Toward Decision-Useful Carbon Information

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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 GHG associated with a firm's economic activity. Applying the taxonomy, I find that information prepared under the widely used *Greenhouse Gas Protocol* generally fails to represent a firm's GHG emissions faithfully. Yet, if certain conditions prevailed, it would faithfully represent a share of those emissions. My findings highlight the need for revising the GHG Protocol as well as recently proposed carbon disclosure mandates and standards, which seek to produce *decision-useful* information but have also adopted the GHG Protocol.

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JEL Classifications: G18, M14, M41, Q54, Q56

1 Introduction

In the global effort to mitigate climate change, companies are increasingly viewed as crucial drivers for a timely transition toward a decarbonized economy[1;2]. Accordingly, over fifteen thousand companies worldwide have pledged to reduce the greenhouse gas (GHG) emissions associated with their economic activity[3]. Current accounting and reporting practices for GHG emissions, however, often leave corporate carbon disclosures and abatement efforts disputed among investors as much as climate advocates[4–6]. To improve the acceptance of their disclosures, companies have been seeking assurance from independent auditors and accreditation from the growing number of voluntary reporting initiatives[7;8]. Recognizing the continued potential of standardization, multiple regulators and standard setters have recently announced mandates and standards for corporate carbon disclosures[9–11].

This paper introduces a taxonomy for examining and ensuring the quality of GHG emissions reported by firms. In direct analogy to international financial accounting standards, the pervasive criterion for reported carbon information is to be *useful* to a firm's stakeholders in making decisions related to the firm. That is, the information is relevant and faithfully represents the actual changes in atmospheric GHG associated with a firm's economic activity. Earlier studies have suggested different ways to improve individual aspects of corporate carbon disclosures, including the comparability[12], consistency[13;14], and reliability[15;16] of reported emission numbers, the measuring of product carbon footprints[17], and the credibility of net-zero targets[18–20]. In contrast, this paper constructs a comprehensive system of qualitative characteristics of carbon information that is derived from generally accepted financial accounting principles[21;22].

Today's most widely used framework for accounting and reporting corporate emissions is the *Greenhouse Gas Protocol*[23]. Using the introduced taxonomy, I find that neither the principles nor the procedures defined in the GHG Protocol generally produce information that faithfully represents a firm's GHG 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. Furthermore, it allows firms to choose the scope, approach, and data for determining their emissions, which enables them to (unintentionally) understate emissions and overstate reductions.

Earlier concerns about the GHG Protocol include that emissions are counted multiple times by different firms and that the reported information is often biased[24], incomplete[25;26],

incomparable[12;27], intransparent[18], and inaccurate[28]. The taxonomy introduced here identifies the causes and gravity of these and other deficiencies. It also shows how the principles and procedures of the GHG Protocol impede individual qualitative characteristics of decision-useful carbon information. Furthermore, the taxonomy determines the conditions that, if they prevailed, would lead to information prepared under the GHG Protocol that faithfully represents a share of firms' GHG emissions.

The findings of this paper highlight the need for revising the carbon disclosure mandates and standards proposed by the European Union (EU), United States Securities and Exchange Commission (US SEC), and International Sustainability Standards Board (ISSB). These initiatives seek to ensure that the carbon information reported by firms will be *decision-useful*[9–11]. At the same time, they have adopted most procedures of the GHG Protocol. This paper shows that the mandates, as currently proposed, will improve the quality of corporate carbon disclosures by confining the room for firms to choose parameters favorably. Yet, they cannot ensure that the reported information will be decision-useful due to deficiencies inherited from the GHG Protocol.

2 Decision-Useful Carbon Information

The taxonomy introduced in this section is constructed in direct analogy to the conceptual frameworks underlying international financial accounting standards[21;22]. These frameworks provide the conceptual basis for the accounting procedures described in the standards by defining the objective of financial reporting and a comprehensive system of generally accepted accounting principles. Specifically, the frameworks seek to ensure that reported information on a firm's economic phenomena is *useful* to the users of financial information in making decisions related to the firm. The criterion of *decision-usefulness* is defined by the system of accounting principles and reflects the quality standard of financial information.

