Corporate Carbon Emission Statements

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January 2023

[1] I am grateful to G. Glenk, J. Kurtz, R. Meier, S. Penman and A. Pistillo for helpful comments and suggestions. Special thanks to R. Kaplan and K. Ramanna for many productive conversations on the subject of carbon accounting during the gestation of this paper.

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Abstract

Current corporate disclosures regarding carbon emissions lack commonly accepted accounting rules. The accrual accounting system for carbon emissions described here takes the rules of historical cost accounting for operating assets as a template for generating a Carbon Emissions (CE) balance sheet and flow statement. The asset side of the CE balance sheet reports the carbon emissions embodied in operating assets. The liability side conveys the firm's cumulative direct emissions into the atmosphere as well as the cumulative emissions embodied in goods acquired from suppliers less those sold to customers. Flow statements report the cradle-to-gate carbon footprint of goods sold during the current period. Taken together, balance sheets and flow statements generate key indicators of a company's past, current and future performance with regard to carbon emissions.

JEL classification: M41, M48, Q53, Q54.

1. Introduction

Recent years have witnessed numerous companies around the world issuing voluntary "net-zero pledges" with regard to their greenhouse gas emissions. According to a recent survey, more than two-thirds of the Fortune 500 firms have now articulated the goal of reaching a net-zero position by 2050.[1] Beyond pledging to drive their corporate carbon footprints to zero in the future, companies increasingly advertise select products as being already "carbon-neutral". While these announcements have been heralded as a potentially significant step in the global decarbonization effort, some analysts have argued that the lack of commonly accepted reporting standards for greenhouse gas emissions ultimately obscures the credibility of corporate claims and commitments to a net-zero position.[2,3]

This perspective article argues that corporate carbon emission reports would become more transparent and credible if companies were to adopt a carbon accrual accounting system that mirrors the accounting for operating assets in financial reports. Traditional accrual accounting enables the separation of stock from flow variables. In direct analogy, an accrual accounting system for carbon emissions enables a CE balance sheet and a CE flow statement, the latter being the pendant to an income statement. We emphasize that, in contrast to financial reporting, the asset side of the CE balance sheet does not report conventional asset values, but instead records the emissions embodied in the firm's operating assets. The sources of these emissions, recorded on the liability side of the balance sheet, are either the firm's own direct (Scope 1) emissions or those incurred by companies along the firm's upstream supply chain.

Just as balance sheets and income statements convey essential information about a firm's financial position, CE statements yield several key indicators of a firm's past, current and future performance in the domain of greenhouse gas emissions. Among the key carbon performance indicators, two central 'stock variables' emerge from the balance sheet. First, the asset side of the CE balance sheet conveys the emissions embodied in the firm's long-term operating assets, e.g., machinery and equipment, as well as in short-term assets, e.g., inventories. The significance of this indicator is that the emissions recorded in operating assets will flow through to the firm's sales products in future periods. Second, the liability side of the CE balance sheet tallies a firm's cumulative direct net emissions, that is, cumulative direct emissions less any applicable carbon dioxide removals, accumulated after some reference date. Cumulative direct emissions are a key performance indictor for technology firms like Google and Microsoft that have set the more ambitious goal of removing from the atmosphere their entire legacy (cumulative) emissions, that is, all net emissions accumulated after some reference date.

With concerns about climate change intensifying, customers increasingly seek information about, and take responsibility for, the emissions that have gone into purchased products and services. Consistent with Kaplan and Ramanna's (2021) E- liability framework, a growing number of companies now report so-called cradle-to-gate carbon footprints for their sales products. For multiproduct firms, the reporting of cradle-to-gate carbon footprints requires an accrual accounting system akin to that used for inventory costing in cost accounting. In direct analogy to Cost of Goods Sold in income statements, Carbon Emissions in Goods Sold (CEGS) represents the aggregate carbon footprint of a firm's sales products in any given year. This flow variable effectively measures a firm's upstream Scope 3 emissions, including its direct (Scope 1) emissions and the indirect emissions embodied in acquired production inputs.

In today's reporting environment, the most common carbon 'flow measure' is a company's direct emissions, adjusted for any recognized CO_2 offsets in the current year. This measure emerges directly from the CE balance sheet as the difference between the beginning and the ending balance of the direct emissions liability account. Any claim for a company to be on a path to net-zero according to the CEGS metric is generally more stringent than a corresponding claim when corporate carbon footprints only comprise direct net emissions. For such a firm to drive CEGS to zero, both its direct emissions and the indirect emissions acquired from suppliers in its production inputs must go to zero.

Since the carbon accrual accounting system described here builds directly on the principles underlying financial accounting, existing accounting enterprise software can easily be adapted to keep the books for carbon accounting. Further, it will be relatively straightforward for external auditors to certify that CE statements were prepared in accordance with principles that mirror the generally accepted accounting principles for operating assets. Auditor certification will be particularly useful for the determination of carbon import duties, as anticipated for the year 2026 by the European Union under its Carbon Border Adjustment Mechanism.[4]

2. Corporate Carbon Accounting

The Greenhouse Gas (GHG) Protocol currently is the commonly accepted reference framework for assessing corporate carbon footprints. The Protocol classifies direct (Scope 1) emissions as those stemming from flue gases and tailpipe exhaust streams at a firm's own production facilities. Indirect emissions (Scope 2 and 3) are those emanating from operations in a company's upstream supply chain as well as those generated by the company's customers and end-use consumers.[5] Scope 2 is a carve-out from the broader category of indirect emissions, as Scope 2 pertains exclusively to the generation of electricity and heat provided by external suppliers.

