# Innovations in Corporate Carbon Accounting

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January 2025

Forthcoming: **Foundations and Trends in Accounting**

[1] I am grateful to T. Becker, M. Carrara, C. Ernst, G. Glenk, J. Glover (editor), P. Holler, L. Lerner, R. Meier, S. Penman and M. Szabo for helpful comments and suggestions.

## Abstract

With the climate crisis intensifying in urgency, the stakeholders of global companies are clamoring for more reliable reporting regarding a company's overall carbon footprint as well as the emissions attributed to individual products and services. In this article, I synthesize recent innovations by select firms, industry consortia, and academic studies in the field of corporate carbon accounting. These innovations pertain to the architecture of a firm's carbon accounting system, for instance, the adoption of transactional double-entry bookkeeping that enables stock variables to be tracked separately from periodic flow variables. In addition to questions of architecture, recent contributions to the field of carbon accounting have raised a host of specific accounting issues pertaining to boundaries, allocation rules and the recognition of carbon credits. Ideally, these issues will be addressed through a set of commonly accepted carbon accounting principles, akin to Generally Accepted Accounting Principles. Wide adoption of such principles would enhance the comparability and reliability of corporate carbon reports, and thereby provide companies with stronger long-term incentives to embark on effective decarbonization pathways.

JEL classification: M41, M48, Q53, Q54.

## 1. Recent Developments in the Field of Carbon Accounting

A growing number of multinational companies have in recent years taken steps to improve their in-house capabilities to measure and report the greenhouse gas emissions resulting from their operations. Investments in these capabilities appear to be motivated by both *regulatory* and *transparency* considerations. [2] This article delineates recent contributions from both practice and academia to the emerging field of corporate carbon accounting.

The Greenhouse Gas (GHG) Protocol arguably remains the most common reference framework for companies to report their greenhouse gas emissions (World Resources Institute, 2004).[3] While voluntary disclosures about carbon emissions have mostly been within the framework of the GHG Protocol, it is important to note that such reporting has not required companies to adopt their own internal carbon accounting system. Instead, it has been common practice to outsource the assessment of a company's carbon emissions to outside consultants who typically perform a life-cycle analysis of the emissions associated with all of a company's production activities.[4] By their very nature, these assessments are typically based on secondary data that reflect historical industry averages rather than primary company-level data based on actual emissions currently incurred by specific suppliers and customers.[5]

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[2] A recent blogpost by McKinsey argues that the domain of corporate carbon reporting, like the domain of financial reporting, is increasingly viewed as within the purview of the CFO's office (Ahlawat et al., 2024).

[3] Throughout this article, carbon emissions refer to tons of carbon dioxide equivalents, that is either tons of $CO_2$ or tons of another greenhouse gas, e.g., $CH_4$, that have been adjusted with a multiplier to reflect the global warming potential of that gas relative to $CO_2$.

[4] Comprehensive reporting of Scope 3 emissions in accordance with the GHG Protocol presents companies with considerable data collection challenges. Focusing on the computer technology industry, a study by Klaassen and Stoll (2021) concludes that firms generally underreport their Scope 3 emissions by about half relative to the categories identified by the GHG Protocol.

[5] Becker (2024) points out the enormous duplication of efforts that are required if every party in a supply chain on its own seeks to assess and audit the emissions that were incurred by all parties preceding it in the supply chain.

The so-called Carbon Border Adjustment Mechanism, to be implemented by the European Union (EU) in 2026, provides a compelling reason for companies to track the actual emissions embodied in individual products to be imported to the EU, e.g. kg of $CO_2$ embodied in a ton of steel manufactured by a particular steel maker in India (European Commission, 2023a). Since cross border carbon taxes will be based on assessed product carbon footprints, companies and European regulators will need to have a common understanding of the accounting methodology to be applied in calculating the $CO_2$ emissions attributed to goods crossing into the EU.

Environmental Product Declarations provide another example in the context of Germany, where companies in select industries have an obligation to account for the $CO_2$ embodied in their sales products. For instance, in order to participate in procurement auctions for public construction projects, cement manufacturers must submit Environmental Product Declarations that document the emissions incurred in producing the particular cement recipe that the bidder is entering into competition (Meier, 2023). Procurement agencies have indicated that the reported carbon content of the cement recipe will become a criterion for selecting contract suppliers.

Countries like the US have offered tax subsidies for low-carbon products depending on a product's assessed carbon intensity (kg of $CO_2$ per unit of the product). For instance, under the Inflation Reduction Act of 2022, production tax credits are available for different types of hydrogen that can be obtained from several competing production technologies. The U.S. Internal Revenue Service has considered a range of acceptable accounting methodologies that respondents can employ to document their eligibility for tax credits (Internal Revenue Service, 2022).[6] For electrolytic hydrogen, sometimes referred to a green hydrogen, manufacturers then

[6] Similarly, French consumers are eligible for cash bonuses on purchased cars, provided the cars are classified as environmentally friendly. Eligibility for this bonus hinges on the $CO_2$ emissions required to manufacture the components of the car being below some threshold value (Pinneau and Guillaume, 2023). One issue of particular

need to document the carbon intensity of the electricity consumed in the electrolytic conversion process (Holler et al., 2025).

Aside from regulatory considerations, the objectives of enhanced reliability and transparency appear to have motivated some companies to invest in their own internal carbon accounting capabilities. The motivation for such in-house capabilities appears to be directly connected to the wave of net-zero pledges that most Fortune 500 companies have issued in recent years.[7] Going substantially beyond a pledge concerning the coming decades, some consumer product companies, including Delta Airlines, Shell, Nestlé and Total, have begun to advertise select products as being already "carbon neutral" (Bloomberg Green, 2021, Greenfield, 2023). These claims have been met with widespread criticisms of greenwashing by environmental protection groups (Tollefson, 2022). In response, the European Union has issued directives to discourage frivolous green claims in 2023 (European Commission, 2023b). Court rulings in Germany have taken the position that companies must have a meaningful methodology in place that allow s them to back up any voluntary claims regarding the carbon neutrality of their products (Zajonz, 2023).

