Accordingly, companies worldwide claim that their economic activity in a given year has been "carbon neutral" based on carbon offsets they purchased and counted against their emissions[35;52]. The preceding analysis shows that deficiencies in the principles and procedures of the GHG Protocol obscure the actual changes in atmospheric GHGs associated with a firm's economic activity. Consistent with this, recent findings suggest that almost all companies with carbon-neutrality claims continue to cause more additions of GHGs to the atmosphere than removals from it[53–55].

4.3 Potential Information Quality

An immediate question is now what information quality companies adhering to the GHG Protocol can achieve in the short run by adopting the taxonomy. To examine this, consider a firm with well-defined organizational boundary such as an individual entity. All three emission scopes and carbon offsets reflect relevant information that is already influencing decisions[30]. Yet, it remains open to what extent these metrics can also reflect a verifiable, neutral, and complete depiction of the firm's atmospheric phenomena.

Scope 1 emissions seek to capture all direct emissions from the firm's operations. These emissions have occurred due to production processes the firm has directed and hence reflect real-world phenomena the firm has controlled (see Figure 4 for illustration). The firm's well-defined organizational boundary and the requirement to include all direct emissions provide that the reported Scope 1 emissions are complete. In addition, the calculation can be verified based on the firm's activity records, publicly available emission factors, and inspections of the firm's production facilities. Finally, the neutrality of Scope 1 emissions depends on the firm's unbiased selection of emission factors when multiple factors are applicable. One way to demonstrate this is by selecting emission factors that are generally accepted as industry standards for the corresponding production processes.

Scope 2 emissions seek to depict the energy supplier's Scope 1 emissions that are directly attributable to the firm's energy consumption. Suppose that the energy supplier has also adopted the taxonomy and faithfully represents the emissions that are directly attributable to the firm's consumption on the energy bill. With the energy supply, the reporting firm obtains control over its share of the supplier's Scope 1 emissions. Furthermore, the firm can provide a verifiable, neutral, and complete depiction of the real-world emissions it has

controlled due to its energy consumption by restating the received information.

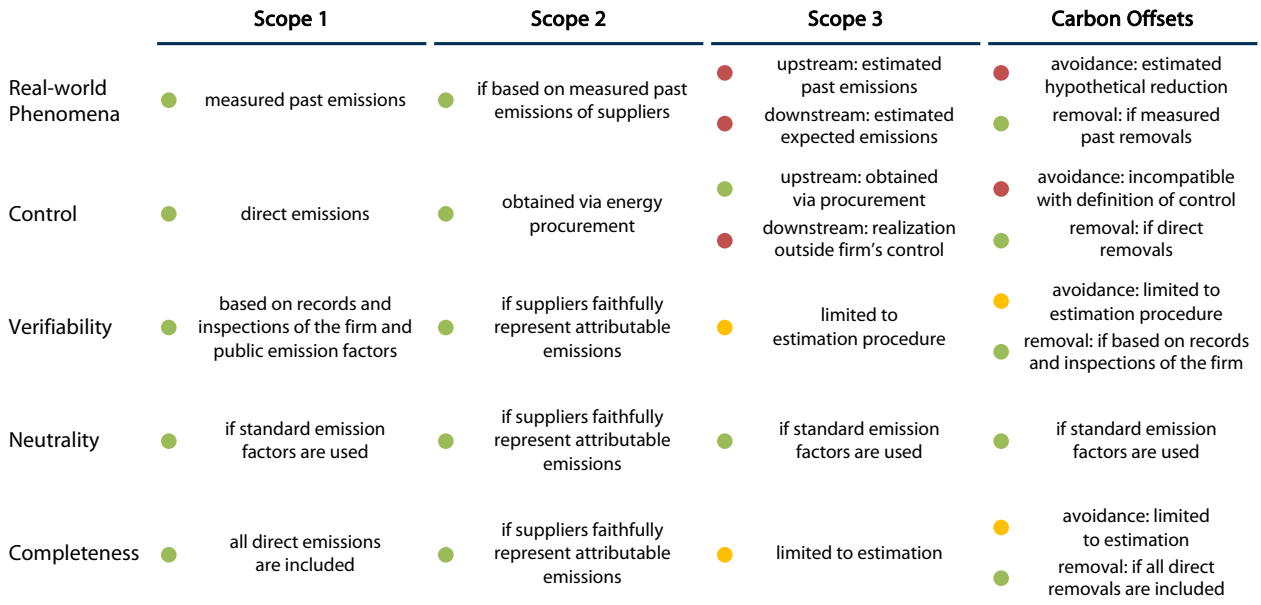


Figure 4. Information quality of carbon metrics. This figure illustrates the information quality companies adhering to the GHG Protocol can achieve in the short run by adopting the taxonomy of decision-useful carbon information.