While Scope 1 emissions are widely measured and verified in jurisdictions that have adopted carbon pricing regulations[6], the assessment of Scope 3 emissions has been uneven in practice. A recent study found that in a sample of 417 companies, the vast majority disclosed their Scope 1 and 2 emissions, and about 20% included some Scope 3 figures.[7] Technology firms like Google indicate that they limit their count of Scope 3 emissions to employee commuting and travel. A survey of the entire computer technology sector found that firms underreport their Scope 3 emissions by about half relative to the standards of the GHG Protocol.[8]

It is widely acknowledged that assessing a company's Scope 3 emissions entails enormous data collection challenges. Most companies hire outside consultants that perform life-cycle analyses of the goods and services transacted by the company. However, outside consultants usually must rely on industry-wide emission estimates rather than the primary data reflecting the actual emissions incurred by the parties along a company's supply chain.[9] A further issue with Scope 3 assessments is that the carbon emissions incurred along a company's downstream supply chain cannot be measured reliably at the time a sales product leaves the company's gates. To illustrate, consider the sale of an aircraft to an airline. According to the GHG protocol, the manufacturer should take a life-cycle perspective in estimating the total lifetime emissions - from cradle to grave - generated by operating the aircraft. Such estimates, however, must remain speculative, as they require forecasts for both routes and miles flown in future years as well as the type of fuel, e.g., kerosene versus sustainable aviation fuels, the aircraft will be using. These considerations explain in part why the current SEC exposure draft envisions a safe harbor provision for corporate Scope 3 disclosures.[10]

The central idea underlying the E-Liability concept of Kaplan and Ramanna (2021) is that companies can reliably measure the actual carbon emissions embodies in their sales products, provided they receive reliable information on the carbon balances embodied in the inputs received from suppliers.[11] At each link in the chain, firms rely on primary data regarding their own production activities, their own direct emissions and the indirect emissions represented by the carbon balances of their production inputs, the latter determined recursively by the firm's upstream suppliers. [12,13,14] Several multinational firms have recently developed internal carbon accounting systems with the aim of calculating cradle-to-gate product carbon footprints in a recursive manner relying on local company-level emissions data at each link of the supply chain.[15]

Returning to the sale of aircraft example, suppose the airline receives a cradle-to-gate footprint measure from the manufacturer. This figure reflects the actual upstream emissions embodied in the constituent aircraft parts as well as the emissions accumulated in the aircraft's assembly. The airline, in turn, calculates the carbon footprint of individual flights by including the emissions associated with fuel combustion, other variable inputs and a depreciation charge for the emissions embodied in the aircraft. Just as the cost of a flight is calculated by relying on internal cost accounting, a carbon accrual accounting system can determine the emissions embodied in a particular flight from the cradle of all requisite inputs to the airline's gate, i.e., the delivery of the flight. Aggregating across all cradle-to-gate figures, the airline calculates its

Carbon Emissions in Goods Sold (CEGS) during a particular year. This metric effectively captures the airline's upstream Scope 3 emissions, including its Scope 1-2 emissions.

The reporting of upstream Scope 3 emissions in accordance with the E-liability concept in no way prevents companies from issuing separate estimates for the downstream Scope 3 emissions associated with the use of their products. While these assessments must intrinsically be estimates, upstream Scope 3 reports can be based on actual emissions incurred along the upstream supply chain as more firms along the supply chain calculate the cradle-to-gate carbon footprints of their own products. Firms seeking to disclose cradle-to-grave carbon footprint measures in accordance with the GHG Protocol standard may therefore find it useful to split these disclosures into cradle-to-gate actuals and gate-to-grave estimates.

A key advantage of determining product carbon footprints in a recursive and informationally decentralized manner along a firm's supply chain is that reliance on primary data creates incentives for firms not only to reduce their own direct emissions but also to exert pressure on their suppliers to reduce their emissions.[16] To witness, Microsoft Corporation has indicated that the carbon emissions attributed to products and services included in the firm's Scope 3 count will become a criterion for supplier selection in the future.[17]

3. Carbon Balance Sheets and Flow Statements

The fundamental identity underlying financial balance sheets maintains that:

$$Assets = Liabilities + Equity$$

at all points in time. The corresponding identity for Carbon Emissions (CE) balance sheets maintains that:

$$CE\ in\ Assets = \ CE\ in\ Liabilities.$$

The unit of measurement for all accounts is one ton of CO_2. For greenhouse gases other than CO_2, the IPCC has recommended conversion factors to arrive at CO_2 equivalents, abbreviated as CO_2e from hereon. We note that the CE balance sheet does not record conventional asset or liability values. Instead, the accounts on the left-hand side record the emissions embodied in the firm's operating assets. The sources of these emissions, recorded on the liability side, are either the firm's own direct (Scope 1) emissions or those incurred by companies along the firm's upstream supply chain.

To illustrate the bookkeeping for carbon accrual accounting, we present a sequence of sample transactions undertaken by the imaginary A-Corp. As shown in Table 1, A Corp. maintains on the asset side of its CE balance sheet accounts for Plant, Property and Equipment (PPE) and Materials (MAT). For illustrative purposes, Table 1 shows only one PPE and one MAT account, but *m* different Work-in-Process accounts (WIP_1, WIP_2, … ,WIP_m), and *n* different Finished Goods accounts (FG_1, FG_2, …. ,FG_n). The second row of Table 1 shows the balances of these stock variables at the beginning of the year (BB). The ending balances (EB) at the bottom of Table 1 reflect the cumulative impact of transactions undertaken during the year. In total, these balances reflect the emissions embodied in operating assets that the company assumes responsibility for (it 'owns') as it acquires production inputs and carries out its operations.