For the taxonomy, the central information is about a firm's atmospheric phenomena. These phenomena refer to changes in atmospheric GHG associated with the firm's economic activity. They include direct emissions of GHG to the atmosphere from the firm's operations and indirect emissions in trade with suppliers and customers whenever direct emissions occur up- or downstream in the value chain. They also include direct or indirect removals of carbon dioxide (CO_2) from the atmosphere attained via technological or nature-based solutions.

Users of such carbon information include internal and external stakeholders of the firm,

such as managers, investors, regulators, customers, and other stakeholders. These users can 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 manifold, including risk assessments, resource allocations, purchasing decisions, and policy choices. Importantly, the taxonomy focuses on the information required to understand the atmospheric phenomena and leaves their interpretation in the specific context of a decision to the users.

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. The usefulness of carbon information is enhanced if it is *timely*, *comparable*, and *understandable*. Meanwhile, its provision is constrained by *materiality* and *benefits* that need to justify costs. Figure 1 illustrates the hierarchy of these qualitative characteristics. Accordingly, either irrelevance or unfaithful representation leads to information that is not decision-useful. Enhancing characteristics improve while constraints limit the usefulness of carbon information, but neither can make information relevant or representationally faithful. The following subsections define and discuss the qualitative characteristics and constraints.

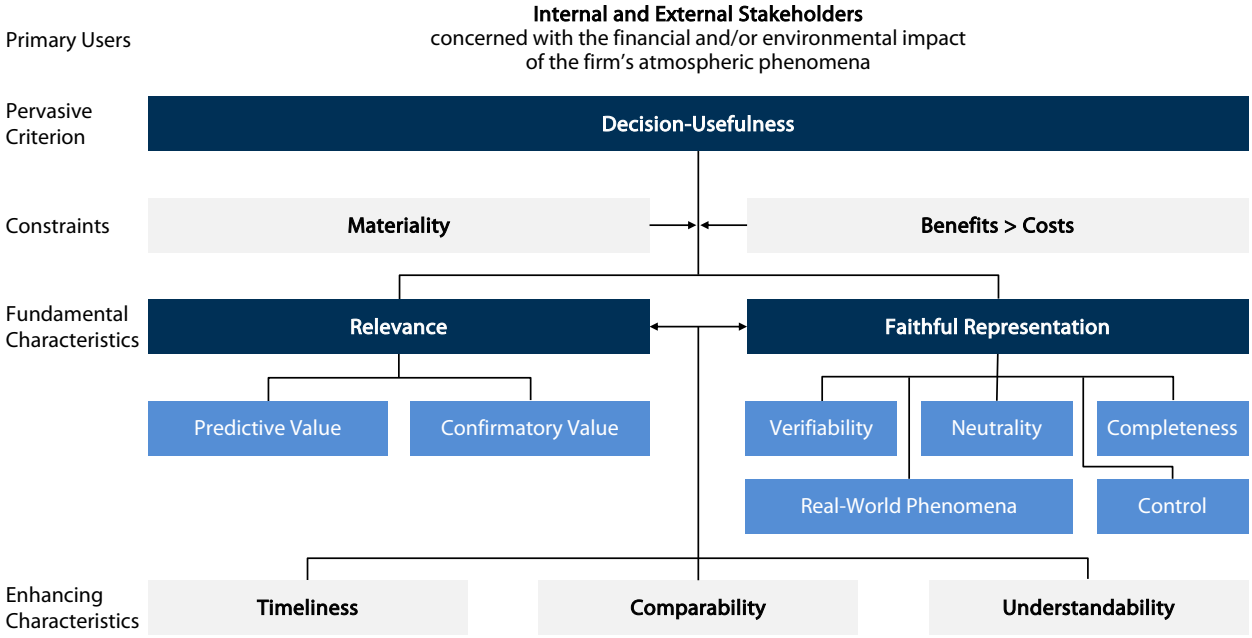

Figure 1. Taxonomy of decision-useful carbon information. Resembling the hierarchy of financial accounting principles, this figure illustrates the relationships between the qualitative characteristics of decision-useful carbon information.

