



CO₂-Statements: Double-Entry Bookkeeping for Integrated Corporate Carbon Accounting

Whitepaper No.2

The Carbon Accounting Standards Initiative (CASI)

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Contents

CO₂-Statements: Double-Entry Bookkeeping for Integrated Corporate Carbon Accounting

- *Integrated Corporate Carbon Accounting*
- *CO₂-Balance Sheets*
- *Net CO₂-Contribution Statement*
- *CO₂-Statement Analysis*
- *The Road Ahead*

Appendix

- *Bookkeeping*

References

Imprint

Integrated Corporate Carbon Accounting

Corporate carbon accounting systems derive company-specific carbon emission metrics based on two sources of data inputs. As illustrated in Figure 1, these data inputs pertain to a) the company's current operational activities such as procurement, production and sales; and b) the company's own direct emissions as well as the indirect emissions embodied in goods and services acquired from suppliers.¹

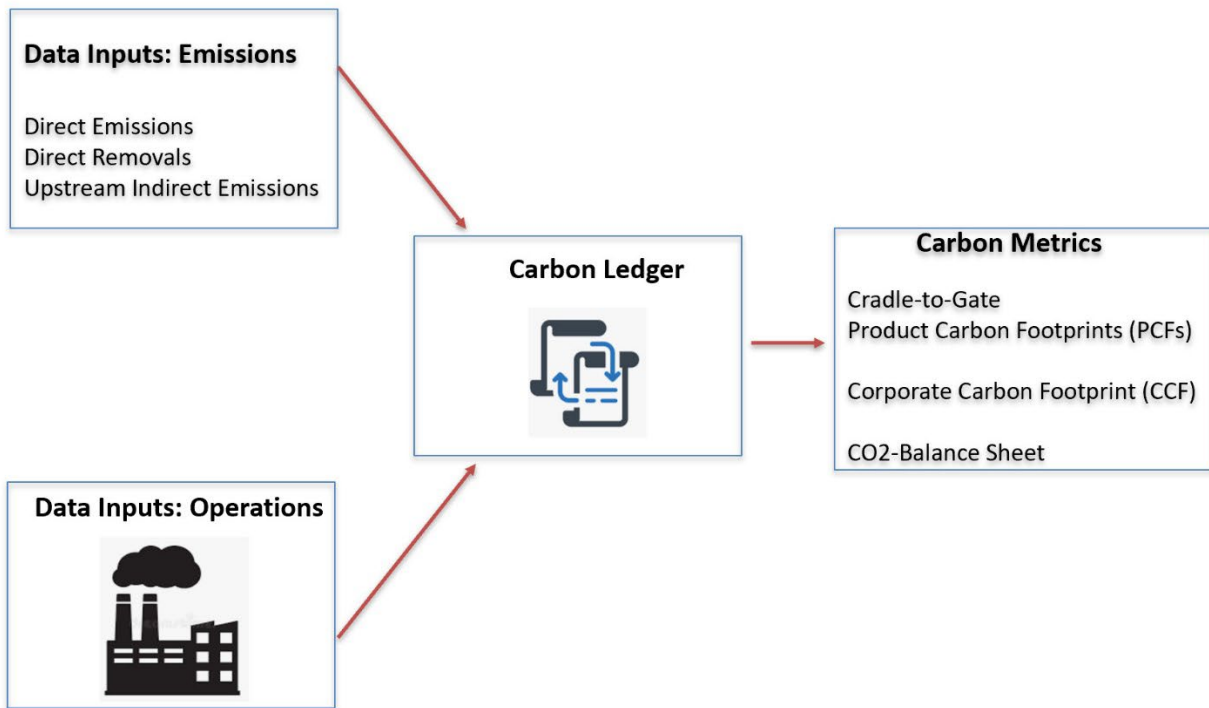


Figure 1: CO₂-Statements

CASI's Whitepaper No. 1 introduced the concept of *Integrated Corporate Carbon Accounting* (ICCA). Integration requires that the *cradle-to-gate Product Carbon Footprints* (PCFs) of an entity's sales products and its *Corporate Carbon Footprint* (CCF) meet the following consistency criteria:

- i. The CCF and the individual cradle-to gate PCFs are derived from the same data inputs regarding emissions and the entity's operating activities in the current period.
- ii. The CCF and individual cradle-to-gate PCFs are determined according to the same carbon accounting standards.
- iii. The CCF metric comprises the cradle-to-gate PCFs of products and services sold in the current period as well as other carbon emissions attributed to the current accounting period.

¹ Consistent with the notation introduced in CASI Whitepaper No.1, our discussion here refers to "carbon emissions", though the actual unit of measurement for the accounting system is tons of CO₂ equivalents (or CO₂e). Thereby greenhouse gases other than carbon dioxide (CO₂) are made comparable to CO₂ itself by applying a commonly accepted multiplier which equals one if the greenhouse gas in question is CO₂.