On the liability side of A-Corp.'s balance sheet are the accounts Emissions Transferred In (ETI), Emissions Transferred Out (ETO) and Direct Emissions (DE). Direct emissions arising from A-Corp's operations during the year are added to the balances in the Work-in-Process (WIP) accounts, with the corresponding liability recorded in Direct Emissions (DE). Thus, the DE account tallies cumulative direct emissions incurred in past periods, following some initial reference date.

Emission transfers across companies are recorded in a manner analogous to receivables and payables of cash in financial accounting. Emissions embodied in goods acquired from suppliers are added to the account balances for PPE and MAT, while the corresponding CE liabilities are recorded in Emissions Transferred In (ETI). The suppliers, in turn, reduce the carbon balances of their own finished goods account by a corresponding number of tons of CO_2, with the same amount reflected in their Emissions Transferred Out (ETO) accounts. While one might expect to find ETO on the opposite balance sheet side of the ETI account, we adopt the convention of recording ETO on the liability side, albeit with a negative sign. That way, the left-hand side of the CE balance sheet exclusively carries the emissions embodied in the firm's operating assets, emissions that will flow through to the firm's sales products in future periods.

Among the six sample transactions recorded in Table 1, the first pertains to the purchase of materials. Ideally, the carbon balances of these materials will be reported by A-Corp's suppliers. Otherwise A-Corp. will need to form an estimate based on industry-level data. In accordance with double-entry bookkeeping, the carbon balance in both the Materials and ETI accounts are increased by x_1 tons (Transaction 1).

When A-Corp transfers materials from inventory to production, the corresponding emissions are transferred to the WIP accounts (Transaction 2). In our illustration, the total carbon balance of materials transferred is $x_2 = x_{21} + x_{22} + \ldots + x_{2m}$ tons. There are no liabilities associated the internal transfer of emissions across operating assets. Similarly, no liability is incurred when depreciation charges reduce the book value of the PPE account (Transaction 3). The beginning balance of the PPE account, BB_{PPE}, represents current book value, that is, initial emissions embodied in acquired machinery and equipment less depreciation charges accumulated in previous periods. Accordingly, the WIP_i accounts absorb depreciation charges in amounts of x_{3i} tons, with the corresponding credit of x_3 going to the PPE account, such that $x_3 = x_{31} + x_{32} + \ldots + x_{3m}$.

Suppose A-Corp. generates x_4 tons of direct carbon emissions during its annual operations. The corresponding bookkeeping entries increase the cumulative liability Direct Emissions (DE) by x_4 tons, while the carbon balances in the accounts WIP_i are increased by x_{4i}, such that $x_4 = x_{41} + x_{42} + \ldots + x_{4m}$.

A-Corp. – CE BALANCE SHEET and TRANSACTION SUMMARY

Table 1

	CE in Assets								=	CE in Liabilities		
Accounts	**PPE**	**MAT**	**WIP_1**	**...**	**WIP_m**	**FG_1**	**...**	**FG_n**	**=**	**ETI**	**ETO**	**DE**
Beginning Balance	BB_{PPE}	BB_{MAT}	BB_{WIP1}	...	BB_{WIPm}	BB_{FG1}	...	BB_{FGn}	=	BB_{ETI}	BB_{ETO}	BB_{DE}
Transactions:												
T_1		X_1							=	X_1		
T_2		$-X_2$	X_{21}	...	X_{2m}				=			
T_3	$-X_3$		X_{31}	...	X_{3m}				=			
T_4			X_{41}	...	X_{4m}				=			X_4
T_5			$-X_{51}$	...	$-X_{5m}$	Z_{51}	...	Z_{5n}	=			
T_6						$-X_{61}$	...	$-X_{6n}$	=		$-X_6$	
Ending Balance	EB_{PPE}	EB_{MAT}	EB_{WIP1}	...	EB_{WIPm}	EB_{FG1}	...	EB_{FGn}	=	EB_{ETI}	EB_{ETO}	EB_{DE}

The bookkeeping entries for Transactions 2-4 reflect internal allocation rules that assign carbon emissions to products, akin to cost accounting rules that assign overhead costs to different products. In the context of carbon accounting, such an assignment rule can be conceptualized as a mapping:

$$\boldsymbol{f\text{: (DE, CE Inputs)} \rightarrow \text{CE Outputs}} \tag{1}$$

Here, the CE balance of inputs reflects the indirect emissions accumulated by the firm's suppliers, their suppliers and so forth. Inputs generally comprise consumable goods, like components that go into a product, and the periodic use of capital goods, in which case the corresponding carbon balance is prorated through annual depreciation charges. We refer to the mapping f(.) in (1) as a Product Carbon Footprint (PCF) allocation system.