Responding to demands by its customers for transparent and reliable product level disclosures, the German company BASF developed a software tool that assigns carbon footprint figures to its more than chemical 40,000 sales products (Saling et al., 2024; BASF, 2022b; Ahlawat, 2024). Referred to as the Strategic $CO_2$ Transparency Tool (acronym SCOTT), BASF has further licensed this tool to its suppliers in order for them to adopt a consistent carbon footprint accounting methodology for intermediate products sold to BASF (BASF, 2022a).

importance is whether the carbon intensity of the electricity consumed in the manufacturing process is determined by the carbon intensity of the grid (kg of $CO_2$ per kilowatt hour) in the country of origin (ETA, 2024).

[7] Results from 2022 surveys suggest that by now more than two-thirds of the Fortune 500 companies have articulated the goal of running their operations with net-zero carbon emissions by the year 2050 (Gill, 2022; Hale et al., 2022, Fankhauser et al., 2021).

The apparent parallels between conventional product costing and the measurement of product carbon footprints suggests that corporate carbon accounting systems also rely on an architecture that tracks the emissions associated with operational transactions through a system of double-entry bookkeeping (Sessar, 2023; Reichelstein, 2024a, Friedl, 2024, Lethmate, 2024; Distler et. al, 2024). Accordingly, the Green Ledger enterprise software, released by SAP in late 2024, is anchored in a system of double-entry bookkeeping for carbon emissions (Ernst, 2024; Asam et al., 2024; Distler et al. 2024). Once corporate carbon accounting systems are implemented as part of a firm's enterprise resource planning system, auditors should face a far more manageable task in certifying firms' carbon disclosures.

## 2. Architecture of Corporate Carbon Accounting Systems

According to the framework of the Greenhouse Gas Protocol (GHG), a company's emissions comprise both its own direct (Scope 1) emissions as well as its indirect (Scope 2 and 3) emissions. As illustrated in Figure 1, Scope 3 includes both the upstream emissions incurred by the firm's suppliers and the downstream emissions incurred during the use phase of the firm's sales products. Scope 2, a subcategory of the broader pool of upstream Scope 3 emissions, pertains only to emissions associated with purchased energy, specifically electricity and heat. The rationale for carving out the separate Scope 2 category presumably reflects that in many industries this emissions category appears to be easier to assess than other indirect emissions in the Scope 3 category.[8]

[8] The reporting mandate formulated by the U.S. SEC in 2024 pertains only to Scopes 1 and 2 emissions (Security and Exchange Commission, 2024). Similarly, the Companies Act of 2013 in Britain mandates that publicly listed companies in Britain report their current Scope 1 and 2 emissions in their annual reports (Downar et al. 2021). Beginning in 2025, the European Sustainability Reporting Standards requires publicly listed firms to report their Scope 1 – Scope 3 emissions (European Commission, 2023c).

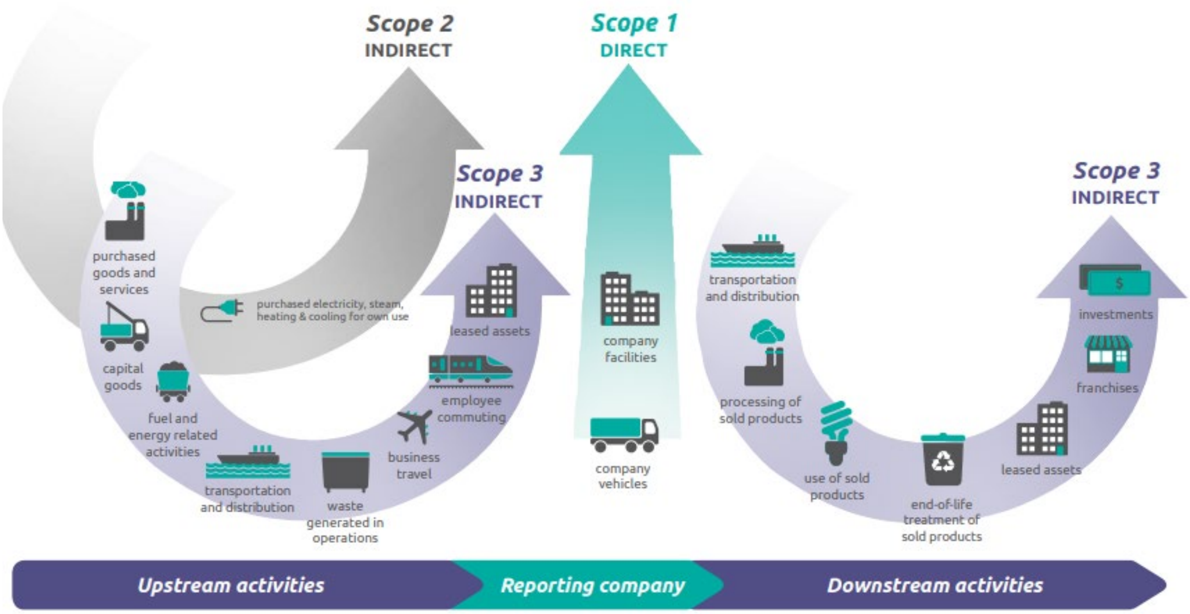


Figure 1: **Greenhouse Gas Protocol** Source: WRI (1998)

The emission categories shown in Figure 1 indicate that the GHG Protocol does not call for an apportioning of the emissions associated with long-term operating assets, e.g., emissions embodied in the construction of a building, to multiple time periods (Glenk, 2024). Put differently, the GHG protocol does not call for a distinction between stock and flow variables, a distinction that is at the core of both financial and cost accounting. Neither does the GHG Protocol derive the carbon footprint measure for an entire company as the aggregate of the carbon footprints of its individual products and services.

In choosing an architecture for a *Corporate Carbon Accounting* (CCA) system, companies must fundamentally decide on the scope of emissions for which they assume responsibility. An airline, for instance, might limit its responsibility to the $CO_2$ its airplanes emit directly by burning kerosene as part of the airline's flight operations. Alternatively, the airline may consider itself at least indirectly responsible for the emissions embodied in the airplanes procured from different OEMs. Such an expanded notion of responsibility seems warranted in most industries, for otherwise the mere outsourcing of carbon intensive production steps could already lower a company's reported carbon footprint.