This second whitepaper describes a particular variant of integrated corporate carbon accounting, which we refer to as the *CO₂-Statement* approach. As the name suggests, this approach adopts the structure of financial statements as a working template. Business transactions are represented in the carbon ledger in accordance with double-entry bookkeeping. This allows the carbon stock variables of the ICCA system to be represented on a *CO₂-Balance Sheet*. The CCF metric emerging from a CO₂-Statement approach will be referred to as an entity's *Net CO₂-Contribution* (NCC). Consistent with item iii) above, this metric does capture the carbon emissions that an entity's products and services sold in the current period, as well as other carbon emissions attributed to the current accounting period, have contributed to the atmosphere. In terms of scopes, this metric comprises an entity's periodic Scope 1, Scope 2 and upstream Scope 3 emissions. Importantly, the Net CO₂-Contribution (NCC) metric is shown to reconcile with the balance sheet, ensuring that an entity's carbon emissions are assessed and reported consistently over time (→ CASI Whitepaper No.1).

To comply with the general framework of the Greenhouse Gas Protocol, the accounting standards for determining the PCFs of individual products can be chosen to comply with the *Product Life Cycle Accounting and Reporting Standard* of the Greenhouse Gas Protocol (GHG Protocol, 2011). Further, the resulting NCC metric can be supplemented to maintain consistency with the Protocol's Corporate Reporting Standard (GHG Protocol, 2024; WRI, 2004), as illustrated in Figure 2.²

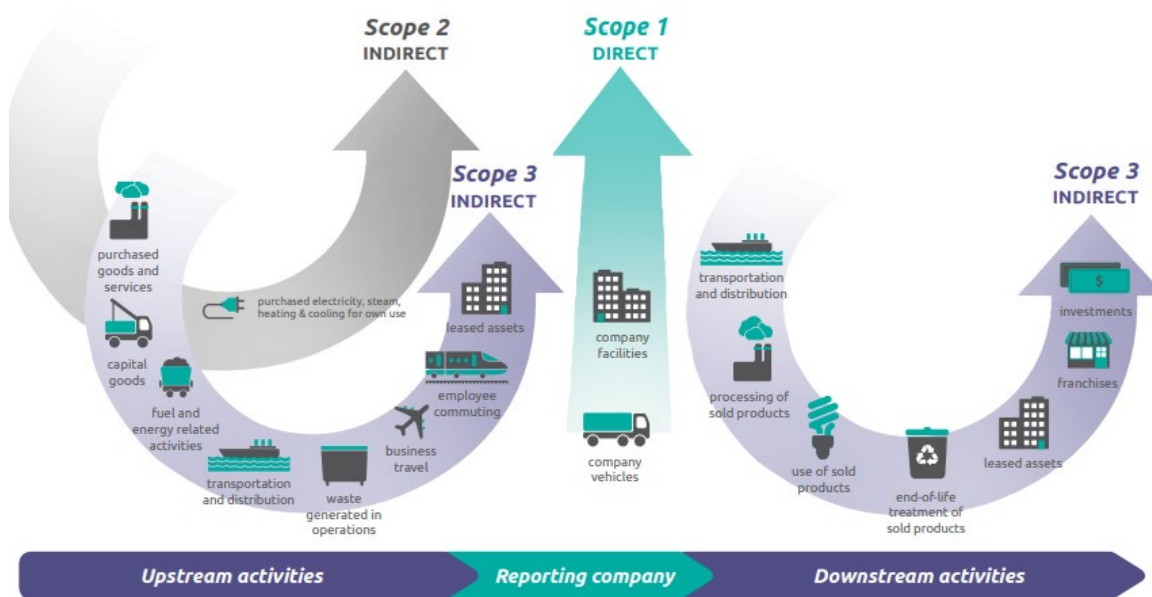


Figure 2: *Corporate carbon reporting standard*

Source: WRI (2004)

² The NCC metric captures the net direct emissions that have been incurred by the entity in question and the indirect emissions incurred by its suppliers. This metric can be expanded to a *Comprehensive Net CO₂ Contribution* metric by supplementing the cradle-to-gate PCF figures with *estimates* of the emissions to be incurred during the use phase of the products sold in the current period. Thus, the cradle-to-gate PCF figures are effectively augmented to cradle-to-grave PCF figures.