The central role of the PCF allocation system is to determine how "overhead" items like direct (Scope 1) and indirect (Scope 2 and 3) emissions are allocated (prorated) among different sales products. To that end, the allocation rules should reflect the specifics of the firm's production processes in order to capture the causal relation between emissions associated with specific production activities and the extent to which different products require these activities.[18] Just as companies generally have discretion in choosing their inventory costing rules for financial reporting purposes, companies will need discretion in tailoring their internal carbon allocation rules to the operational structure of their business. A basic requirement for any allocation system is balancedness: the sum of direct emissions and indirect emissions embodied in production inputs equals the emissions assigned to outputs. This balancing property was maintained in the bookkeeping entries for transactions T2-T4 above, as "debits" always equaled "credits". Beyond balancedness, the allocation bases (drivers) underlying a company's internal PCF allocation rules should be proxy measures for resources consumed and their associated carbon emissions.[19] The Appendix illustrates how standard cost accounting concepts, such as activity-based costing, joint cost allocation and ISO rules, have been used to configure the internal carbon allocation systems of companies in the cement and chemicals industry.[20,21]

As more companies along a supply's chain adopt their own internal PCF allocation systems, the measurement of carbon footprint for products moving along the supply chain will increasingly 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. Importantly, this recursive calculation process will be based on firm-level data that reflect the actual direct emissions incurred at each stage. To illustrate, the chemicals company BASF determines the PCF of its roughly 40,000 BASF sales products with its internal digital tool SCOTT (acronym for Strategic CO_2 Transparency Tool).[22] By licensing this tool, BASF seeks to make its own internal carbon accounting system "interoperable" with the company's suppliers.[23]

Once work-in-process is completed, the carbon balances accumulated in the WIP accounts are transferred to the corresponding FG accounts on the asset side of the CE balance sheet. Thus, $x_{51}+x_{52}+ \ldots + x_{5m} = z_{51}+z_{52}+ \ldots + z_{5n}$, reflecting again the balancing property of the underlying allocation system. When finished goods are finally sold, the customers of product i assume responsibility for x_{6i} tons of CO_2. The ETO records these sales transactions as x_6 tons transferred out, where $x_6 = x_{61}+x_{62}+ \ldots + x_{6n}$ (Transaction 6). Since the ETO accounts maintains cumulative balances, the carbon emissions in goods sold from previous years remain on the CE balance sheet.

In summary, double-entry bookkeeping ensures that for each transaction the entries on the left-hand side of the CE balance sheet sum up to those on the right-hand side. For each balance sheet account (column), the ending balance equals the beginning balance plus the sum of all transaction entries. All ending balances are non-negative, with the exception of the ETO account, which only carries negative balances to reflect emissions transferred out to customers. While our illustration here has focused on tangible goods like materials and equipment, the accounting can include emissions associated with intangible goods, such as employee travel. These would be charged to the WIP accounts, with the corresponding entries recorded in ETI.

The CE flow statement provides customers and the public with line-item information on the carbon emissions the firm has accumulated in the goods it sold in the current period. Extracting the entries for the final Transaction 6, Table 2 shows the CE flow statement for A-Corp., assuming the company discloses all line items for emissions embodied in its *n* sales products.

Table 2: A-Corp. – CE Flow Statement

x_{61}	=	Carbon Emissions in Sales of Product 1
x_{62}	=	Carbon Emissions in Sales of Product 2
.	=	.
.	=	.
.	=	.
x_{6n}	=	Carbon Emissions in Sales of Product n
x_6	**=**	**Carbon Emissions in Goods Sold = Carbon Emissions Transferred Out**

The balance x_{6i} reflects product i's calculated carbon intensity, CI_i, that is, the tons of CO_2 embodied in one unit of product i. Equivalently, $x_{6i} = CI_i$ * (Units of Product i sold). CI metrics are becoming an increasingly important disclosure item. In some European countries, for instance, bidders in public procurement auctions are now required to report and certify the carbon intensity of the products they offer in public tenders.[24]

Carbon Emissions in Goods Sold (CEGS) measures the aggregate cradle-to-gate footprint of the portfolio of products sold in any given time period. As such, the CEGS metric effectively captures a firm's entire "Upstream Scope 3" emissions, including its Scope 1 and 2 emissions. Companies generally will need discretion in tailoring their internal PCF allocation systems to reflect their own operational structure and the different point sources of emissions. Such latitude leaves open the possibility of downward biases in the carbon intensities of select products. Absent any build-ups or depletions of inventories, however, the aggregate CEGS is unaffected by the specifics of the internal allocation system, provided balancedness is maintained. Any downward bias in the reported carbon intensity of select customer-sensitive products will then be accompanied by a corresponding upward bias in other products shown on the CE flow statement.

In closing this section, we note that while in financial accounting 'income' is calculated as the difference between sales revenue and costs (period expenses), emissions embodied in goods sold are transferred "at cost" in the carbon accounting system described here. Thus, the carbon accounting analogue of the flow variable "income" is, by construction, always equal to zero, that is (EB_{ETO} - BB_{ETO}) - CEGS = 0. To show a "profit" in the sense of having positively contributed to the world's climate, the CEGS metric would need to turn negative, at least for companies that assume responsibility for the emissions embodied in acquired production inputs. Turning CEGS into a negative number, however, will require the use of carbon offsets.

4. Accounting for Carbon Offsets

Most multinational firms that have pledged to cease emitting greenhouse gases by 2050 have made their pledge on a net-zero basis. Thus, any gross emissions remaining at the target date must be compensated by carbon offsets. Recent years have witnessed a boom in the voluntary carbon markets, fueled by companies purchasing carbon offsets.[25] Offset claims are frequently grouped into avoidance and removal offsets. Avoidance offsets are generated, for instance, through investments in renewable energy facilities. The reasoning underlying such offset accounting is that the renewable energy facility will induce other economic parties to consume less electricity from the grid, thereby avoiding the emissions associated with grid-based electricity.