2.1 Fundamental Characteristics

Table 1 provides the definitions for the fundamental characteristics of decision-useful carbon information, which are adapted from those for financial information[21;22]. Consistent with the definition of *relevance*, carbon information is increasingly included in corporate decisions. Investors state that it allows them to assess climate-related risks and opportunities. Emissions data are thus used in capital allocation decisions, including investment or voting decisions, insights into governance and risks management practices, integration into valuation models, as well as credit research and assessments[10]. Alternatively, companies and public institutions, including Apple[29], BMW[30], and the Federal Government of the US[31], plan to make quantitative carbon information a criterion for selecting suppliers. Furthermore, many consumer-oriented firms in Europe and the US have introduced (qualitative or quantitative) information on the GHG emissions associated with their products.

Table 1. Fundamental characteristics.

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 GHG 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 GHG.
◦ 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.

As stated in Table 1, a faithful representation obtains if and only if the information is a *verifiable*, *neutral*, and *complete* depiction of the *real-world atmospheric phenomena* that the reporting firm *controls*. Real-world atmospheric phenomena only include changes in atmospheric GHG that have occurred in the past to measure a firm's actual contribution to climate change so far. This distinction is crucial since firms today commonly aggregate emissions that have occurred with those expected to occur going forward[32]. Some firms even count removals pledged to be attained in the future against emissions that have already materialized[33]. Such aggregation obscures the actual changes in atmospheric GHG.

Control, as defined in Table 1, establishes a unique attribution of atmospheric phenomena to firms[34]. This is essential for resolving the frequent responsibility disputes over emissions today. For instance, industrial manufacturers of products like steel or cement regularly ignore emissions from burning waste as an alternative fuel based on the argument that these emissions would have occurred at nearby waste incineration plants[35]. But operators of such incineration plants note that they no longer burn the waste. 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 over emissions is consistent with transferring financial claims and obligations associated with the traded economic asset[36].

Verifiability ensures that the reported carbon information is free from error. Verification of atmospheric phenomena can be direct by checking a depicted phenomenon or indirect by checking the inputs and recalculating the outputs. It requires no single-point number since a range of possible amounts and the related probabilities can be verified. Over the past decade, over 50% of S&P 500 firms that disclosed corporate emissions requested assurance by an external auditor[7]. For about 90% of the reported emissions figures, though, the auditors could not verify the disclosures. Instead, they issued "limited" assurances, meaning that no evidence of misreporting had come to their attention.

Neutrality implies that emissions are not understated, while removals are not overstated. Today, firms can choose the scope of reported emissions or the methodology and data to calculate them. Accordingly, early findings suggests that firms have systematically reported lower emissions in corporate sustainability reports published on their websites than on CDP, a platform for corporate carbon disclosures[25;26]. In addition, firms might have cherry-picked favorable methodologies[24] or emission intensity factors[28] for calculating their emissions.

Finally, completeness means that no emissions and removals are omitted. Today, though, firms often report emissions for only a subset of procured goods and services[25;26;37]. Central to completeness is a firm's organizational boundary regarding the entities, operations, assets, and other holdings within the firm's organization. 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, the activities included for reporting atmospheric phenomena would be incomplete if they omitted activities included for reporting the firm's economic phenomena[10].

2.2 Enhancing Characteristics and Constraints

Table 2 shows the definitions of the three enhancing characteristics of decision-useful carbon information, which are also adapted from those for financial information[21;22]. All three characteristics are often not met today. For instance, companies regularly disclose their GHG emissions later than their financial statements, arguing that current procedures for preparing them are complex and laborious[27]. Impeding comparability, the form and content of corporate carbon disclosures vary substantially across firms and periods[12;27]. This variance mainly stems from companies preparing their disclosures based on different third-party frameworks[10], choosing their organizational boundaries according to alternative rules[26], or changing the scope of reported emissions across periods[25]. Impairing understandability, firms often disclose only partial information on the methodology, data sources, and assumptions used to determine their emissions[26]. The recent proliferation of voluntary carbon disclosure frameworks has further contributed to the reporting fragmentation[10;38].

Table 2. Enhancing characteristics.

Characteristic	Definition
Timeliness	Information is available to users in time to be capable of influencing their decisions.
Comparability	Users can identify similarities and differences between two sets of real-world atmospheric phenomena. Consistency facilitates comparability by requiring the same carbon accounting principles and procedures from period to period within a firm and in a single period across firms.
Understandability	Users with reasonable knowledge of atmospheric phenomena who study the information with reasonable diligence can comprehend its meaning. Comparability enhances understandability.