Select European companies, including BASF, BMW and Heidelberg Materials, have in recent years built up in-house capabilities to assess the *cradle-to-gate* Product Carbon Footprint (PCF) of individual products and services.[9] In contrast to the cradle-to-grave perspective of the GHG Protocol, cradle-to-gate PCFs measures seek to include all emissions embodied in a product, beginning with the extraction of raw materials and ending at the stage where the product is shipped to the firm's customers.[10]

Some companies, including BASF, have pioneered a *decentralized* system of calculating the carbon footprint of intermediate products that are passed along the company's supply chain. In direct analogy to the structure of inventory costing, inputs acquired from suppliers then carry a carbon balance -- a tag -- that reflects the emissions accumulated up to that stage in the supply chain.[11] The receiving business, in turn, relies on its own internal carbon accounting system to calculate the cradle-to-gate PCFs of its sales products based on the carbon content for acquired inputs-- the $CO_2$ tags issued by suppliers -- and a share of its own actual emissions.[12]

Taking the architecture of cost accounting systems as a template, the determination of product carbon footprints can be grounded in transactional bookkeeping that allows for individual work-in-process accounts to be debited with both the direct and indirect emissions

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[9] See, for instance, Meier (2022), Landaverde et al. (2023), HeidelbergCement (2021), BASF (2022b), Kurtz (2022), Kaplan, Ramanna and Reichelstein (2023), Becker (2024), BMW Group Vehicle Footprint Reports (2024).

[10] In 2024, BMW pioneered a new corporate carbon steering tool, CO2MOS, for Scope 3 emissions. It takes product carbon footprint data of select vehicles and extrapolates from this data to the entire product portfolio. BMW achieved "reasonable assurance" from its auditors for this assessment, the first automotive OEM worldwide to do have received such certification (BMW Group Report, 2023; Lu et al. 2024).

[11] To ensure consistency and transparency in the decentralized footprint calculations, BASF has made its SCOTT tool available to its suppliers (Saling et. al, 2024). Further, the carbon accounting systems put in place by BASF's suppliers are subject to certification.

[12] Kaplan and Ramanna (2021) refer to this sequential approach of passing on product carbon balances along supply chains as the E-Liability method.

accumulated at different stages of the production process.[13] Such carbon accounting systems can also comprise multiple emission pools (the equivalent of cost pools) in which emission balances are accumulated during the production process. Through a sequence of calculation steps, these balances are ultimately assigned (allocated) to the company's sales products. While there will frequently be multiple "reasonable" allocation rules to choose from, one universal constraint on these rules is that they must be *balanced:* every kg of $CO_2$ accounted for at a particular stage, either directly or indirectly, is assigned to one -- and only one -- emissions 'object', and ultimately to one end product.

If all companies along a firm's supply chain adopt their own in-house carbon footprint measurement system, the resulting cradle-to-gate PCFs that are passed along the supply chain will reflect an allocated share of each company's actual direct emissions, an allocated share of those actually incurred by its immediate suppliers, their suppliers' suppliers, and so forth up the entire supply chain. [14]

As described here, the sequential and decentralized method of accounting for emissions in a supply chain has two desirable features. First, there should be no double counting of emissions attributed to an individual product or service. Double counting is one of the frequent concerns mentioned in connection with the Greenhouse Gas Protocol (Glenk, 2024). Second, the focus on emissions actually incurred in a supply chain results in a desirable substitution of secondary by primary data. [15] The focus on actual emissions incurred is crucial from an incentive perspective. When companies undertake costly effort efforts to reduce their own direct emissions or the indirect emissions incurred by their suppliers, the reported cradle-to-gate PCFs

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[13] The CCA system described in Reichelstein (2024a) records the corresponding credits on the firm's carbon emissions balance sheet (see Figure 3 below) either in the account for *Direct Emissions* or the account *Emissions Transferred In*, with the latter account recording emissions acquired from suppliers.

[14] This feature is readily seen in the context of a stylized hierarchical supply network in which each firm assembles and sells a single indivisible intermediate product, which, in turn, is assembled from components procured by that firm's Tier 1 suppliers. In such production networks there would be no need to allocate emissions among different products. The resulting cradle-gate PCFs then simply are the sum of the direct emissions incurred by all parties preceding it in the hierarchical supply network.

[15] External databases may provide an effective default solution for calculating PCFs in supply networks where some of the companies have not installed their own in-house PCF measurement system.

will immediately and fully reflect these reductions. In stark contrast, the incentives to reduce direct or indirect emissions are effectively muted if reported PCFs are based on secondary data obtained from historical industry averages.

The individual Product Carbon Footprint (PCF) measures can be aggregated into an annual *Carbon Emissions in Goods Sold* (CEGS) metric. As illustrated in Figure 2, CEGS is obtained as the sum of the individual carbon intensities (i.e., PCFs) multiplied with the current sales quantity of each product. Certain emission categories, such as employee travel, may not be viewed as sufficiently related, in a causal sense, to any of the products currently sold (Catena-X, 2023; BASF 2021b). Nonetheless emissions related to employee travel can be included in the measure of the company's current corporate carbon footprint if that metric is to capture the Scope 1, Scope 2 and upstream Scope 3 emissions incurred in connection with a company's current operations. This suggests recognizing emissions not sufficiently related to any of the firm's sales products as "period expenses" in line items under the category General and Administrative (G&A) emissions. The sum of CEGS and G&A emissions then yields the company's current CE flow. In direct analogy to profits or losses in financial accounting, a company's CE flow provides a measure of its current corporate carbon footprint. Expressed in tons of $CO_2$, this metric indicates the damage that the delivery of the firm's products sold in the current period, in conjunction with the current period G&A emissions, have contributed to the global climate.