The responsibility accounting framework described here posits that a company investing in renewable energy will record lower indirect emissions to the extent that clean electricity actually replaces carbon-intensive electricity previously obtained from the grid. If the clean electricity is sold to third parties, however, the investor should not claim the reduction in the carbon footprint of the third party as an offset for itself. That would entail double counting, unless the third party were to record on its books the same amount of carbon-intensive electricity as it did before the investment in the renewable energy facility.[26] These considerations have led organizations like the Science Based Target Initiative and companies like Microsoft and Stripe not to recognize avoidance offsets in the calculation of corporate carbon footprints.[27]

There are multiple ways of extending the accrual accounting system introduced above to include negative emissions through CO_2 removals. Here, we illustrate one conservative approach to recognizing "durable" removals. The illustration assumes the same transactions T1-T4 shown in Table 1. Suppose now that A-Corp. acquires an offset from a provider that claims to have "durably" removed u_5 tons of CO_2 from the atmosphere. The criterion for durability here refers to an assurance that the CO_2 absorbed will not be released back into the atmosphere for a sufficiently long period of time, say hundreds of years. The removal activity could be nature-based, e.g., a piece of land that is being afforested, or engineered, e.g., direct air capture combined with geological sequestration.[28]

Table 4 shows Direct Removals (DR) as a new account on the CE balance sheet. While the acquired removal of u_5 tons could have been recorded with a negative sign in the liability account Direct Emissions (DE), the continuing controversy surrounding the legitimacy of removal activities suggests that companies report gross direct emissions separately from removals.[29] Recognizing the removal of u_5 tons of negative emissions, A-Corp. correspondingly reduces the carbon balance of its WIP_i account by u_{5i} tons such that such $u_5 = u_{51}+u_{52}+ \ldots + u_{5m}$. Assuming there is no inherent link between A-Corp.'s production process and the removal activity undertaken by the third party provider, A-Corp. would generally retain full flexibility in allocating u_5 tons of CO_2 among its WIP accounts. The remaining transactions in Table 3 parallel those in Table 1. In particular, the balancing constraints $v_{61}+v_{62}+ \ldots + v_{6m} = w_{61}+w_{62}+ \ldots + w_{6n}$ and $x_7 = x_{71}+ x_{72}+ \ldots + x_{7n}$ are met.

To date, few companies have been explicit regarding the threshold required for removals to be considered sufficiently durable to merit offset recognition.[30] In the absence of a generally accepted accounting standard, companies can supplement their CE statements with disclosures regarding the duration profile of the portfolio of removal acquisitions that the company has recognized on its books.

A-Corp. – CE BALANCE SHEET and TRANSACTION SUMMARY (INCL. REMOVALS)

Table 3

	CE in Assets								=	CE in Liabilities			
Accounts	**PPE**	**MAT**	**WIP_1**	**…**	**WIP_m**	**FG_1**	**…**	**FG_n**	**=**	**ETI**	**ETO**	**DE**	**DR**
Beginning Balance	BB_{PPE}	BB_{MAT}	BB_{WIP1}	…	BB_{WIPm}	BB_{FG1}	…	BB_{FGn}	=	BB_{ETI}	BB_{ETO}	BB_{DE}	BB_{DR}
Transactions:													
T_1		x_1							=	x_1			
T_2		$-x_2$	x_{21}	…	x_{2m}				=				
T_3	$-x_3$		x_{31}	…	x_{3m}				=				
T_4			x_{41}	…	x_{4m}				=			x_4	
T_5			$-u_{51}$	…	$-u_{5m}$				=				$-U_5$
T_6			$-V_{61}$		$-V_{6m}$	w_{61}	…	w_{6n}	=				
T_7						$-X_{71}$	…	$-X_{7n}$			$-x_7$		
Ending Balance	EB_{PPE}	EB_{MAT}	EB_{WIP1}	…	EB_{WIPm}	EB_{FG1}	…	EB_{FGn}	=	EB_{ETI}	EB_{ETO}	EB_{DE}	EB_{DR}

The accounting illustrated in Table 3 is conservative to the extent that the recognition of u_5 tons of CO_2 removed immediately reduces the carbon balances in the firm's inventory accounts in the same period. Less conservative accounting would allow companies to capitalize any acquired removals and expense them in future periods at their discretion. In particular, if the operating assets delivering the CO_2 removals are owned by the company in question, accumulated removals could be carried on the asset side of the CE balance sheet with a negative sign.

5. CE Statements to Assess Corporate Net-Zero Pledges

Corporate carbon emission statements, comprising CE balance sheets and flow statements, will enable analysts to gauge multiple indicators of a company's past, current and future carbon performance. In particular, CE statements will be effective in monitoring firms' progress on their paths towards net zero emissions.

Some technology firms, including Google and Microsoft, have articulated emission reduction goals that go beyond simply achieving a net-zero position by 2050. These companies aspire to become "climate neutral" in terms of removing, by a specific target date, their entire legacy emissions accumulated after their inception date. CE balance sheets allow the public to monitor progress towards achieving such goals. Specifically, the account balances for $EB_{DE} + EB_{DR}$, that is, cumulative direct net emissions, would need to turn negative at the target date and stay negative thereafter.

For companies that consider themselves responsible for the indirect emissions acquired through their upstream supply chains, "climate neutrality" becomes a more stringent goal. The sum of the account balances $EB_{DE} + EB_{DR} + EB_{ETI}$ must then turn negative at the target date and remain negative thereafter. On the asset side of the balance sheet, the stock variable total emissions in operating assets provides a lower bound on the emissions that will materialize in CE_{GS} in future periods, as these emissions, in addition to future direct emissions, will flow through to goods sold in future periods.