From a cost-benefit perspective, the CO₂-statement approach offers multiple advantages. On the cost side, the double-entry bookkeeping structure for the carbon ledger allows for a relatively straightforward integration into existing Enterprise Resource Planning systems (Ackermann et al., 2025, Distler et al., 2024 and Saling et al., 2025). At the same time, the double-entry structure facilitates an auditor's task of providing assurance that an entity's CO₂ statement has been prepared in accordance with established carbon accounting standards. As more entities in a supply network adopt their own in-house ICCA system, the task of auditors will be further simplified as the PCFs associated with production inputs received increasingly reflect primary data that have already received auditor assurance (Becker, 2025; CASI Whitepaper No.1).

On the benefit side, CO₂-Statements yield a range of *Key Carbon Performance Indicators (KCPIs)* that provide management and analysts with comprehensive information about a company's current emissions performance and any progress the company may have made over time. In conjunction with the NCC metric, the CO₂-Balance Sheet enables management and analysts to address the following commonly asked questions:

- Is the business on track to achieve certain self-selected carbon reduction targets?
- Has the business reduced its aggregate carbon intensity, that is, the corporate carbon footprint in relation to the value of goods and services delivered?
- Are individual business segments staying within their assigned carbon emission budgets?
- To what extent should carbon reductions achieved be attributed to the company's own operations, successful efforts by its suppliers, or the use of carbon credits?
- What is the PCF contribution of an individual sales product in relation to the overall CCF, and how does this contribution relate to the product's profitability?

In closing the section, we note that while our discussion in this whitepaper will refer to specific carbon accounting standards, our primary concern here is with the architecture of ICCA systems. A comprehensive discussion of alternative carbon accounting standards that comply with the core principles of *completeness, timely recognition, temporal consistency, accuracy and unbiasedness* (CASI Whitepaper No.1) will be the subject of future whitepapers.

CO2-Balance Sheets

The carbon stock variables of an integrated corporate carbon accounting system can be represented on a CO2-Balance Sheet, akin to a financial balance sheet. Table 1 illustrates a corresponding ledger architecture in the context of an example: the imaginary company GOCASI Ltd.³ Table 1 shows the company's opening carbon balance sheet on January 1, 2025.

Buildings						100	Indirect Emissions Transferred In						22,220
Year	prior to 2022	2022	2023	2024			Year	prior to 2022	2022	2023	2024		
	130	-10	-10	-10			Scope 2	10,000	500	600	850		
Machinery & Equipment						150	Upstream Scope 3	6,000	1,280	1,440	1,550		
Year	prior to 2022	2022	2023	2024									
	195	-15	-15	-15									
Materials						600	Direct Emissions						1,712
Year	prior to 2022	2022	2023	2024			Year	prior to 2022	2022	2023	2024		
	0	0	0	600				1,270	130	125	187		
Work-in-Process Goods A						0							
Year	prior to 2022	2022	2023	2024									
	0	0	0	0									
Work-in-Process Goods B						0	Direct Removals						-22
Year	prior to 2022	2022	2023	2024			Year	prior to 2022	2022	2023	2024		
	0	0	0	0				0	0	-10	-12		
Finished Goods A*						620							
Year	prior to 2022	2022	2023	2024									
	0	80	-80	620									
Finished Goods B**						80	Legacy Emissions						-22,360
Year	prior to 2022	2022	2023	2024			Year	prior to 2022	2022	2023	2024		
	35	5	-40	80				-16,910	-1,850	-2,300	-1,300		
Total	360	60	-145	1,275	1,550		Total	360	60	-145	1,275	1,550	

Table 1: GOCASI's Opening CO2-Balance Sheet for the Year 2025 (in tCO_{2e})

For each account, the balance sheet in Table 1 provides line-item information on the recent yearly changes in that account. The cumulative balances on January 1, 2022, are shown in the column emissions "prior to 2021". The next three columns then show the annual increases or decreases, thereby creating a three-year trend line for key carbon performance indicators.⁴ Double-entry bookkeeping ensures that for each of the years 2022, 2023 and 2024, the column totals on the left- and right-hand side are identical.

In contrast to financial balance sheets, the left-hand side of a CO2-balance sheet does not show asset values but instead reports the tons of CO_{2e} embodied in an entity's operating assets. For instance, the materials that GOCASI has in its materials inventory on January 1, 2025, have an assessed aggregate carbon footprint of 600 tCO_{2e}. Similarly, the account balances for Machinery and Equipment and Buildings reflect the original carbon footprint assessments of those fixed

³ The Appendix provides details on GOCASI's business transactions during the year 2025.

⁴ The balance sheet could, of course, provide additional line-item information by showing the increase and decreases for more than the past three years.

assets, adjusted by cumulative annual depreciation charges, which, in turn, reflect the anticipated useful life of those assets.