It is worth emphasizing that the CE flow metric is a suitable measure of a firm's current corporate carbon footprint only if the firm assumes responsibility for its own direct emissions and the indirect emissions attributed to the inputs acquired from suppliers.  For the CE flow measure to represent a "profit" (gain), rather than a loss, the business would have to engage in negative emissions in the form of carbon removals. As discussed further in Section 4 below, direct removals can be recognized in individual PCFs (effectively becoming a source of "revenue"), or in a lump- sum fashion as negative G&A emissions the CE Flow Statement.

| | | |
|---|---|---|
| $PCF_1 \cdot s_1$ | = | CE in Sales of Product *1* (in t of $CO_2$) |
| $PCF_2 \cdot s_2$ | = | CE in Sales of Product *2* (in t of $CO_2$) |
| . | = | . |
| . | = | . |
| . | = | . |
| $PCF_n \cdot s_n$ | = | CE in Sales of Product *n* (in t of $CO_2$) |
| $\sum PCF_i \cdot s_i$ | = | **Carbon Emissions in Goods Sold (CEGS)** |
| $X$ | = | General & Administrative Emissions |
| $\sum PCF_i \cdot s_i + X$ | = | **CE Flow** |

Figure 2: **CE Flow Statement**

At the close of the accounting cycle, the CE Flow metric can be reconciled to a *CE Balance Sheet*. As illustrated in Figure 3, this balance sheet represents carbon stock variables that are carried across time periods. The ending balances (EB) for the accounts on the asset side report the emissions embodied in the firm's operating assets. For long-term assets (capital goods), the account balances report current book values, which are calculated as the original carbon balances of the acquired assets less accumulated depreciation and amortization charges. In contrast, the account balances for work-in-process or finished goods are comprised of the indirect emissions embodies in acquired inputs as well as a share of the firm's direct emissions.

The liability side of the CE balance sheet shows the emissions that have been accumulated either directly by the firm itself in the account *Direct Emissions*, or indirectly by the firm's suppliers in the account *Emissions Transferred In*. The account *Direct Removals* is effectively a contra-liability account. By definition, its balance is always negative (as indicated by the parentheses) so that the sum of Direct Emissions and Direct Removals represents the cumulative Net Direct Emissions (NDE) incurred by the firm. The difference between the ending and beginning balance in NDE therefore shows the company's current NDE. We note that this metric is additive in the sense that the change in net direct emissions across all economic entities (companies, households and other emitting entities) is equal to the current total emissions into the atmosphere, less current removals from the atmosphere.[16]

<table>
<tr><th colspan="2">CE in Assets</th><th colspan="2">CE in Liabilities and Equity</th></tr>
<tr><td>Buildings</td><td>$EB_{BLD}$</td><td>$EB_{ETI}$</td><td>Emissions Transferred In</td></tr>
<tr><td>Machinery & Equipment</td><td>$EB_{MAC}$</td><td>$EB_{DE}$</td><td>Direct Emissions</td></tr>
<tr><td>Raw Materials</td><td>$EB_{MAT}$</td><td>$(EB_{DR})$</td><td>Direct Removals</td></tr>
<tr><td>Work-in Process</td><td>$EB_{WIP}$</td><td rowspan="2">$EB_{EQ}$</td><td rowspan="2">Equity</td></tr>
<tr><td>Finished Goods</td><td>$EB_{FG}$</td></tr>
</table>

Source: Adapted from Reichelstein (2024a)

Figure 3: **CE Balance Sheet**

By construction, the carbon emissions in assets and liabilities are balanced via the *Equity* account that effectively represents a firm's *legacy* emissions. In direct analogy to how owners' equity represents retained profits and losses in financial accounting, the Equity account records the sum of the CE flows that have been accumulated in past periods[17]. As long as a firm's sales products have positive PCFs (gross emissions exceed any applicable carbon credits), the annual CE flow will add further "losses" to the firm's Equity account. The corresponding final

[16] For the year 2024, the sum of all current net direct emissions is likely to be close to 40 billion tons of $CO_2$ (Friedlingstein et al, 2023). This figure has remained stable in recent years. It does not include other greenhouse gas emissions such as methane.

[17] There are several practical approaches to setting up an initial balance sheet that estimates the emissions dating back for a certain number of time periods prior to the year in which the initial balance sheet is issued (Reichelstein 2024a). In the simplest variant, all accounts on the initial CE balance sheet are set zero and therefore there would be no need to estimate the emissions incurred prior to the initial accounting period.

bookkeeping entry that reconciles the CE flow statement to the CE balance sheet therefore becomes:

$$Change\ in\ Equity = -(CE\ Flow).$$

In closing this section, we note that the CCA system described here has taken a historical cost perspective by seeking to capture the emissions actually incurred in the current period and in past periods. A common practice in managerial accounting is to contrast actual cost figures with standard costs that are based on ex-ante budgeted values for products and services (Datar and Rajan, 2020). Comparison of standard and actual cost figures then enables a comprehensive variance analysis that allows management to pinpoint either inefficiencies or unforeseen developments that have occurred in different parts of the organization. Similar management planning and control considerations may motivate companies to design their CCA systems so that ex-ante standard values for PCFs can be compared ex-post with actually incurred emissions.[18]

## 3. Carbon Management Based on Key Emission Performance Indicators

One central purpose of adopting an in-house carbon accounting system is to enable management to steer the company on its path towards decarbonization.[19] Such steering, in turn, requires the CCA system to generate several Key Emission Performance Indicators (KEPIs). Like key financial metrics derived from financial statements, the CCA systems described here yield several key indicators by which management can gauge whether the company is on track

[18] The carbon accounting system described in Penman (2024) also seeks to reconcile past projections with actual results delivered. In contrast to the historical cost approach described above, Penman (2024) envisions an accounting system that allows companies to capitalize investments that are expected to reduce the firm's emissions in the future. These investments then represent *carbon emission assets* as opposed to the *carbon emissions in assets* represented on the left-hand side of the CE Balance sheet shown in Figure 3 above. The assets in Penman's framework are counterbalanced by corresponding liabilities such that subsequent changes to assets and liabilities are reconciled through an income statement showing the company's actual Scope 1 emissions for the current period.