Upstream Scope 3 emissions effectively reflect estimates of the real-world emissions the firm has obtained from suppliers. Downstream Scope 3 emissions, by construction, reflect estimates of the expected emissions customers will incur. Estimations are only verifiable to the extent that the specific calculation done by the firm has been performed without error. For auditors to perform such limited verification, the firm must disclose the methodology and input parameters used in its calculation. For neutrality, the firm needs to demonstrate that it selected input parameters without bias, for instance, by using generally accepted activity and emission data whenever available. The completeness of up- and downstream Scope 3 emissions is limited to the estimation. In principle, the firm must account, for upstream Scope 3 emissions, for all procured goods and services and all material emissions that these goods and services have accumulated. For downstream Scope 3 emissions, the firm must account for all sold goods and services and all material emissions that these goods and services will accumulate during their use and end-of-life treatment. Yet, estimations may be more or less sophisticated depending on the information available.

A common perception is that the shortcomings of upstream Scope 3 emissions are mainly due to limited data availability. If the firm could hypothetically obtain primary informa-

tion on the direct emissions of all multiple-tier suppliers, upstream Scope 3 emissions would indeed reflect real-world emissions the firm has obtained from its suppliers. Since this is virtually impossible, however, the firm could build on the conceptual approach to Scope 2 emissions and transfer control over the real-world atmospheric phenomena embedded in goods and services along the value chain, as suggested in earlier work[21;24;25;56]. The emissions embedded in procured goods and services are then determined in a recursive and informationally decentralized manner along the supply chain[57]. Thus, the reporting firm does not need to obtain information on upstream emissions from all multiple-tier suppliers but only from its immediate ones. This approach relies on suppliers in the value chain to faithfully represent the GHG emissions accumulated by the goods and services traded. Yet, public and private organizations worldwide are seeking to make quantitative carbon information a criterion for supplier selection[39–41].

Carbon offsets, as conceptualized in the GHG Protocol, are estimates of potential GHG avoidance or removal. The verifiability, neutrality, and completeness of these estimates are analogous to those of Scope 3 emissions. An exception occurs when the baseline scenario underlying the estimation is effectively not hypothetical, as is the case for technological solutions of CO_2 removal. In such cases, carbon removals reflect real-world phenomena the project developer has controlled. Their calculation can then be simplified and symmetric to the one of Scope 1 emissions. Accordingly, the resulting number is verifiable, neutral, and complete, where standard emission factors establish neutrality. Any emissions associated with the removal project, such as potentially those from electricity consumption, must be counted separately. Project developers must also continue to demonstrate the additionality of their projects. In practice, carbon removals are increasingly considered "high quality" only if they permanently sequester CO_2 from the atmosphere[33;58]. In contrast, the taxonomy imposes no permanence requirement as reversible phenomena are recognized separately at different points in time.

5 Outlook

Current accounting practices for GHG emissions often leave corporate carbon disclosures and abatement efforts obscured. This perspective has introduced a taxonomy for assuring the quality of corporate carbon information. In direct analogy to financial accounting standards, information on a firm's GHG emissions is to be *decision-useful* to stakeholders. That is, the

information is relevant and faithfully represents the actual changes in atmospheric GHGs associated with a firm's economic activity. Applying the taxonomy to the GHG Protocol, I find that information prepared under the GHG Protocol generally fails to represent a firm's GHG emissions faithfully. Yet, if firms adhering to the GHG Protocol adopted the taxonomy, they could immediately improve their disclosures and faithfully represent some of their emissions.

Recognizing the potential of standardized carbon information, the EU, US SEC, and ISSB plan to introduce mandates and standards for corporate carbon disclosures[29–31]. These initiatives seek to ensure that reported information on a firm's atmospheric phenomena will be *decision-useful*. While the US SEC provides no details on what constitutes decision-useful carbon information, the EU and ISSB provide qualitative characteristics of a firm's sustainability information in general[59;60]. These definitions are broadly consistent with those introduced in Section 4.1, but they omit characteristics corresponding to control and real-world atmospheric phenomena.

