Corporate Carbon Emission Statements

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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 is grounded in the rules of historical cost accounting for operating assets, enabling the preparation of balance sheets and flow statements. The asset side of the 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 multiple indicators of a company's past, current and future performance with regard to carbon emissions.

JEL classification: M41,M48, Q53, Q54.

1. Introduction

According to a recent survey, more than two-thirds of the Fortune 500 firms have by now articulated "net zero by 2050" goals with regard to their greenhouse gas emissions (Gill, 2022). Such voluntary pledges have received considerable attention as a potentially significant step in the global effort to limit the damages resulting from climate change. Some firms have gone beyond a mere net zero pledge by setting the more ambitious goal of removing from the atmosphere their entire legacy emissions, that is, all emissions accumulated after some reference date.

Climate advocates have pointed out that the lack of common measurement and reporting standards for greenhouse gas emissions has obscured the actual commitment implied by existing corporate net zero pledges (Tollefson, 2022). The Greenhouse Gas (GHG) protocol, the common reporting standard for assessing corporate carbon footprints, classifies emissions into direct (Scope 1) and indirect (Scope 2 and 3) buckets. In its most comprehensive form, Scope 3 is to capture all emissions along a firm's supply chain, including upstream suppliers and downstream customers. It is widely acknowledged that comprehensive compliance with the Scope 3 GHG standard imposes enormous data collection challenges. In fact, many companies either do not report their Scope 3 emissions, or confine such reports to select categories, e.g., employee travel (Hale, 2021).

Aside from data collection issues, downstream Scope 3 emissions require, by their very nature, estimates of the anticipated future use of a product. These estimates must become more speculative as the useful life of the product increases. A recent article by Kaplan and Ramanna (2021) points out that companies can reliably measure the actual product carbon footprints of their own sales products, provided they receive reliable information on the carbon emissions embodied in the inputs received from suppliers. Cradle-to-gate product carbon footprints are then calculated in a recursive and informationally decentralized manner as goods move along a supply chain. At each link in the chain, firms rely on knowledge of 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.[2] Kaplan and Ramanna (2021) refer to this decentralized accounting method as E-Liability accounting.

This paper builds on the E-Liability framework by introducing Double-Entry Carbon Accounting (DCA) for measuring and reporting corporate carbon emissions. In direct analogy to historical cost accounting for operating assets, DCA results in a statement of Carbon Emissions (CE), comprising a CE balance sheet and a CE flow statement. 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, such as plant, property and equipment, as well as short-term assets in the form of inventories. The significance of this metric 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 (legacy) direct net emissions, that is, cumulative direct emissions less any applicable direct carbon removals, accumulated after some initial reference date.

In today's reporting environment, the most common carbon footprint 'flow measure' is a company's direct (Scope 1) emissions, adjusted for any applicable CO_2 removals, in any given 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. A more comprehensive flow measure emerges from the CE flow statement under a double-entry accounting system. In direct analogy to Cost of Goods Sold in income statements, we refer to this metric as Carbon Emissions in Goods Sold. As the name suggests, this metric conveys the

[2] Several multinational firms have recently implemented such cradle-to gate carbon footprint accounting systems. See, for instance, BASF (2021), Kaplan, Ramanna and Reichelstein (2022) and Meier (2022).

aggregate cradle-to-gate carbon footprint of goods sold during the current period. Any claim for a company to be on a path to net-zero according to this metric is generally more stringent than a corresponding claim when corporate carbon footprints only comprise direct net emissions. Specifically, consider a company that is in a steady state in terms of the volume of goods produced and sold, and further this company does not engage in direct removals. In order for such a firm to drive the aggregate carbon emissions of goods sold to zero, it must drive to zero both its direct emissions and the indirect emissions embodied in its production inputs.

The double-entry carbon accounting framework introduced here is motivated by the objective of informing customers of a product about the carbon emissions that have gone into the product. To that end, 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. Accordingly, it is the aggregate carbon emissions in goods sold by the company in any given period, rather than the company's direct emissions, that serves as a measure of the firm's current carbon footprint.

One advantage of the DCA framework described in this paper is that existing enterprise software can easily be adapted to keep the books for carbon emissions. Further, DCA reports should be readily accessible to external auditors seeking to verify that the resulting statements are prepared in accordance with principles that mirror generally accepted accounting principles. Auditor certification will be a critical step towards greater transparency and credibility of corporate reporting on carbon emissions.