[19] Recent articles by Asam et al. (2024), Saling et al. (2024) and Becker (2024) all emphasize this fundamental purpose.

to meet any self-selected emission reduction targets, e.g., to achieve a net zero position by 2050. When reported externally on a regular basis, these KEPIs will also be informative for analysts and external stakeholders in assessing a company's current standing in its overall carbon transformation process, as well as its prospects for future progress.

Provided companies assume responsibility for their Scope 1, Scope 2 and upstream Scope 3 emissions, the periodic CE flow is arguably the most comprehensive KEPI. However, in contrast to the carbon intensities assigned to individual products (i.e., kg of $CO_2$ per unit), the CE flow metric is an absolute figure the magnitude of which will partly reflect growth or contraction in the firm's operations. One way to control for changes in operational size is to calculate an Average Carbon Intensity (ACI), given by the ratio:

$$ACI = \frac{CEGS}{COGS}.$$

For a car manufacturer, the aggregate *ACI* metric would then report the average number of kg of $CO_2$ per dollar of manufacturing cost incurred for the cars sold in the current period.[20] For a cement company with a homogeneous product portfolio, it will suffice to add up the production quantities of different recipes in order to arrive at an ACI that yields the kg of CO2 per ton of cementitious material (Landaverde et. al, 2023).

The CE flow statement can be supplemented with line-item information about individual PCFs by disclosing the percentages pertaining to direct (Scope 1) and indirect (Scope 2 and upstream Scope 3) emissions, respectively. Companies that acquire removal credits to reduce the PCF of targeted consumer sensitive products can achieve additional transparency by disclosing the magnitude of any applicable removal credits that were applied to these products.

[20] Alternatively, if a significant share of a company's current upstream Scope 3 emissions are not viewed as inventoriable, but are recognized as G&A emissions, it might be more appropriate to consider the ratio:

$$ACI^{+} = \frac{CEGS + G\&A\ Emissions}{COGS + SG\&A\ Expenses} = \frac{CE\ Flow}{COGS + SG\&A\ Expenses}.$$

We recall that, in contrast to the cradle-to-gate emissions perspective taken in this paper, the GHG Protocol takes a cradle-to-grave perspective that also seeks to hold companies accountable for carbon emissions incurred during the use phase of a product. By their very nature, the emissions that a product will cause during the use phase can at best be estimated, but not measured, at the time the sales product leaves the company's gates. For commodities, like steel or chemicals, the estimation of use phase emissions seems particularly daunting as these commodities could become parts in a potentially large variety of end products.[21] In contrast, use phase emissions can arguably be estimated with greater statistical confidence for mass-produced items sold directly to consumers. These considerations strongly suggest to separate any product-level disclosures on carbon footprints into two $CO_2$ components: i) the actual cradle-to-gate emissions as measured through the chain of CCA systems and ii) an estimate of the use phase emissions in the product's gate-to-grave phase.[22]

Regardless of the scope of a company's CCA system, current Net Direct Emissions (NDE) remain a carbon metric of primary interest. This metric can be gauged from the beginning and ending balances of the accounts Direct Emissions and Direct Removals on the CE balance sheet. Analysts will get a better understanding of recent changes and improvements in a company's NDE if the CE balance sheet provides additional line-item information on the recent history of this variable. For instance, if $EB_{DE}^{2024}$ shows the tonnage of $CO_2$ the company has accumulated in direct (Scope 1) emissions by the end of the year 2024, this figure can be supplemented with line items showing the recent annual direct emission increments. Thus, in addition to $EB_{DE}^{2024}$ the account Direct Emissions would then show the time series:

$$(x_{DE}^{2024}, x_{DE}^{2023}, \ldots . x_{DE}^{2020}, EB_{DE}^{2019}).$$

[21] Kaplan and Ramanna (2024) argue that it only makes sense for consumer-oriented companies to estimate and report the projected use phase emissions of their sales products.

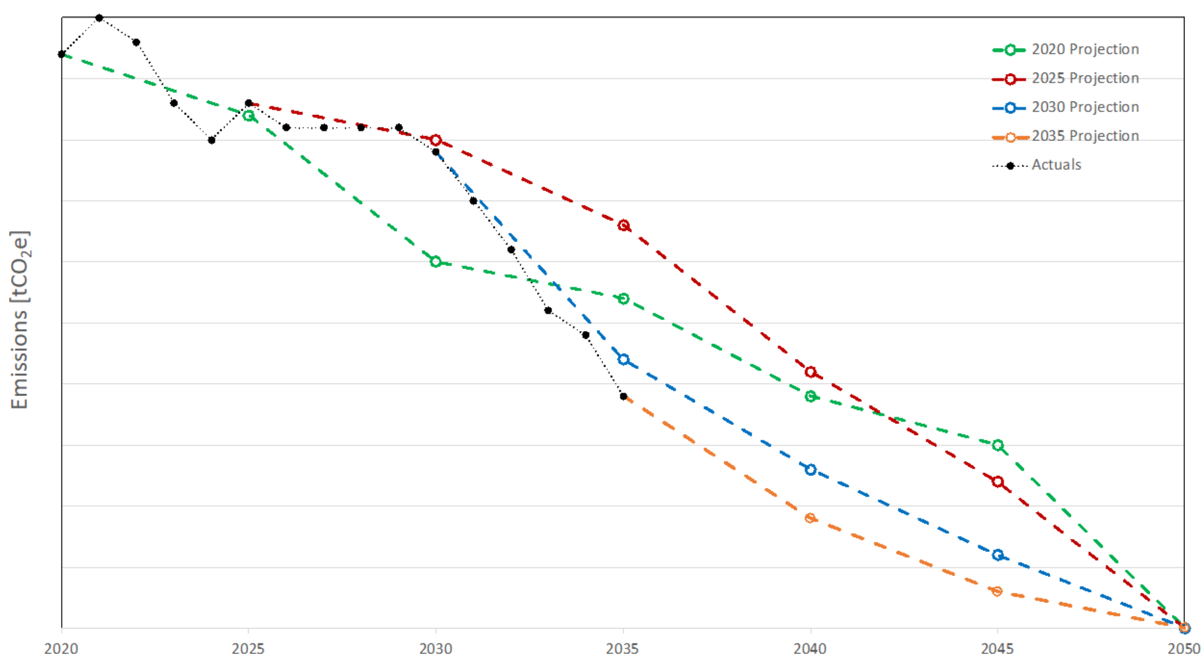
[22] The case study by Lu et al. (2024) on BMW's decarbonization efforts highlights the importance of including use phase emissions for a car manufacturer. Otherwise, the company would effectively not convey the emission implications of switching from internal combustion engines to electric vehicles.