Direct net emissions, i.e., direct emissions minus direct removals, in any given period is currently the most common flow measure of a company's carbon footprint. This flow measure emerges from the CE balance sheet as the difference $EB_{DE} + EB_{DR} – (BB_{DE} + BB_{DR})$. From a global climate change perspective, the significance of this metric is that the sum of all direct net emissions in any given year, when added up across all economic entities, including firms, households, and other carbon emitting entities, yields the net addition of CO_2 to the atmosphere. However, because this metric only accounts for emissions within a company's gates, it can be "managed" downward by outsourcing carbon-intensive activities to outside vendors.

The aggregate CEGS metric, in contrast, is invariant to outsourcing emission-intensive activities, precisely because companies assume responsibility for their own direct emissions and their acquired indirect upstream Scope 3 emissions. Further, a net-zero trajectory according to the CEGS metric generally requires direct emissions to approach zero. Specifically, suppose a company is in a steady state in terms of the volume of production and sales. Further, if the company does not engage in carbon removals, an emissions trajectory for which CEGS goes to zero implies that both current direct emissions as well as the carbon balance in acquired assets, i.e., $EB_{PPE} + EB_{MAT}$, go to zero. For firms not in a steady state in terms of production and sales volume, CEGS may go to zero, while there is a compensating build-up of emissions in FG or WIP. Any such build-up, however, would be detectable from the CE balance sheet.

Well ahead of the 2050 target date, consumer-oriented companies like Shell, Nestle and Total have increasingly begun to market select products as "carbon neutral".[31] The accounting framework described here enables firms to back up such claims with additional disclosures. Specifically, any claim that the carbon intensity of a particular product is already zero will be substantiated by decomposing its carbon intensity measure, CI, into product-specific components: direct and indirect emissions as well as direct removals. Additional disclosures on how the firm's direct removals were allocated among the products labeled "carbon neutral" would lend further credibility to such claims.

6. Concluding Remarks

Recent “Net Zero by 2050” pledges by major companies have been received with some skepticism, in part because of the lack of common metrics to assess corporate carbon footprints. This paper has argued that the time-tested principles of historical cost accounting for operating assets can serve as a template for corporate carbon accounting.

An essential building block of the accrual accounting system advocated here is the cradle-to-gate carbon footprint of individual products. The aggregate emissions in goods sold provide a comprehensive flow measure of the annual carbon footprint of companies that assume responsibility for the emissions embodied in acquired production inputs. CE balance sheets track a firm’s carbon performance over time. Specifically, cumulative direct emissions, cumulative direct removals as well as the carbon emissions embedded in operating assets are key indicators of a firm’s past and future carbon emissions.

The cost of adopting the carbon accrual accounting rules described in this paper should prove modest. Since these rules essentially copy the rules of historical cost accounting for operating assets, existing financial accounting software should only require limited modifications. Further, auditors should face no conceptual barriers in certifying that a carbon emission statement has been prepared in accordance with accounting principles consistent with those used in preparing financial statements.

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Appendix
Supplementary Material: Corporate Carbon Emission Statements

This appendix elaborates on the material in Section 3, arguing that the general principles underlying firms' cost accounting systems can guide the design of an internal PCF allocation system. The primary role of cost accounting is to assign values to a company's inventory of intermediate and finished goods.[1] Upon sale, these cost values transfer from the balance sheet to the income statements as Cost of Goods Sold.

Conceptually, a cost accounting system can be represented as a function $f: R^m \rightarrow R^n$ that map *m* different expenditure line items to the firm's *n* different sales products and/or services. Cost line items are generally classified as either direct or overhead. As the name suggests, direct costs are immediately attributable to a product and therefore do not require an allocation rule. For instance, the payment made to a supplier for a part that goes exclusively into one sales product is charged directly, i.e., dollar for dollar, to the sales product. In contrast, overhead costs represent expenditures for resources that serve multiple products and therefore require allocation among these products. These allocations are calculated according to an *allocation base* (driver) such as a physical measure (e.g., volume, weight, square footage), time, or an economic measure (e.g., the market prices of the sales products).[2,3]

For external reporting purposes, companies have considerable discretion in structuring their internal cost accounting systems. Specifically, the inherent jointness of overhead costs makes it impossible in most industries to identify a product's "true cost." As a consequence, companies regularly revise their cost accounting procedures with the goal of obtaining better predictions for the overhead costs that will be incurred when there are changes either in the production technology or the mix of the firm's sales products. Aside from this forecasting purpose, cost accounting also provides a tool for ex-post cost control by enabling managers to attribute cost overruns to particular production steps and/or products.