Like financial information, carbon information will be called *material* if its omission or misstatement can influence the decisions made by users. Materiality depends on the type and magnitude of a change in atmospheric GHG judged in the particular circumstances of its 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 emissions associated with all goods and services procured than if it amounts to 1%. Alternatively, the classification of direct emissions as indirect may not be material as long as both types are included. Studies in the finance and accounting literature have examined the financial materiality of corporate GHG emissions in monetary values[39–42]. For carbon information to be useful in financial and environmental impact assessments, concerns about whether the omission or misstatement of a particular phenomenon can influence decisions will have to be evaluated in tons of atmospheric GHG.

Finally, 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 on climate action, and informed decision-making by investors, managers, customers, policy-makers, and other stakeholders[9;10]. Meanwhile, the costs of disclosing carbon information 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[43;44]. Cost-benefit assessments are inherently subjective and will need to be conducted by the company, regulator, or standard setter adopting the taxonomy. Today, the issues of current practices described above are widely agreed to impede the benefits of carbon information while also causing significant costs[10;38].

Financial accounting standards are themselves subject to continuous revision. For instance, 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[45;46]. 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 constituting characteristics of verifiability, neutrality, and completeness[21;22]. Similarly, other decision criteria, such as *simplicity*, *preciseness*, *operationality*,

practicality, or *acceptability*, are considered components of the overall weighing of costs and benefits[21]. These considerations are directly applicable to corporate carbon information.

Earlier studies have suggested different ways to improve the quality of carbon information[12–15]. In particular, Brander et al.[32] propose that firms report emissions and removals when and where they occur. In addition, carbon removals are increasingly considered "high quality" only if they permanently sequester CO_2 from the atmosphere[47;48]. In the taxonomy introduced here, changes in atmospheric GHG are recognized by the controlling firm once they occur. As such, the taxonomy captures the suggestion by Brander et al.[32] without imposing a location requirement. It also imposes no permanence requirement for carbon removals as reversible phenomena are recognized separately at different points in time.

3 The Greenhouse Gas Protocol

Since its introduction in 1997, the GHG Protocol has become the most widely used methodology for accounting and reporting corporate GHG emissions. Public and private organizations worldwide have adopted it. In addition, it has been integrated into voluntary reporting frameworks (e.g., CDP, ISSB, Science Based Target Initiative, Task Force on Climate-Related Financial Disclosures, Value Reporting Foundation, and Global Reporting Initiative) and proposals of mandatory disclosure regulations (e.g., by the EU and the US SEC). The subsequent analyses assume that a reporting firm fully adheres to the GHG Protocol.

3.1 Current Information Quality

The objective of the GHG Protocol is to "*ensure that the reported information represents a faithful, true, and fair account of a company's GHG emissions*"[23]. Compared with the preceding taxonomy, this objective is focused on emissions and ignores removals. In addition, a true and fair account is generally considered equivalent to a faithful representation as it results from information being verifiable, neutral, and complete[21;22]. As discussed, a faithful representation is inferior to the criterion of decision-usefulness since information can be faithfully representative 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.*

To achieve its objective, the GHG Protocol defines principles and procedures for determining corporate GHG emissions. While the principles seek to provide conceptual guidance, the procedures describe individual steps for how to arrive at different numbers of corporate GHG emissions. Table 3 provides the principles and their definitions as stated in the GHG Protocol. In comparison with the taxonomy of decision-useful carbon information outlined in Figure 1, these principles and definitions show two main deficiencies. First, the selection of principles is adverse as it misses qualitative characteristics necessary for a faithful representation (i.e., verifiability, neutrality, control, and real-world atmospheric phenomena). At the same time, it includes principles that are no 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[21;22].

Table 3. 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.