For determining corporate GHG emissions, all three initiatives have generally adopted the procedures of the GHG Protocol[30;31;61]. Specifically, they all require firms to disclose Scope 1, 2, and 3 emissions. These disclosures are to exclude the impact of any purchased or generated carbon offsets and be expressed both disaggregated by each of the seven major GHGs and aggregated in terms of CO_2 equivalents. Scope 3 emissions are to include both up- and downstream emissions but only those sub-categories that are considered material. In addition, all three proposals require firms to separately disclose any obtained carbon offsets.

Different from the GHG Protocol, the EU and US SEC require firms to set their organizational boundaries for reporting GHG emissions pursuant to existing financial accounting standards. They also require firms to use common emission intensity factors for calculating Scope 1 and 2 emissions. The EU thereby refers to the methodologies of the EU Emissions Trading System[62] and the US SEC to those of the US Environmental Protection Agency[63]. Furthermore, the two regulators require firms to obtain at least limited assurances from third-party auditors for their disclosures. Over the coming years, this lower bound is scheduled to rise to reasonable assurance, which is the same level expected for financial audits and is to confirm a faithful representation. Acknowledging data limitations, the US SEC excludes Scope 3 emissions from the assurance requirement.

As it becomes clear from the preceding analysis, the envisioned mandates by the EU and

US SEC will improve the information quality of corporate carbon disclosures. In particular, the specification of a firm's organizational boundary and of emission factors for calculating Scope 1 and 2 emissions will ensure the verifiability, neutrality, and completeness of the respective metrics. Yet, the envisioned mandates cannot ensure that the metrics of the GHG Protocol exhibit the information quality they could achieve. They also cannot ensure that all reported carbon information will be decision-useful primarily due to deficiencies inherited from the GHG Protocol. Crucial deficiencies include that the envisioned mandates establish no unique attribution of emissions to firms and insufficiently differentiate between realized, estimated, and expected future emissions. As a consequence, the total real-world atmospheric GHGs a firm controls at a particular point in time will remain unclear.

Future studies in this line of work can build on the taxonomy introduced here to develop a comprehensive carbon accounting system. Such a system can draw upon elements of the GHG Protocol and financial accounting standards to ensure that reported information on a firm's atmospheric phenomena is decision-useful. Crucial to this system will be the introduction of specific procedures for emissions embedded in goods and services traded across the system's boundary, that is, between firms that have adopted the system and those that have not. Such procedures will facilitate the system's adoption and maintain its integrity. Faithful accounting for GHG emissions will also allow for introducing performance measures for assessing the carbon footprint of firms and their products. Such measures can complement carbon border adjustment mechanisms[64], like the one envisioned by the EU[65]. They will also permit the credible specification of net-zero pledges and continuous monitoring of corporate decarbonization efforts.

References

[1] Nature. Make businesses truly sustainable. *Nature* **620**, 467 (2023).

[2] Hsu, A. *et al.* A research roadmap for quantifying non-state and subnational climate mitigation action. *Nature Climate Change* **9**, 11–17 (2019).

[3] Lui, S. *et al.* Correcting course: the emission reduction potential of international cooperative initiatives. *Climate Policy* **21**, 232–250 (2021).

[4] Bolton, P. & Kacperczyk, M. T. Firm Commitments (2022).

[5] Bjørn, A., Lloyd, S. M., Brander, M. & Matthews, H. D. Renewable energy certificates threaten the integrity of corporate science-based targets. *Nature Climate Change* **12**, 539–546 (2022).

[6] Krabbe, O. *et al.* Aligning corporate greenhouse-gas emissions targets with climate goals. *Nature Climate Change* **5**, 1057–1060 (2015).

[7] Gipper, B., Ross, S. & Shi, S. X. ESG Assurance in the United States (2022).

[8] Freiberg, D., Grewal, J. & Serafeim, G. Science-Based Carbon Emissions Targets (2021).

[9] Azar, J., Duro, M., Kadach, I. & Ormazabal, G. The Big Three and corporate carbon emissions around the world. *Journal of Financial Economics* **142**, 674–696 (2021).