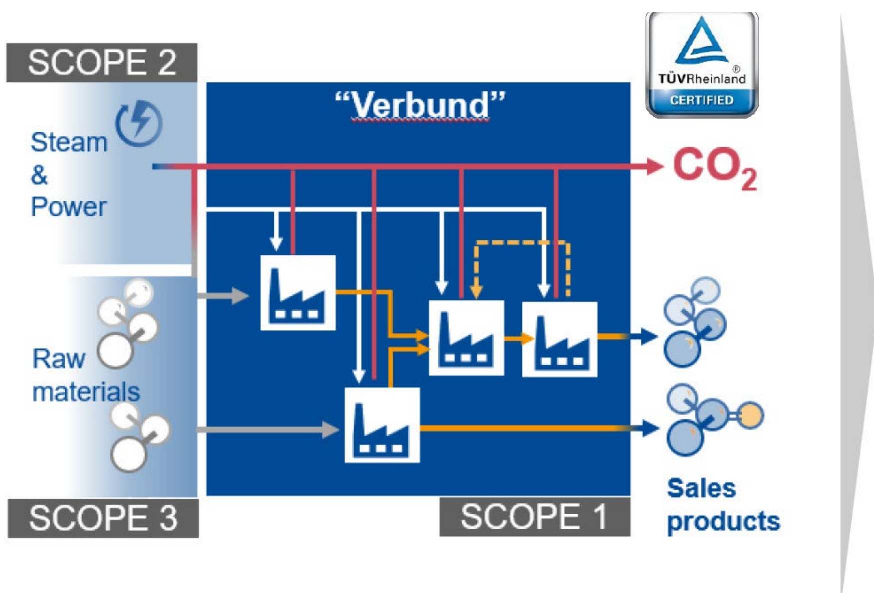
In the context of carbon accounting, the carbon balance of a part (component) that belongs exclusively to one product should also be fully absorbed by that product, akin to the treatment of a direct cost item. As mentioned in connection with transaction T1 in Section 3, the carbon footprint measure of a part (component) is ideally reported by the part's supplier based on its own carbon footprint measurement system. Otherwise, the buyer of the part must form its own proxy-measure based on secondary, industry-wide data.

A company's Scope 1 and Scope 2 emissions will generally be overhead items that require meaningful allocations among the company's different products. To that end, companies already collect the requisite data on direct process and tailpipe emissions (Scope 1) incurred at specific production steps. Similarly, most companies continuously trace the usage of electricity and heat energy to particular production steps and activities, allowing them to attribute the Scope 2 emissions associated with electricity and heat obtained from external vendors to those production activities. Scope 3 emissions embodied in machinery and equipment can also be attributed to the production activities where the assets are located. For these types of production inputs, the corresponding emission charges require an intertemporal allocation, i.e., a depreciation charge, that reflects the useful life of the asset in question. The emissions accumulated in different production activities are ultimately assigned to the firm's products. This assignment can be the outcome of a multi-step procedure that reflects each product's usage of different production activities. Below, we illustrate such activity-based allocation rules in the context of the cement industry where companies seek to measure and report the carbon intensity of alternative cementitious materials, i.e., tons of CO_2 per ton of cementitious material.

As more companies along a supply's chain adopt their own PCF allocation system, the resulting carbon footprint measures of products moving along the supply chain will increasingly 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. Importantly, this recursive calculation process is based on firm-level data that reflect the actual direct emissions incurred at each stage. Except for the hypothetical scenario of single-product firms, there will be a need for carbon allocations. To illustrate such a hypothetical scenario, suppose that every firm along a supply chain produces and sells only one product, which may require the external supply of multiple inputs. Suppose further that the production processes require no capital goods and therefore there are no intertemporal allocations in the form of periodic depreciation charges for the carbon balances embodied in long-term assets. Firms simply assemble parts acquired from suppliers in their sales products, and in doing so incur direct emissions in the process. In such a hypothetical environment, the resulting cradle-to-gate carbon footprint measure of each sales product will exactly be equal to the total direct emissions accumulated from all parts and components going into that product.[4]

As one of Europe's largest CO2 emitters, the chemical company BASF faces increasing demands from customers to calculate carbon footprint measures for its more than 40,000 chemical sales products.[5] As mentioned in Section 3, the company's product carbon allocation system has been automated through its online tool SCOTT (Strategic CO_2 Transparency Tool). Figure 1 illustrates the flow of intermediate products and their accompanying carbon balances through the firm's network of production sites.

Figure 1: Product carbon footprint accounting at a chemical company



Source: Kurtz (2022b)[6]

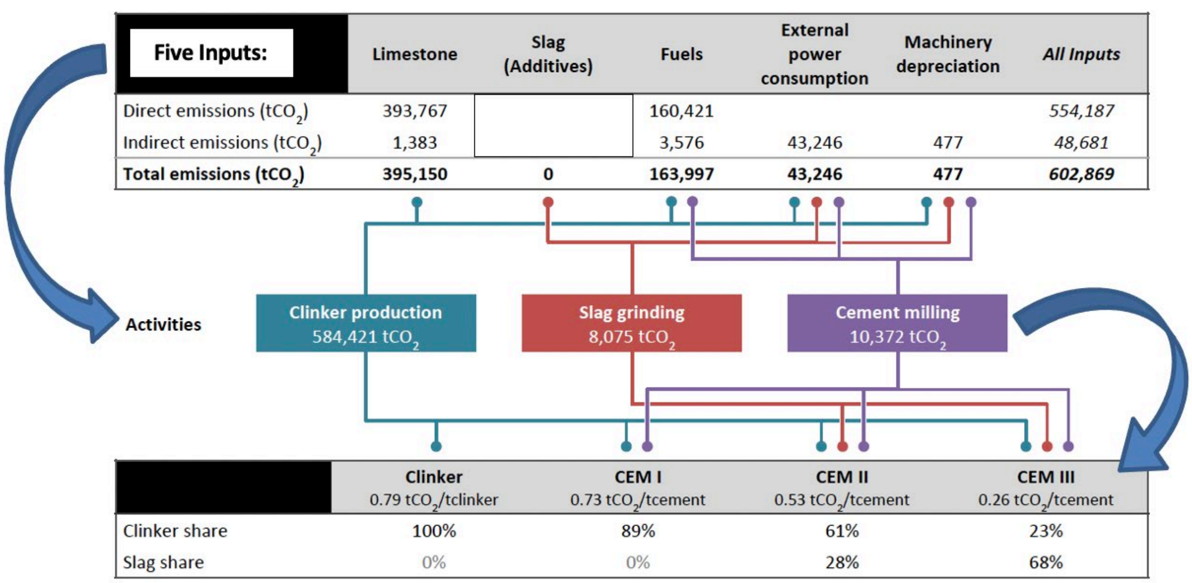
For its 700 plants worldwide, BASF procures about 20,000 different raw materials and about 10 TWh of energy annually from external vendors. The manufacture of chemicals frequently involves joint production processes, that is, work-in-process batches comprise multiple products moving in tandem through a particular production step. BASF discloses that it relies on ISO-compliant allocation bases to assign the carbon emissions associated with joint production processes to individual products.[7] Applicable examples include physical- and revenue-based allocation bases (drivers). These allocation methods are commonly featured in cost accounting textbooks. The use of a particular allocation base for costing purposes, though, does not necessarily mean that the same allocation base is used for carbon accounting purposes. [8] The emissions assigned to products include a periodic depreciation charge for the carbon balances of plant, property and equipment. SCOTT enables management at BASF to decompose a product's overall carbon footprint into its Scope 1-2-3 components, and to trace the accumulated emissions back to production steps that were major emission contributors.[9]