Second, the principles' definitions are vague and confused. In particular, the definition of relevance describes a faithful representation but not what constitutes relevant information. Completeness, as defined in Table 3, allows firms to choose their boundary, which enables them to (unintentionally) omit emissions. The definition of consistency describes steps for improving understandability but not what constitutes consistency. Furthermore, the defini-

tion of transparency describes elements of verifiability and understandability, while the one for accuracy includes aspects of neutrality. Yet, both cannot be considered equivalent to the respective definitions in Tables 1 and 2. Finally, equivalent specifications for the criteria control, real-world atmospheric phenomena, and timeliness are not included in the definitions in Table 3.

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 can be organized into four main steps. As detailed in Box 1, firms first choose their organizational boundary regarding the included entities, operations, and economic assets. Then, they choose their operational boundary regarding the included share of Scope 1, 2, and 3 emissions. Afterward, they calculate the GHG emissions for each included entity and emission scope. Finally, they can account for carbon offsets obtained on the voluntary carbon market.

Box 1. Main Procedures of the GHG Protocol.

Step 1. Choose the Organizational Boundary. Companies owning or controlling other entities can choose between the so-called *equity share* or *control* approach for consolidating GHG emissions. Under the equity share approach, a firm accounts for the GHG emissions of associated entities according to its share of equity in the entities. Under the control approach, the firm determines the share of consolidated GHG emissions according to its perceived level of control over the entities. Different from Table 1, control refers to financial or operational control. Financial control describes the firm's ability to direct the "*financial and operating policies*" of an entity "*with a view to gaining economic benefits.*" Operational control is the firm's authority to *"introduce and implement operating policies"* at the entity[23].

Step 2. Choose the Operational Boundary. The GHG Protocol defines the operational boundary in terms of three emission scopes. Scope 1 emissions reflect direct emissions from a firm's operations within its organizational boundary. Scope 2 emissions are indirect emissions associated with energy (i.e., electricity, steam, heat, or cooling) consumed by the firm. Specifically, Scope 2 emissions seek to capture the share of the supplier's Scope 1 emissions resulting from the energy generation that is directly attributable to the firm's

consumption. Scope 2 emissions exclude overhead emissions from transmitting energy or operating the suppliers business. Finally, Scope 3 emissions are all other indirect emissions incurred by upstream suppliers and downstream customers of the firm. These emissions are differentiated into sub-categories and intended to capture the life-cycle emissions of goods and services[49].

Step 3. Calculate Corporate GHG Emissions. The general procedure for calculating corporate GHG emissions is that firms first identify all emission sources within the chosen boundaries. Then, they multiply a measure of activity at each emission source with a corresponding emission intensity factor that quotes the amount of GHG emitted per unit of activity. To describe the calculations formally, let q_i denote the measure of activity for emission source $i \in I_{j,x}$ of entity $j \in J$ within a given reporting period. $I_{j,x}$ denotes the set of all included sources of Scope x emissions for $x \in \{1, 2, 3\}$ of entity j, while J gives the set of included entities. Furthermore, let $\vec{e_i}$ denote the vector of emission intensity factors for all seven major GHGs and their aggregate value in CO_2 equivalents based on the latest estimates of the gases' global warming potential. Finally, let α_j reflect the chosen share at which the firm consolidates the emissions of entity j. Supposing that the firm exhibits no trade between included entities, the firm's total periodical Scope x emissions are given by:

$$\sum_{j \in J} \alpha_j \sum_{i \in I_{j,x}} q_i \cdot \vec{e_i}. \tag{1}$$

For Scope 1 emissions, values for q_i are usually 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 retrieved from the firm's records, and the emission factors from public databases. For Scope 2 emissions, firms can sometimes use their energy bills for activity and emission data. If energy suppliers provide no information on emissions, firms can resort to average intensity factors from public databases. For Scope 3 emissions, the GHG Protocol recommends that firms use, as much as possible, primary information on all production steps and the corresponding activity and emission data from their multiple-tier suppliers and customers. Acknowledging the practical difficulty of collecting such data, the GHG Protocol allows firms to estimate emissions based on exemplary production processes and industry averages[50]. Values for q_i 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.