[10] GHG Protocol. A Corporate Accounting and Reporting Standard (2004). URL `https://ghgprotocol.org`.

[11] Bingler, J. A., Kraus, M., Leippold, M. & Webersinke, N. Cheap talk and cherry-picking: What ClimateBert has to say on corporate climate risk disclosures. *Finance Research Letters* **47**, 102776 (2022).

[12] Klaaßen, L. & Stoll, C. Harmonizing corporate carbon footprints. *Nature Communications* **12**, 6149 (2021).

[13] Depoers, F., Jeanjean, T. & Jérôme, T. Voluntary Disclosure of Greenhouse Gas Emissions: Contrasting the Carbon Disclosure Project and Corporate Reports. *Journal of Business Ethics* **134**, 445–461 (2016).

[14] Jia, J., Ranger, N. & Chaudhury, A. Designing for Comparability: A foundational principle of analysis missing in climate reporting systems. (2022).

[15] Bajic, A., Kiesel, R. & Hellmich, M. Handle with Care: Challenges and Opportunities of using Company-Level Emissions Data for Assessing Financial Risks from Climate Change (2021).

[16] Fankhauser, S. *et al.* The meaning of net zero and how to get it right. *Nature Climate Change* **12**, 15–21 (2022).

[17] Downie, J. & Stubbs, W. Corporate Carbon Strategies and Greenhouse Gas Emission Assessments: The Implications of Scope 3 Emission Factor Selection. *Business Strategy and the Environment* **21**, 412–422 (2012).

[18] Rogelj, J., Geden, O., Cowie, A. & Reisinger, A. Three ways to improve net-zero emissions targets. *Nature* **591**, 365–368 (2021).

[19] Bjørn, A., Lloyd, S. & Matthews, D. From the Paris Agreement to corporate climate commitments: Evaluation of seven methods for setting "science-base" emission targets. *Environmental Research Letters* **16** (2021).

[20] Brander, M., Ascui, F., Scott, V. & Tett, S. Carbon accounting for negative emissions technologies. *Climate Policy* **21**, 699–717 (2021).

[21] Brander, M. & Bjørn, A. Principles for accurate corporate GHG inventories and options for market-based accounting (2023).

[22] Comello, S., Reichelstein, J. & Reichelstein, S. Transparency and Accountability on the Path to Net-Zero (2023).

[23] Bolton, P. *et al.* Mandatory Corporate Carbon Disclosures and the Path to Net Zero. *Management and Business Review* **1**, 1–21 (2021).

[24] Kaplan, R. S. & Ramanna, K. Accounting for Climate Change. *Harvard Business Review* (2021).

[25] Kaplan, R. S. & Ramanna, K. We Need Better Carbon Accounting. Here's How to Get There. *Harvard Business Review* (2022).

[26] Kaplan, R. S., Ramanna, K. & Reichelstein, S. Getting a Clearer View of Your Company's Carbon Footprint. *Harvard Business Review* (2023).

[27] FASB. Conceptual Framework for Financial Reporting (2006). URL `https://fasb.org`.

[28] IASB. Conceptual Framework for Financial Reporting (2018). URL `https://www.ifrs.org`.

[29] European Union. Directive (EU) 2022/2464 (2022).

[30] SEC. The Enhancement and Standardization of Climate-Related Disclosures for Investors (2022). URL `https://bit.ly/3D69X8Z`.

[31] ISSB. IFRS S2 Climate-related Disclosures (2022).

[32] GHG Protocol. Product Life Cycle Accounting and Reporting Standard (2011). URL `https://ghgprotocol.org`.

[33] Microsoft. Criteria for high-quality carbon dioxide removal (2021). URL `https://bit.ly/3k4Sfvj`.

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

[35] Elgin, B. & Rangarajan, S. What Really Happens When Emissions Vanish (2022). URL http://bit.ly/3w9EfDq.

[36] Toffel, M., Serafeim, G., Gino, F., van Sice, S. & Quinn, T. Fiji water: Carbon negative? (abridged) (2022).

[37] Matthews, H. S., Hendrickson, C. T. & Weber, C. L. The importance of carbon footprint estimation boundaries. *Environmental Science and Technology* **42**, 5839–5842 (2008).

[38] Esty, D., Cort, T., Strauss, D. & Yeargain, T. Toward Enhanced Sustainability Disclosure: Identifying Obstacles to Broader and More Actionable ESG Reporting (2020). URL https://bit.ly/3iO5FeV.