Here, $x_{DE}^{202i}$ denotes the firm's direct emissions in the year *202i*, while $EB_{DE}^{2019}$ denotes the cumulative direct emissions at the end of the year 2019, with the entries in the above vector summing up to $EB_{DE}^{2024}$**.** If the same line-item information is provided for the recent history of direct removals, analysts of the CE balance sheet will obtain an informative forecast for the firm's net direct emissions in the near future.

Technology firms, like Microsoft, Google and Stripe have set particularly ambitious decarbonization goals that go beyond simply achieving a net zero position (Comello et al, 2023). Instead, these companies aspire to undo their entire legacy emissions, that is, the emissions that have been accumulated in their corporate past. For companies that confine responsibility to their own Scope 1 emissions, attainment of this climate neutrality goal would mean that the sum the two accounts Direct Emissions and Direct Removals on the CE balance sheet will need to turn positive at some point in the future. Assuming a company accepts responsibility for its Scope 1, Scope 2, and upstream Scope 3 emissions, the relevant KEPI then becomes the Equity account on the CE balance sheet. Since this account records the company's past CE flows, its balance would need to turn positive in order for the business to have undone its legacy emissions.

When it became common practice for multinational companies to issue net zero pledges a few years ago, environmental groups expressed understandable skepticism on two grounds. First, in many instances companies did not specify the applicable carbon metrics involved, and secondly the due dates of these pledges were so many decades into the future that current executives could not possibly be held accountable for these pledges (Comello et al. 2023). One way to guard against charges of "creative optimism" and greenwashing is for companies to commit to a framework of time-consistent carbon reporting. The main purpose of such a reporting framework is to enable analysts and observers to compare earlier emission reduction goals to actual results delivered, and to do so on an ongoing basis.

For concreteness, suppose the KEPI of interest is the company's annual CE flow.  For the illustration depicted in Figure 4, the company in question had issued an original forecast of future CE flows in the year 2020, as shown by the green trajectory. This trajectory specified reductions goals at five-year milestones and, for simplicity, assumed a linear interpolation between the milestones. A new forecast trajectory (red curve) was issued in 2025. It initiated at the actual CE flow figure realized level in 2025 and stayed in effect until 2030. For the illustration depicted in Figure 4, the latest forecast is issued in 2035 (the current year) and this trajectory is "spliced" together with the actual CE flow results up to that year.




Source: Comello et al. 2023

Figure 4:  **Time-Consistent Corporate Carbon Reporting**

At each point in time, the chart shown in Figure 4 generates an integrated report on earlier forecasts, forecast revisions and actual emissions incurred. Specifically, this reporting framework provides incentives to select targets that are deemed realistic rather than overly optimistic. Managers will anticipate that the actual emission reductions achieved in future years are compared to the earlier self-selected targets, and crucially, these performance assessments will be made in the foreseeable future. In the context of the above illustration, in particular, management could point out in the year 2035 that the company over-delivered in emission reductions relative to all previous forecasts.

It is worth noting that the above framework of comparing self-selected forecasts to actual results can also serve as an internal budgeting mechanism rather than an external reporting framework. For instance, the green trajectory issued in 2020 can be interpreted as a carbon budget for a specific division. The area under the green curve then yields that division's total emissions budget over a 30-year horizon. Because of likely changes in regulatory policy and technological conditions, divisional management is given the opportunity to revise its forecast trajectories at five-year intervals. The company's central management, in turn, receives integrated reports on past forecasts, forecast revisions and the emission results actually delivered.

## 4. Towards Generally Accepted Carbon Accounting Principles

A central feature of the carbon accounting systems described in Section 2 is that they operate in a sequential and informationally decentralized manner. To calculate the cradle-to-gate PCFs of their own sales products, companies need to understand where their own direct emissions were incurred in the production process and the differential impact of these emissions on their sales products. In contrast, for the carbon emissions embodied in acquired production inputs, firms can rely on data (carbon tags) that accompany the transfer of these inputs. To ensure consistency and reliability of the resulting PCF figures along an entire supply chain, it will be critical that the calculations performed at each stage have conformed to a set of commonly accepted carbon accounting principles. [23] While no such principles have been widely adopted thus far, some industry associations have issued industry-specific guidelines and rulebooks for

[23] Beginning in 2026, the European Sustainability Reporting Standards require will require auditors to provide "reasonable" rather than "limited" assurance on companies' carbon disclosures.

the calculation of cradle-to-gate PCFs (Catena-X, 2023; TfS, 2023; World Business Council for Sustainable Development, 2023).

Explicit and transparent rules for determining product carbon footprints will also need to be adopted by the European Union when it implements the Carbon Border Adjustment Mechanism (CBAM) that imposes carbon tariffs based on the assessed $CO_2$ content of goods imported into the EU (European Commission, 2023a).[24] Similar needs pertain to national regulations that make subsidies for low-carbon products contingent on their assessed carbon footprint. Applicable examples here include the tax credits available under the Inflation Reduction Act for low carbon hydrogen (Internal Revenue Service, 2022), or the French ecological cash bonus available for automobiles with sufficiently low $CO_2$ content (ETA 2024; Pinneau and Guillaume, 2023).

The *boundaries* for emission categories to be included in the assessment of product carbon footprints presents one major issue on which there does yet seem to be a consensus. Employee commuting provides one example of an emissions category that many companies view to be outside their domain of responsibility and control. Other frequently mentioned boundary issues concern employee travel, the use of biomass, or the use of recycled materials (BASF, 2022b; Catena-X, 2023; Reichelstein, 2024a). While reasonable in-or-out arguments can be made in connection with each one of these issues, it is important to note that the accounting standards to apply will ultimately have tangible implications for firms' willingness to invest in low carbon technologies. The use of biomass, or, more generally, inputs with biogenic uptake, provides a point in case for the "real" effects associated with the choice of accounting rules.[25]

[24] The state of California has already instituted a carbon border adjustment mechanism for electricity that is imported from neighboring regional power markets (Xu and Hobbs, 2021).