BASF has indicated in direct communication that as of late 2022 only a minority of the company's suppliers provide their own in-house carbon footprint measure for raw materials sold to BASF. For most of its raw materials, the company currently relies on carbon footprint measures provided by external LCA consultants.[10] By licensing the SCOTT tool to independent software companies, BASF seeks to standardize the calculation of product carbon footprints among its suppliers in the chemical industry. A comprehensive adoption of internal carbon allocation systems along the supply chain would ensure that cradle-to-gate product carbon footprints are increasingly based on actual company-level emissions data.

Several recent studies have argued that the principles of activity-based costing[11,12] can serve as a template for the design of product carbon allocation systems (PCAS) in the cement industry[13]. The main ingredient in traditional cement is clinker, which is obtained by heating crushed limestone in a kiln, a process that releases large quantities of CO_2. Cement producers have increasingly sought to replace clinker with low-carbon additives such as slag or calcined clay. The following description draws on a recent study of carbon accounting for a cement plant of Heidelberg Materials, formerly Heidelberg Cement.[14] The company commissioned the study in the face of new regulations at the German and European level to provide reliable carbon footprint measures for cement products offered in auctions for public construction projects.[15,16]

The top two rows in Figure 2 show the annual direct (Scope 1) and indirect emissions (Scope 2 and 3) incurred at the plant. With the exception of external power consumption, the indirect emission figures were based on third-party estimates that Heidelberg Materials made available for the study. The relatively minor depreciation charge in Figure 2 reflects that the company confined this category to emissions embedded in the steel required to build the cement plant. Further, this carbon balance was divided equally by the number of years the plant is assumed to be operational. Because slag, originating from the manufacture of steel, has traditionally been considered a waste product, the study followed the guidelines of the Energy Accounting and Reporting Standard of the Cement Industry by assigning slag a carbon balance of zero.[17]

Exhibit 2: Activity-Based Emission Allocations for Cement Products



Source: Landaverde et al. (2022)[18]

The plant in question delivers four products comprising three cement recipes, labeled CEM I-III, and clinker which is subsequently transferred to other cement plants for further processing. The carbon allocation system examined in the study proceeds in two steps. First, all direct and indirect emissions are assigned to three manufacturing activities: clinker production, slag grinding and milling, where clinker and slag were mixed and milled into cement powder. In this first step, the emissions associated with the processing of limestone are charged exclusively to clinker production. The company relied on its own records to allocate the emissions embodied in fuels among the two activities clinker production and cement milling.

In the second step, the emissions accumulated in each of the three activities are assigned to the four products. The emissions from clinker production are prorated among clinker and the three cement products in proportion to each product's clinker percentage, ranging from 89% for CEM 1 to 23% for CEM III. Slag grinding emissions are distributed to CEM II and CEM III based on their slag percentages, 28% and 68%, respectively. Finally, milling emissions are spread uniformly across the three cement products since milling time and energy consumption were regarded as independent of the ingredient mix.

The resulting carbon intensities, i.e., tons of CO_2 per ton of cementitious material, in Figure 2 demonstrate the potential for reducing the reported carbon content of CEM II and III by substituting slag for clinker in the cement recipe. At the same time, these cementitious materials involve a tradeoff for the manufacturer because, when mixed with water and gravel, CEM II and III require longer waiting times for concrete to harden.[19]

With slag becoming increasingly attractive as a substitute for clinker in the manufacture of cement, the steel industry association has argued that slag is no longer a waste product. Correspondingly, the joint production process that yields steel and slag in fixed proportions should no longer assign zero carbon emissions to slag.[20] While the World Steel Association prefers to allocate emissions in proportion to the relative mass of steel and slag produced, the Global Cement and Concrete Association prefers an allocation based on the relative value of steel and slag.[21] Such discrepancies entail the potential for significant under-counting of emissions if the two industries were to adopt different allocation methods in calculating the product carbon footprints of steel and cement, respectively. Similar issues arise when multiple natural resources are jointly extracted in a mining operation and the extracted resources are sold to different industries.[22] Of course, under-counting of emissions will not be an issue in a system where carbon-to-gate product carbon footprints are determined sequentially such that the buyer accepts the carbon balance (E-Liability") of the acquired input, e.g. slag, which has been determined according to the supplier's own PCF allocation rules.

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