[39] Apple. Apple calls on global supply chain to decarbonize by 2030 (2022). URL https://bit.ly/3GyBtMJ.

[40] Lu, S., Serafeim, G. & Toffel, M. W. Driving Decarbonization at BMW (2022).

[41] The White House. FACT SHEET: Biden-Harris Administration Proposes Plan to Protect Federal Supply Chain from Climate-Related Risks (2022). URL https://bit.ly/3Xpm0p2.

[42] Brander, M. The most important GHG accounting concept you may not have heard of: the attributional-consequential distinction. *Carbon Management* **13**, 337–339 (2022).

[43] Bednar, J. *et al.* Operationalizing the net-negative carbon economy. *Nature* **596**, 377–383 (2021).

[44] Christensen, H. B., Hail, L. & Leuz, C. Mandatory CSR and sustainability reporting: economic analysis and literature review. *Review of Accounting Studies* **26**, 1176–1248 (2021).

[45] Downar, B., Ernstberger, J., Reichelstein, S., Schwenen, S. & Zaklan, A. The impact of carbon disclosure on financial performance under low carbon constraints. *Review of Accounting Studies* (2021).

[46] Grewal, J. & Serafeim, G. Research on Corporate Sustainability: Review and Directions for Future Research. *Foundations and Trends in Accounting* **14**, 73–127 (2020).

[47] Barker, R. & Mayer, C. How Should a Sustainable Corporation Account for Natural Capital? (2017).

[48] Ilhan, E., Krueger, P., Sautner, Z. & Starks, L. T. Climate Risk Disclosure and Institutional Investors. *The Review of Financial Studies* (2023).

[49] Flammer, C., Toffel, M. W. & Viswanathan, K. Shareholder activism and firms' voluntary disclosure of climate change risks. *Strategic Management Journal* **42**, 1850–1879 (2021).

[50] Schnackenberg, A. K. & Tomlinson, E. C. Organizational Transparency: A New Perspective on Managing Trust in Organization-Stakeholder Relationships. *Journal of Management* **42**, 1784–1810 (2016).

[51] Pahle, M. *et al.* Safeguarding the energy transition against political backlash to carbon markets. *Nature Energy* (2022).

[52] Hale, T. *et al.* Assessing the rapidly-emerging landscape of net zero targets. *Climate Policy* **22**, 18–29 (2022).

[53] Calel, R., Colmer, J., Dechezleprêtre, A. & Glachant, M. Do Carbon Offsets Offset Carbon? (2021).

[54] Tollefson, J. Climate pledges from top companies crumble under scrutiny (2022).

[55] Rathi, A., White, N. & Pogkas, D. Junk Carbon Offsets Are What Make These Big Companies 'Carbon Neutral' (2022). URL `http://bit.ly/40JeOXl`.

[56] Kaplan, R. S., Ramanna, K. & Roston, M. Accounting for carbon offsets – Establishing the foundation for carbon-trading markets (2023).

[57] Reichelstein, S. Corporate Carbon Accounting: Balance Sheets and Flow Statements (2023).

[58] The European Commission. European Green Deal: Commission proposes certification of carbon removals to help reach net zero emissions (2022). URL `https://bit.ly/3XC2nKt`.

[59] EFRAG. Draft European Sustainability Reporting Standards - ESRS 1 General requirements (2022). URL `https://www.efrag.org/lab6`.

[60] ISSB. IFRS S1 General Requirements for Disclosure of Sustainability-related Financial Information (2022).

[61] EFRAG. Draft European Sustainability Reporting Standards - ESRS E1 Climate Change (2022). URL `https://www.efrag.org/lab6`.

[62] The European Commission. EU Emissions Trading System (EU ETS) (2023). URL `http://bit.ly/3HeBSnO`.

[63] EPA. Direct Emissions from Stationary Combustion Sources (2020). URL `https://bit.ly/3Dobsiz`.

[64] Böhringer, C., Fischer, C., Rosendahl, K. E. & Rutherford, T. F. Potential impacts and challenges of border carbon adjustments. *Nature Climate Change* **12**, 22–29 (2022).

[65] Droege, S. & Fischer, C. Pricing carbon at the border: Key questions for the EU (2020).