[25] For cement manufacturers, the use of biomass rather than fossil fuels for heating purposes presents one decarbonization instrument (Glenk et al., 2024). However, the combustion of biomass also generates direct (Scope 1) emissions. The willingness to incur the cost of substituting biomass for fossil fuels may therefore hinge on biomass being assigned a negative carbon footprint corresponding to its prior uptake of $CO_2$ through photosynthesis.

The structure of the CE flow statement shown in Figure 2 allows for certain emission categories to be excluded from the assessed product carbon footprints, yet to be included in the periodic CE flow measure and thereby the measure of the firm's current corporate carbon footprint. Travel by executives is a good example in this context. Companies clearly have control over this pool of emissions, though there is frequently no direct causal connection to any of the firm's sales products. Commonly applied financial accounting rules then suggest recording these emissions as period expenses in the G&A section of the CE flow statement.

The argument for classifying certain emission categories as current G&A emissions, rather than as "inventoriable" emissions, can also be made for the depreciation charges corresponding to the emissions embodied with capital goods. In the parlance of managerial accounting, this classification amounts to assessing product carbon footprints according to a "variable costing" rather than a "full costing" approach (Datar and Rajan, 2020). Following the reasoning in managerial accounting textbooks, one advantage of limiting the boundaries of PCFs to "variable" emissions is that the resulting metrics will not be burdened by overhead emissions that are effectively sunk, as they have been incurred in the past and therefore are no longer controllable. On the other hand, the PCF figures reported under a "variable costing" approach will be incomplete insofar as the aggregate PCF figures do include certain 'overhead emissions

In addition to boundary questions, generally accepted carbon accounting principles will also have to address a host of issues related to *emission allocations*. While both Catena-X and TfS take the general position that "allocations are to be avoided" (Catena-X, 2023), certain emission categories such as the $CO_2$ content of energy consumed at individual process steps or the direct (Scope 1) emissions incurred at a particular production facility are, by their very nature, overhead emissions that ultimately require allocations among multiple emission objects.

Both cross-sectional and inter-temporal allocations are an integral part of any cost accounting system. One broad recommendation emerging from the cost accounting literature is that the design of overhead cost pools and the corresponding allocation bases (drivers) should reflect the *causal link* between i) resources consumed in individual production activities and ii) the reliance of individual products on these production activities (Kaplan and Anderson, 1998; Datar and Rajan, 2019). This causal-link principle can also serve as a high-level criterion for classifying allocation rules as appropriate for the purposes of carbon accounting.

Allocation rules are required to assign carbon emission intensities to the electricity consumed by different customers on a grid. The so-called *location-based* approach submits that electrons on the grid cannot be traced from power generators to specific customers. Put differently, the location approach negates any causal link between different electricity generation sources and the electricity delivered to particular customers. Therefore, every kWh of electricity delivered is assigned the same carbon intensity, calculated as the grid's overall average carbon intensity for a particular time period.[26]

In contrast to the location-based approach, a *market-based approach* allows for effective causal links to be established via bilateral contracts between power producers and customers. These contracts then provide justification for claims that the electricity consumed by individual customers should be matched to a specific power source, frequently a renewable power source.[27] Clearly, the adoption of either one of these two accounting methods as the preferred methodology under generally accepted carbon accounting principles would have far reaching implications for the incentives to locate energy intensive businesses in different jurisdictions or to finance new renewable energy developments (ETA, 2024; Pinneau and Guillaume, 2023; Becker, 2024).

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[26] Carbon intensities can, of course, be calculated on different time scales, e.g., on an hourly or annual basis.
[27] Recent articles in the popular press report that some technology firms are lobbying for a rather broad interpretation of the market-based approach. Accordingly, power customers would then be able to include renewable energy certificates that were generated in other parts of the world, even though these power producers have no access to the grid from which the particular customer draws its electricity (Bryan, et al. 2024; O'Brien 2024).

For joint production processes, the assignment of common process costs to individual products has long been controversial. Commonly encountered for chemical processes, the inherent jointness of such processes reflects that multiple outputs are produced in fixed proportions as part of a single production process. Without expressing a clear preference, the cost accounting literature simply lists alternative “reasonable” allocation bases (drivers) that can be applied to allocate joint process costs to individual products (Datar and Rajan, 2020). Facing the same indeterminacy issues for carbon emissions, the industry consortia Catena-X (2023) and TfS (2023) have issued detailed guidelines regarding the allocation bases to be used for green-house gas emissions that emerge from joint production processes in the automotive and chemicals industries, respectively.[28]

The architecture of CCA systems, including the configuration of pools for certain emission categories and the choice of attendant allocation bases, will inevitably leave companies with some discretions to favor the PCFs of some products at the expense of others. It should be kept in mind, though, that this discretionary factor essentially disappears in the aggregate CEGS statement (Figure 2). Provided the underlying allocation rules are balanced at each step, the bottom line CEGS figure is largely unaffected by any biases in the adopted allocation rules. [29] Further, by comparing the aggregate CEGS statements of different firms in the same industry, analysts may be able to detect systematic biases in the underlying allocation rules adopted by a particular company.

[28] The case study by Landaverde et al. (2023) illustrates the impact of using physical drivers (weight or volume) rather than net-revenues to allocate the emissions incurred at a steel plant, where, in addition to steel, slag is produced as a co-product. The choice of allocation bases adopted for this joint production process has immediate implications for the attractiveness of slag as a raw material that can substitute for limestone in the production of cement (World Steel Association, 2014). The main implication for carbon accounting standards is that, to maintain consistency in the supply chain, the overhead emission rules applied by the steel plant must also be reflected on the carbon books of the customer buying the slag.

[29] Like the well-known effect of lowering COGS by charging a larger share of overhead costs to products that remain in inventories, firms may effectively lower their CEGS in any given period by capitalizing the emissions of products that remain in inventory on the CE balance sheet.