2. The Greenhouse Gas Protocol

The Greenhouse Gas (GHG) 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.[3] 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 outside suppliers.

Measurement and verification of Scope 1 emissions is widely practiced, particularly in jurisdictions that have adopted carbon pricing regulations (Downar et al., 2021). Assessing a company's indirect emissions in the Scope 2 bucket is also relatively straightforward, provided energy suppliers report on the emissions associated with the generation of energy in different segments of the grid.

The assessment of Scope 3 emissions, however, has been controversial and uneven in practice (Gill, 2022). A recent study by Hale (2021) 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. Assessing a product's full Scope 3 emissions according to the GHG protocol poses particular informational challenges on the downstream side of a supply chain. Consider, for example, 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 must remain speculative as they require forecasts for both miles flown in future years and the type of fuel, e.g., kerosene versus sustainable aviation fuels, the aircraft will be using.[4]

Kaplan and Ramanna (2021, 2022) point out two major advantages to a system focused on measuring the cradle-to-gate carbon footprint of products. First, the measurement task can be solved recursively along a firm's supply chain in an informationally decentralized manner. Returning to the aircraft example, an airline will accordingly take as given the carbon footprint for its acquired aircraft, as reported by the aircraft manufacturer. This footprint measure reflects the actual emissions embodied in the constituent parts and components as well as the

[3] The protocol identifies 15 different Scope 3 categories as well as minimal boundaries for each category.
[4] In practice, technology firms like Google indicate that they limit their count of Scope 3 emissions to employee commuting and travel. Surveying the entire computer technology sector, Klaassen and Stoll (2021) found that firms underreport their Scope 3 emissions by about half relative to the standards of the GHG protocol.

assembly of the aircraft.[5] In providing travel services for its customers, the airline, in turn, calculates the carbon footprint of a particular flight by including the emissions associated with fuel combustion, other variable inputs and a depreciation charge for the emissions embodied in the aircraft.

From a responsibility accounting perspective, a second advantage of determining product carbon footprints in a recursive and decentralized manner along a firm's supply chain is that firms now have incentives not only to reduce their own direct emissions but also to exert pressure on their suppliers to reduce their emissions.[6] Progress on either front will enable companies to report lower carbon footprints for their sales products.[7]

The cradle-to-gate accounting approach in no way prevents firms from issuing separate estimates for the downstream Scope 3 emissions associated with the use of their products. While downstream Scope 3 assessments must necessarily remain hypothetical estimates, cradle-to-gate figures can be based on actual emissions incurred along the upstream supply chain. Firms seeking to disclose cradle-to-grave carbon footprint measures in full accordance with the GHG Scope 3 standard may therefore find it useful to split these disclosures into cradle-to-gate actuals and gate-to-grave estimates.

The double-entry carbon accounting (DCA) system described in this paper enables an accrual accounting system that distinguishes between stock and flow variables. In direct analogy to the proration of cash flows in financial accounting, carbon emissions are allocated across time periods, e.g., depreciation charges, and across products, e.g., indirect emissions associated with electricity consumption. The resulting balance sheet and flow statement enables analysts to track multiple indicators of a firm's carbon emission performance over time.

[5] See also Pomponi (2016).
[6] In its annual report, Microsoft Corporation states 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 (Microsoft, 2021).
[7] Kaplan, Ramanna and Reichelstein (2022) point out that as long as upstream Scope 3 emissions are estimated based on secondary data reflecting industry averages rather than primary data reflecting actual emissions, the current GHG Scope 3 standard offers only weak incentives for a company to reduce its actual emissions.

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:

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

Without loss of generality, we suppose that the unit of measurement for all accounts is one ton of CO_2.[8]

The left-hand side of the CE balance sheet does not represent conventional 'assets'. Rather these figures reflect the emissions the company assumes responsibility for (it 'owns') as it acquires production inputs and carries out its operations. Direct emissions arising from a firm's operations during a particular accounting period are added to the balances in the Work-in-Process (WIP) accounts, with the corresponding liability recorded in Direct Emissions (DE). This recording reflects the firm's responsibility for its direct CO_2 emissions. We note that the DE account is a stock variable that tallies the company's cumulative direct emissions incurred in past periods, following some initial reference date.