Step 4. Account for Carbon Offsets. Finally, firms can account for carbon offsets obtained on the voluntary carbon market. Carbon offsets are certificates of the avoidance or removal of GHG through mitigation projects. Frequent examples include afforestation, forest protection, the deployment of renewable power plants, or the installation of direct air capture facilities[47]. The amount of GHG compensated through such projects is calculated as the difference between the emissions associated with a project and a baseline representing a hypothetical scenario for what emissions might have been without the project. Central to this calculation is that project developers can demonstrate that their project is additional and not the baseline itself. This additionality has initially been intended to ensure the integrity of a fixed emissions cap under a GHG emission program, such as the European Emission Trading System, for which the offset might be used.

For reporting, the GHG Protocol requires firms to disclose the chosen organizational boundary and consolidation approach. They must also report their Scope 1 and 2 emissions, while reporting Scope 3 emissions and carbon offsets is optional. Firms that include Scope 3 emissions must specify which sub-categories are covered. If they report carbon offsets, the GHG Protocol recommends that firms detail which have been verified and approved by an external GHG program. For each reported emission scope, firms need to disclose the total amount of all seven major GHGs separately in metric tons and the overall aggregate in tons of CO_2 equivalents, in both cases without the impact of any carbon offsets.

In light of the taxonomy, it shows that the procedures of the GHG Protocol also exhibit two main deficiencies. First, they inherently lead to fuzzy information. As detailed in Box 1, Scope 2 and upstream Scope 3 emissions seek to capture the real-world emissions the firm has obtained from upstream suppliers who incurred them in their production processes. Based on exemplary production processes and industry averages, the calculations by the reporting firm can, at most, return an estimate of these emissions. Downstream Scope 3 emissions seek to capture expected emissions the firm's customers will incur by using or consuming the firm's goods or services. These emissions reflect no real-world phenomena, and their realization lies outside 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 include leeway 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. Accordingly, early evidence suggests that companies have taken advantage of this flexibility by choosing parameters favorably[25;26;28]. Together, the two deficiencies impair the comparability and understandability of reported information. They also increase the complexity 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.*

Information resulting from the GHG Protocol is today widely treated as if it faithfully represents 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[33;51]. However, the preceding analysis shows that deficiencies in the principles and procedures of the GHG Protocol obscure the actual changes in atmospheric GHG 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 GHG to the atmosphere than removals from it[52–54].

3.2 Potential Information Quality

An immediate question now is what information quality the GHG Protocol can achieve if certain conditions were to prevail. To examine this, consider firms with well-defined organizational boundaries, such as individual entities that do not partially own or control other entities. All three emission scopes and carbon offsets reflect relevant information that already affects decisions[10]. Yet, it remains open to what extent these metrics also reflect a verifiable, neutral, and complete depiction of a firm's atmospheric phenomena.

Scope 1 emissions seek to capture all direct emissions from a 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. 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 selecting emission factors without bias whenever multiple ones are applicable. One way for firms 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 the supplier's Scope 1 emissions are a verifiable, neutral, and complete depiction of the direct real-world emissions the supplier has controlled. With the energy supply, the reporting firm then obtains control over its share of the supplier's Scope 1 emissions. Suppose also the supplier faithfully represents the emissions that are directly attributable to the firm's consumption on the energy bill. The firm can then 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.

Upstream Scope 3 emissions effectively reflect estimates of the real-world emissions the reporting firm has obtained from suppliers. Downstream Scope 3 emissions, by construction, reflect estimates of the expected emissions customers will incur. Estimations are verifiable to the extent that the particular calculation done by the reporting firm has been conducted without error. For auditors to conduct 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 can be more or less elaborate depending on the available information.

A widespread opinion is that the shortcomings of upstream Scope 3 emissions are mainly due to limited data availability. Indeed, if the reporting firm could hypothetically obtain

primary information on the direct emissions of all multiple-tier suppliers, upstream Scope 3 emissions would reflect real-world emissions the firm has obtained from its suppliers. Since this is practically near impossible, firms could build upon 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[16;55–57]. Upstream Scope 3 emissions are then determined in a recursive and informationally decentralized manner along the supply chain[58]. The reporting firm thus needs to obtain information on upstream emissions not from all multiple-tier suppliers but only from its immediate ones. This approach depends on suppliers in the value chain faithfully representing the GHG emissions that the traded goods and services have accumulated. Yet, public and private organizations worldwide seek to make quantitative carbon information a criterion for selecting suppliers[29–31].