The recognition and accounting treatment of carbon credits arguably presents one of the most complex and controversial issues that needs to be addressed by generally accepted carbon accounting principles. Separate from the compliance markets for $CO_2$ emission permits, the credits traded in the voluntary carbon markets have been used to offset companies' reported gross emissions. At the same time, selective application of such credits has enabled advertising claims that select consumer products, like gasoline or air travel, are already carbon neutral today. (Bloomberg New Energy, 2021; Greenfield, 2023).

Carbon credits can be broadly classified as either *avoidance* or *removal* credits. As the name suggests, Party A claims an avoidance credit for x kg of $CO_2$ if due to some mitigation action taken by A, e.g., investment in a renewable power facility, party B will reduce its reported $CO_2$ emissions by x kg, relative to some emissions reference point. The general concept of determining cradle-to-gate product carbon footprints in a sequential manner based on emissions actually incurred in a company's supply chain strongly suggests that avoidance credits should not be considered eligible for recognition. Doing so would imply that the same credit is effectively double counted. In calculating the carbon footprint of its products, party A will impute zero emissions for the electricity it receives from its own renewable power sources. Yet, party B will effectively duplicate this accounting when it offsets the emissions from its own grid-based electricity consumption with the credit acquired from party A.[30]

Removal credits are generated when either nature or an economic entity actively removes $CO_2$ from the atmosphere and subsequently stores the captured CO2 so to prevent its reentry into the atmosphere. Removal credits generally satisfy the criterion of "additionality", a criterion that is widely invoked in the discussion about what constitutes high-quality carbon offsets (Comello et al., 2023). In order for removal credits to be recognized on a company's carbon books, some of the largest recent buyers (off-takers) insist on permanent and irreversible sequestration, i.e., there must be a high degree of confidence that the captured $CO_2$ will not re-

[30] The Science-Based Target Initiative (SBTI) also advocates for avoidance credits not to be recognized in corporate carbon footprint measures. (Comello et al. 2022).

enter the atmosphere for at least another 1,000 years (Microsoft, 2021; Frontier, 2023).[31] The direct air capture facility operated by Climeworks in Iceland, where the captured $CO_2$ is mineralized in volcanic rock, provides a prime example of permanent and irreversible emission removals that are deemed irreversible (Wilcox, Kolosz, and Freeman, 2021).[32]

Concerns about the high costs of removals that are both permanent and irreversible suggest broadening the scope of removal projects that are eligible for recognition as part of a company's CCA system. Large-scale reforestation projects are a case in point, as these projects are far less expensive per ton of $CO_2$ captured and stored, yet the captured $CO_2$ might conceivably reenter the atmosphere in the foreseeable future. The CE balance sheets introduced in Section 2 above enable companies to classify different types of removal credits according to their durability (Reichelstein, 2024b), e.g., duration ranging anywhere from 100 to 1,000 years. Further, if x tons of $CO_2$ removed in a particular year are deemed potentially reversible prior to the stated target sequestration date (e.g., 100 years in the future), then such 'risky' removals would be marked conservatively as 'contingent liabilities' on the CE balance sheet. They would thereby effectively offset direct removals on the CE balance sheet, while not lowering the firm's current carbon footprint, that is, the current CE flow (Reichelstein, 2024b). The proposed accounting treatment would be similar to how potential future liabilities are treated in financial accounting, with companies initially taking a charge to income corresponding to these potential liabilities.

Aside from the issue of which removal projects should be recognized on a company's carbon books, generally accepted carbon accounting principles will need to address whether companies should have wide ranging discretion in assigning eligible removal credits to individual PCFs. Such discretion may indeed provide the incentives necessary to acquire such credits in the first place. Similar to the reasoning supporting a market-based approach to

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[31] Kaplan, Ramanna and Roston (2023) argue that carbon credits should only be issued for removals that are known to be both permanent and irreversible.

[32] Wilcox, Kolosz and Freeman (2021) and Joppa (2021) discuss a wide range of alternative carbon dioxide removal technologies.

account for Scope 2 emissions, it can be argued that the contractual arrangement between the party undertaking the removals and the buyer of the removal credits creates the causal link that justify giving the buyer discretion in assigning specific tons of $CO_2$, that have been captured and sequestered, to particular products. Buyers of such removal credits can mitigate concerns about selective greenwashing by providing line information on the use of removal credits for individual product carbon footprint calculations.

## 5. Concluding Remarks

With the 10-year anniversary of the Paris climate agreement approaching, it is becoming increasingly clear that the ambitious goal of limiting the global temperature increase to 1.5°C is no longer realistic. To accelerate the transition to a decarbonized net zero economy in the coming decades, consumers, companies and governments are increasingly seeking reliable information about the carbon emissions embodied in traded goods and services. Businesses can play a central role in providing such information by adopting internal carbon accounting systems that track emissions at a transactional level.

Carbon reporting grounded in corporate carbon accounting systems will gain significantly in comparability and reliability provided these reports are prepared in accordance with generally accepted standards akin to generally accepted carbon accounting principles or international financial reporting standards. While such standards are not likely to be widely adopted in the near future, voluntary associations for different industries may nonetheless continue to set specific carbon accounting standards for their members. This would certainly facilitate the task of auditors in providing reasonable assurance that the carbon metrics reported by an individual company in a particular industry were prepared in accordance with the standards set forth by that industry.

## Appendix

### Glossary of Acronyms

**CBAM:** Carbon Border Adjustment Mechanism

**CCA:** Corporate Carbon Accounting

**CCF:** Corporate Carbon Footprint

**CE:** Carbon Emissions

**CEGS:** Carbon Emissions in Goods Sold

**COGS:** Cost of Goods Sold

**$CO_2$:** Carbon Dioxide

**DNE:** Direct Net Emissions

**EB:** Ending Balance

**EU:** European Union

**ETI:** Emissions Transferred In

**GHG:** Greenhouse Gases

**IPCC:** Intergovernmental Panel on Climate Change

**KEPI:** Key Emissions Performance Indicator

**PCF:** Product Carbon Footprint

**U.S.:** United States

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