Any emissions embodied in goods acquired from suppliers are added to the account balances for operating assets. The corresponding liabilities are recorded in an account labeled Emissions Transferred In (ETI).[9] The suppliers, in turn, credit their own finished goods account by a corresponding number of tons of CO_2 and debit their accounts Emissions Transferred Out (ETO) by the same amount.[10]

To illustrate the bookkeeping under DCA, consider a sequence of hypothetical transactions that A-Corp. undertakes in the course of a year. As shown in Table 1, the company maintains

[8] For greenhouse gases other than CO_2, for instance methane (CH_4), the IPCC has recommended conversion factors to arrive at CO_2 equivalents (abbreviated as CO_2e from hereon). Alternatively, firms could report their emissions for greenhouse gases other than CO_2 as part of separate GHG statements.

[9] The main purpose of the ETI and ETO accounts is to maintain the double-entry bookkeeping system. Emission transfers across companies play a role analogous to receivables and payables of cash in financial accounting.

[10] Transfer of a good does not 'absolve' the supplier from the responsibility for the emissions embodied in the good sold, since these emissions remain in the cumulative ETI and DE accounts of the supplier's CE balance sheet.

accounts for Plant, Property and Equipment (PPE) and Materials (MAT) on its CE balance sheet. Further, there are *m* different Work-in-Process accounts (WIP_1, WIP_2, … ,WIP_m), and *n* different Finished Goods accounts (FG_1, FG_2, …. ,FG_n). 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). While one would naturally expect to find the ETO account on the opposite side of the ETI account on the balance sheet, we adopt the convention of recording Emissions Transferred Out on the liability side, albeit with a negative sign. The purpose of this convention is that the left-hand side of the balance sheet is confined to emissions embodied in the firm's operating assets, emissions that will flow through to the firm's sales products in future periods.

The second row of Table 1 shows the account balances 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. Our first sample transaction pertains to the purchase of materials with an embodied carbon balance of x_1 tons of CO_2 from an outside supplier. The carbon footprint of these materials will either be reported by the supplier, or otherwise A-Corp. will need to provide its own estimate based on industry-level data. Recognizing the purchase, A-Corp. debits the Materials account by x_1 tons and credits the account ETI by the same amount (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 $x_2 = x_{21} + x_{22} + … + x_{2m}$ tons. There are no liabilities associated with these internal bookkeeping entries. Similarly, no liability is incurred when depreciation charges are subtracted from the book value of machinery and equipment (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 are debited by depreciation charges in the amount of x_{3i} tons and the PPE account is credited x_3 tons, with $x_3 = x_{31} + x_{32} + … + x_{3m}$.

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_{ET0}	EB_{DE}

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

Assigning carbon emissions to a firm's work-in-process and finished goods accounts requires allocation rules akin to those used for inventory costing. Managerial accounting textbooks emphasize that economically meaningful inventory costing requires tracking the overhead resources required for different products. Activity Based Costing (ABC) seeks to capture the causal relation between products and required overhead resources by a two-step allocation process. Accordingly, overhead line items are first assigned (allocated) to production activities and in the second step the overhead costs accumulated for each activity are assigned to the different outputs. Both of these mappings require the choice of suitable allocation bases, frequently referred to as "drivers" (Kaplan and Cooper, 1998).

In the context of carbon accounting, both the direct and indirect emissions associated with particular steps (activities) of the production process are allocated to the WIP batches passing through that production step. Reflecting on the processing needs of different products, this allocation process will result in differentiated Carbon Intensity (CI) measures, i.e., tons of embodied CO_2 per unit of a particular product. In the context of cement production, the Appendix illustrates how an activity-based emission allocation scheme generates CI figures for different cement recipes.[11]

Several multinational firms have recently adopted activity-based emission allocation mechanisms to determine the carbon-to-gate carbon footprints of their sales products (Kaplan, Ramanna and Reichelstein, 2022). The allocation of a firm's direct carbon emissions to its sales

[11] When European cement manufacturers participate in public procurement auctions, they frequently report carbon footprint measures for the cement product in question as part of an Environmental Product Declaration, e.g., Cementa AB, HeidelbergCement Group (2022).

products appears particularly complex in industries such as minerals extraction, steel and chemicals.[12] This added complexity frequently reflects joint production processes where WIP batches necessarily comprise multiple products moving together through the same production step.[13]