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, attained removals reflect real-world phenomena the project developer has controlled. The calculation of these removals can then be simplified and symmetric to the calculation 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. Also, the project developer still needs to demonstrate the project's additionality.

4 Policy Implications

Recognizing the potential of standardized carbon information, the EU, US SEC, and ISSB plan to introduce mandates and standards for corporate carbon disclosures[9–11]. According to the corresponding proposals, these initiatives seek to ensure that reported information on a firm's atmospheric phenomena will be decision-useful. The proposal by the US SEC provides no details on what constitutes decision-useful carbon information. In contrast, 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 2, but they omit characteristics corresponding to control and real-world atmospheric phenomena.

For determining corporate GHG emissions, all three proposals have generally adopted the procedures of the GHG Protocol[10;11;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 proposals by 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 Emission Trading System[62] and the US SEC to those of the US Environmental Protection Agency[63]. Furthermore, the two proposals 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.

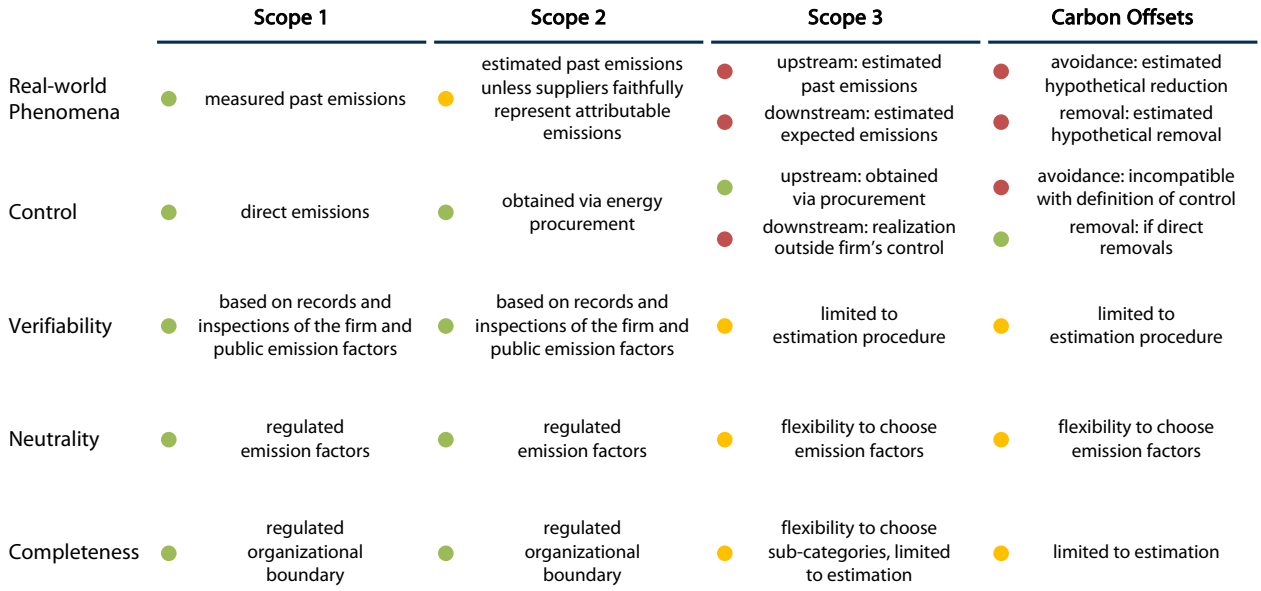

Figure 2. Information quality of metrics. This figure illustrates to what extent the metrics of the GHG Protocol prepared under the envisioned mandates by the EU and US SEC reflect a verifiable, neutral, and complete depiction of a firm's atmospheric phenomena.

As Figure 2 illustrates, 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 achieve 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 amount of real-world atmospheric GHG a firm controls at a particular point in time will remain unclear.

5 Conclusion

Current accounting practices for GHG emissions often leave corporate carbon disclosures and abatement efforts obscured. This paper 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 GHG 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 certain conditions were to prevail, it would faithfully represent a part of those emissions. My findings also highlight the need for revising the recently announced carbon disclosure mandates and standards, which seek to produce decision-useful information but have also adopted the GHG Protocol.

Future studies in this line of work can build upon 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.

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