Upon completion, 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, $x_{51}+x_{52}+ \ldots + x_{5m} = z_{51}+z_{52}+ \ldots + z_{5n}$. The final step in our sample transactions for A-Corp. involves the sale of goods to customers. While income is calculated as the difference between sales revenue and period expenses in financial accounting, our DCA system accounts for emissions embodied in sales products to customers ‘at cost’. Thus, the carbon accounting analogue of the flow variable ‘income’ is, by construction, always equal to zero. Nonetheless, a CE flow statement has informational value as firms report the emissions embodied in different product groups. Table 2 provides an illustration for A-Corp., assuming the company discloses line items for the emissions embodied in the sales of each of its *n* 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 values x_{6i} are derived from each product’s calculated carbon intensity, CI, and the sales

[12]See Cannon et al. (2017).

[13] To that end, the German chemicals company BASF recently developed the digital tool SCOTT (acronym for Strategic CO_2 Transparency Tool) in order to calculate the cradle-to-gate carbon footprint of more than 40,000 different chemical sales products (BASF, 2021). By licensing the SCOTT tool to suppliers, BASF seeks to make such accounting systems “interoperable” (Luers et al., 2022).

volume of the product. Specifically, $x_{6i} = CI_i$ * (Units of Product i sold).[14] As the customers of A-Corp. take responsibility for the emissions in goods bought from A-Corp., the company records a 'revenue' of x_6 tons of CO_2 in its ETO account. The final transaction in Table 1 (Transaction 6) reconciles the flow statement with the balance sheet: the balances in the finished goods account, FG_i, are decreased by x_{6i} tons, while the negative balance in ETO is increased by x_6 tons.

As noted above, firms generally have discretion in choosing the rules that allocate current direct and indirect emissions among individual products. Specifically, the calculated carbon intensity of individual products depends on the chosen activity-based emission allocation rules (Transaction 5 in Table 1).[15] However, assuming there are no significant build-ups or depletions in inventory, the aggregate Carbon Emissions in Goods Sold (CE_{GS}) is less sensitive to this discretionary choice. From that perspective, CE_{GS} provides a comprehensive bottom line measure of a firm's current carbon footprint, reflecting the firm's own direct emissions as well as the indirect upstream Scope 3 emissions.

We note in passing that cradle-to-gate product carbon footprints have a particularly simple interpretation in a hypothetical setting without accruals. To that end, suppose every firm along a supply chain sells only one product, though it may rely on multiple production inputs. Suppose further there are no depreciation charges for long-term assets, because firms simply assemble parts and components acquired from suppliers in their sales products. The carbon footprint measure of each sales product will then exactly be equal to the total direct emissions accumulated from all parts and components going into that product.

In summary, the double-entry bookkeeping construct of 'credits equal debits' ensures that for each transaction the entries on the asset side of the balance sheet sum up to those on the liability 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

[14] Firms seeking to coarsen the information they disclose about the carbon footprint of individual sales products can do so by aggregating multiple products into one product line.

[15] In direct analogy to inventory costing, overhead allocation rules leave firms with discretion regarding the share of overhead costs assigned to individual sales products (Kaplan and Cooper, 1998).

exception of the ETO account on the liability side, since this account reflects the 'revenues' corresponding to the emissions in goods sold. Finally, we note that while our illustration here has focused on transactions for tangible goods like materials and PPE, the accounting described here can comprise intangibles like labor services. For instance, A-Corp. might charge the indirect emissions associated with employee travel and commuting to its WIP account, with the corresponding entry recorded in the ETI account.

4. Accounting for Negative Emissions

The vast majority of 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 offsets (Bloomberg Green, 2021). Offset claims are frequently grouped into avoidance and removal offsets (Comello et al., 2022). 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, electricity that is more carbon intensive than renewable electricity.

Our responsibility accounting framework 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.[16] That would entail double counting, unless the third party were to maintain in its bookkeeping that it consumes the same amount of carbon-intensive electricity as it did before the investment in the renewable energy facility.

[16] These considerations have led organizations like the Science Based Target Initiative, Microsoft Corporation and others not to recognize avoidance offsets in the calculation of corporate carbon footprints.

The DCA framework described in the previous section is readily generalized to transactions that entail negative emissions through direct carbon removals.[17] For illustrative purposes, consider B-Corp., a utility that generates electricity as its only sales product. The first three transactions in Table 3 exactly parallel those for A-Corp in Table 1. Since B-Corp. is a single-product firm that does not store the electricity generated, there is only one WIP and no FG inventory account.

Suppose B-Corp. acquires an asset with a recorded negative carbon balance. This could, for instance, be a forest through which the previous owner has removed and stored x_4 tons of CO_2 from the atmosphere by afforesting land that heretofore was not used as a carbon sink. Table 3 shows the corresponding bookkeeping entries. They mirror those for the acquisition of plant, property and equipment, except that the negative carbon balance is recorded in a separate asset side account, titled Carbon Sinks (CS) (Transaction 4).

If the forest absorbs an additional x_5 tons of CO_2 during the year, the company correspondingly increases the negative balance of Carbon Sinks and records the same quantity, again with a negative sign, in a new liability account titled Direct Removals (DR).[18] In recognizing this removal on its books, the company claims that in the current year an additional x_5 tons of CO_2 were absorbed from the atmosphere and stored in its forest (Transaction 5). Clearly, it will be crucial that any such claim be verifiable, preferably through attestation by an independent certifier.

B-Corp. may seek to transfer negative emissions from Carbon Sinks to its inventory accounts in order to lower its reported CE_{GS}. Accordingly, an internal transfer of negative x_6 tons reduces the carbon balance in the WIP account, with a corresponding increase in the account Carbon Sinks (Transaction 6). Rather than giving companies full discretion in shifting negative emissions

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[17] Numerous analysts have argued that meeting the goals of the Paris climate agreement will require not only drastic reductions in carbon emissions, but also the creation of additional carbon sinks that store CO_2 removed from the atmosphere.

[18] Carbon removals could be included with a negative sign in Direct Emissions (DE). Given widespread concerns about the 'legitimacy' of carbon removal projects, companies may opt for the added transparency that results from disaggregating these two accounts (Fankhauser et al., 2022).

from Carbon Sinks to products, a more 'conservative' accounting rule might impose the additional constraint that any such transfers be limited to quantities of CO_2 that the company has itself directly removed, i.e., stipulate that $x_6 < x_5$. Finally, suppose B-Corp. incurs an additional x_7 tons of direct emissions in producing electricity (Transaction 7). Assuming that the ending balance in its electricity WIP account is zero, B-Corp's Carbon Emissions in Goods Sold are equal to $x_2 + x_3 – x_6 + x_7$, with a corresponding entry of $–(x_2 + x_3 – x_6 + x_7)$ in the ETO account (Transaction 8).[19]

[19] The carbon intensity of the electricity generated, measured in tons of CO_2 per kilowatt-hour, is obtained as $x_2 + x_3 – x_6 + x_7$ divided by the total number of kilowatt-hours produced.

B-Corp. – CE BALANCE SHEET and TRANSACTION SUMMARY

Table 3

	CE in Assets				=	CE in Liabilities			
Accounts	**CS**	**PPE**	**MAT**	**WIP**	=	**ETI**	**ETO**	**DE**	**DR**
Beginning Balance	0	BB_{PPE}	BB_{MAT}	0	=	BB_{ETI}	BB_{ETO}	BB_{DE}	BB_{DR}

Transactions:

T_1			X_1		=	X_1			
T_2			$-X_2$	X_2	=				
T_3		$-X_3$		X_3	=				
T_4	$-X_4$				=	$-X_4$			
T_5	$-X_5$				=				$-X_5$
T_6	X_6			$-X_6$	=				
T_7				X_7				X_7	
T_8				$-X_2 - X_3 + X_6 - X_7$			$-X_2 - X_3 + X_6 - X_7$		
Ending Balance	EB_{CS}	EB_{PPE}	EB_{MAT}	0	=	EB_{ETI}	EB_{ETO}	EB_{DE}	EB_{DR}

In the intensifying public discussion about the legitimacy of carbon offsets, it has frequently been suggested that carbon removals are of "high quality" only if they are permanent insofar as the CO_2 removed is also durably sequestered from the atmosphere. The preceding accounting rules for B-Corp. do not impose any permanence requirement in order for carbon removals to be eligible for recognition on the balance sheet. Instead, temporary removals can be fully recognized, provided any subsequent reversals in the form of direct emissions are recognized consistently. Specifically, suppose that the following year B-Corp. harvests the trees in the forest and processes the lumber into wood pellets, which then become the energy feedstock for power generation.[20] The carbon footprint measure of the electricity sold (CE_{GS}) must then include the direct emissions caused by burning the pellets. Thus, the direct removal recognized in the previous year is effectively reversed by the direct emissions that result from burning the pellets. At the same time, the CE_{GS} of the electricity sold is reduced by the remaining negative emissions embodied in Carbon Sinks, that is, the quantity $x_4 + x_5 - x_6$ in Table 3. Further, the balance in the account Carbon Sinks correspondingly drops to zero.

The preceding transactions and accounting representations have assumed that a company recognizing direct removals will also own or control the assets that enable the removals. Firms may, however, merely want to acquire a claim to having directly removed x tons of CO_2 during a particular accounting period. Such claims can be exchanged in the voluntary carbon markets. In our illustration above, if B-Corp. were to sell such claims, it would only record $x_5 – x$ tons of direct removals on its balance sheet, and cede the claim for the remaining x tons of removals to the buyer of the claim.[21]

[20] This example is motivated by the supply chain of the British power company Drax. It processes lumber obtained from pine trees in North Carolina into wood pellets that are subsequently shipped to the company's electric power plants (https://edition.cnn.com/interactive/2021/07/us/american-south-biomass-energy-invs/).
[21] Concerns about the legitimacy of carbon offsets would be ameliorated significantly if all trading entities prepared carbon emission statements according to consistent accounting standards, and these statements received auditor certification (Comello et al., 2022).

5. Assessing 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 useful 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 some 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 $EB_{DE} + EB_{DR} + \mathrm{EB}_{ETI}$ 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 be included in $\mathrm{CE}_{\mathrm{GS}}$ 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 $\mathrm{EB}_{\mathrm{DE}} + \mathrm{EB}_{\mathrm{DR}} – (\mathrm{BB}_{\mathrm{DE}} + \mathrm{BB}_{\mathrm{DR}})$. 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 (or CO_2 equivalents) to the atmosphere. However, because this metric only accounts for emissions within a company's gates, it is subject to being "managed" downward by outsourcing carbon-intensive activities to outside vendors.

The aggregate CF_{GS} metric, in contrast, is invariant to outsourcing emission-intensive activities, precisely because companies consider themselves just as responsible for their direct emissions as they do for their upstream Scope 3 emissions. Further, if a company is on a net zero path according to the CE_{GS} metric, it must also be driving its direct emissions to zero. Specifically, consider a company that does not engage in carbon removals and is in a steady state in terms of the volume of production and sales. An emissions trajectory for which CE_{GS} goes to zero then implies that both current direct emissions as well as the carbon balance in acquired assets, i.e., $EB_{PPE} + EB_{MAT}$, go to zero.[22]

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' (Bloomberg Green, 2021). Our DCA framework enables firms to back up such claims with additional disclosures. Specifically, any claim that the carbon intensity of a particular product is already zero could 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.

[22] If the firm is not in a steady state in terms of production and sales volume, the carbon footprint of goods sold may go to zero, while there is a compensating build-up of emissions in FG or WIP. Any such build-up, however, would be visible on the balance sheet.

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 a company's annual carbon footprint, provided the business considers itself responsible 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 DCA framework described in this paper should prove modest. Since DCA is grounded in the rules of historical cost accounting for operating assets, existing financial accounting software should only require limited modifications. As a consequence, there should also not be any conceptual barriers for auditors in certifying the accuracy of the reported carbon emission statements.

Appendix

The purpose of this Appendix is to illustrate an activity-based emission allocation scheme that assigns multiple sales products their carbon intensities, CI. These carbon intensities, expressed as tons of CO_2 per unit of the product, are essential to calculating the aggregate CE_{GS} in Table 2. Specifically, an activity-based emission allocation scheme serves as the basis for transferring emissions from the WIP accounts to the FG accounts, in Transaction 5 in Table 1.[23]

The following description draws on a recent study by Meier (2022) in the context of cement production. The main ingredient in traditional Portland cement is clinker, which is produced by heating crushed limestone in a kiln, a process that releases massive amounts of CO_2. Cement producers have increasingly sought to replace clinker with supplementary cementitious materials, such as slag, a by-product from steel manufacturing, or calcined clay.

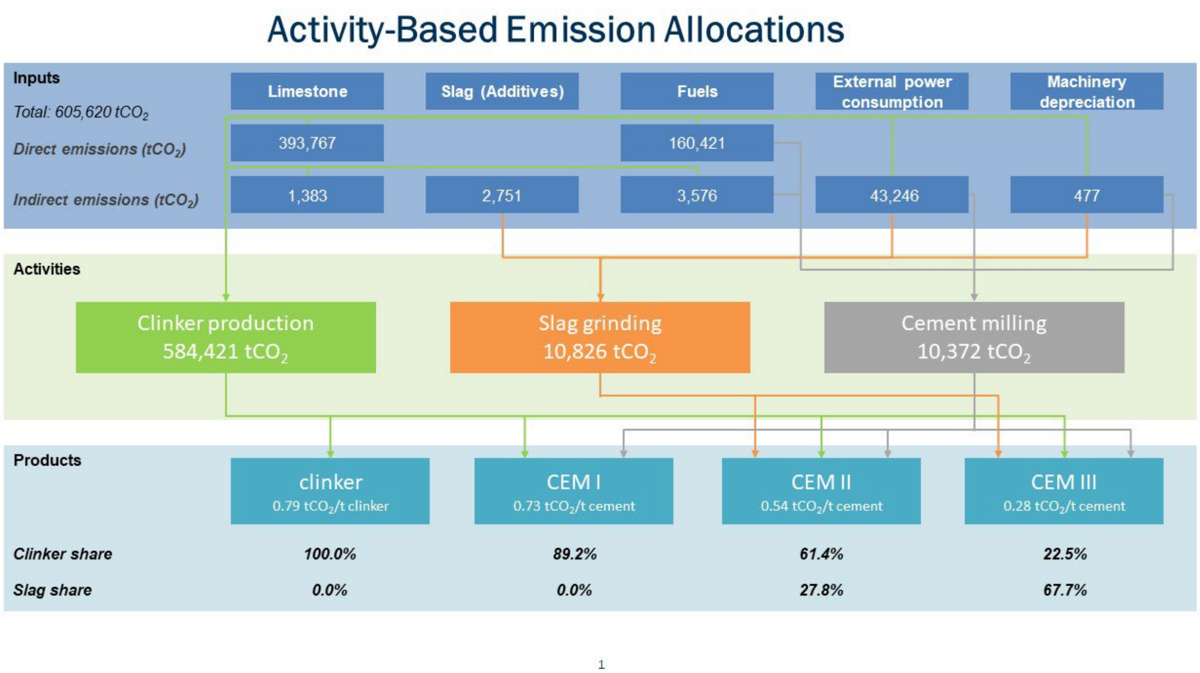

Exhibit 1: Activity Based Emission Allocations for Cement Products **Source: Meier (2022)**

[23] Allocation issues are moot in connection with B-Corp. because for this company electricity is supposed to be the only sales product.

The top two rows of Exhibit 1 show the direct and indirect emissions at a German plant of Heidelberg Materials (formerly HeidelbergCement), grouped into five input categories. The indirect emission figures came from the company's suppliers or were supplied by third-party estimates when direct data were not available. The indirect CO_2 balance of slag, for instance, reflects an allocation of the emissions from steel production, based on the relative market values of steel and slag.

The study by Meier (2022) adopts an activity-based model to assign plant-level carbon balances to the four products, clinker and CEM I-III. First, direct and indirect emissions were allocated to the three manufacturing activities: clinker production, slag grinding, and milling, where clinker and slag were mixed and milled into cement powder. Next, the study allocated the emissions accumulated in each activity to the four products. The emissions from the clinker production were allocated to the product 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 were distributed to CEM II and CEM III based on their slag percentage, 28% and 68%, respectively. Milling emissions were 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 demonstrate how substituting slag for clinker in cement recipes can substantially reduce the reported carbon content of the CEM II and III products. Finally, it is worth noting that the emission intensity figures shown in Exhibit 1 are very close to those HeidelbergCement reported as part of its Environmental Product Declarations, information that the company frequently submits in connection with bids submitted for public procurement auctions.[24]

[24] See HeidelbergCement (2021)

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