As discussed in Whitepaper No.1, the carbon content of acquired production inputs ideally reflects primary data for the actual direct emissions incurred by CASIGO's suppliers, their suppliers and so forth. The availability of such primary data, however, hinges on the companies in a supplier network widely adopting their own in-house carbon accounting system. Until such time, companies will have to maintain the current practice of relying on secondary data sources that estimate the carbon footprints of these acquired assets. Such estimates typically rely on internal or external life-cycle analyses (LCA) based on historical industry-wide averages (BASF, 2022; Kaplan and Ramanna, 2021; Kurtz 2022).

The Finished Goods accounts in Table 1 show the emissions embodied in GOCASI's two sales products, labeled A and B. The account balances here reflect the *cradle-to-gate PCFs* (measured in tCO₂e per unit) of each product as well as the number of units of the product the company has in stock at the beginning of fiscal year 2025. In contrast to the carbon balances for inputs and production assets received from suppliers, such as materials and machinery, the cradle-to-gate PCF figures also reflect the company's own direct (Scope 1) emissions that were incurred as part of the production process.

The right-hand side of the balance sheet shows a company's net carbon liabilities and its legacy carbon emissions. Liabilities comprise the accumulated indirect (Scope 2 and upstream Scope 3) emissions embodied in goods and services received from the entity's suppliers.⁵ The liabilities also comprise the entity's accumulated direct (Scope 1) emissions, net of any *negative emissions* that reflect direct carbon removals undertaken by the entity (or a contractor acting on its behalf). As shown below, the Legacy account represents the Net CO₂-Contribution (NCC) an entity has accumulated in past years. Since all direct and indirect emissions are either capitalized on the left-hand side of the balance sheet or immediately included in the NCC account, double-entry bookkeeping ensures that the *balance sheet identity*:

$$\text{Carbon Emissions in Assets} = \text{Carbon Emission Liabilities} + \text{Legacy Carbon Emissions}$$

is maintained at all times.

Net CO₂-Contribution Statement

To illustrate the preparation of CO₂-statements, our running example considers a sequence of representative business transactions related to procurement, production and sales. The Appendix shows the journal entries for these transactions, with the corresponding debits and credits to the different accounts represented in a Transactions Tableau. This tableau also provides details on how GOCASI determines the cradle-to-gate PCFs of its two product lines. Since both direct and upstream indirect emissions frequently take the form of *overhead emissions*, an ICCA system must

⁵ Specifically, the liability accounts record the emissions accumulated relative to a date at which the company adopted an inaugural CO₂-balance sheet. For simplicity, the account balances on this initial balance sheet could all be set to zero. A more complete approach would require companies to go through their data records to derive a CO₂-balance sheet that backdates the emissions that would have been recorded over a certain number of years prior to the inaugural adoption of the carbon accounting system.

specify allocation rules for assigning overhead emissions to individual products (Kurtz, 2022; Saling et al., 2025). A simplifying assumption of the GOCASI example is that the allocations for Scope 1 and Scope 2 emissions can be tied unambiguously to the required processing times for each of the two product lines at different stages of production. For the year 2025, GOCASI assesses the cradle-to-gate-PCFs for the two product lines at 3.0 tCO₂e and 3.1 tCO₂e per unit, respectively. These figures also reflect the assumption that the amount of materials (Scope 3) required for each product is proportional to the volume of production.

The *Net CO₂ Contribution* (NCC) statement shown in Table 2 is organized like a traditional income (Profit & Loss) statement. The expenses comprise the company’s *Carbon Emissions in Goods Sold* (CEGS), which reflect the PCFs of the different sales products multiplied by the current sales quantities. In are General & Administrative emissions. These emission items are viewed as not sufficiently related to the production process to include them in CEGS, yet these emissions were unambiguously incurred to support the company’s operations in the current accounting period. In our example, the 45 tCO₂ General & Administrative emissions correspond to carbon depreciation charges for fixed assets, electricity use related to administration, and business travel by executives.

Any tons of carbon dioxide directly removed from the atmosphere in the current accounting period constitute a source of ‘revenue’ in the NCC statement. GOCASI is assumed to have directly removed 5 tCO₂e in 2025, leaving 1,442 tCO₂e that products sold and other periodic activities have net contributed to the atmosphere in 2025. We interpret this figure as the company’s *Corporate Carbon Footprint* (CCF) for 2025. Consistent with the basic axioms of ICCA (Section 1 above), the CCF metric represents the total net direct (Scope 1) and indirect (Scope 2 and upstream Scope 3) emissions that were incurred in order to deliver products and services to customers in the current accounting period. Importantly, the emissions embodied in goods sold are removed from the asset side of the entity’s balance sheet in the period of sale. This timing will coincide with the period in which the PCFs of the products sold are recognized on the books of the entity’s customers.

Net CO ₂ -Contribution Statement	
620 Emissions in sales of Product A produced in 2024 (200 units x 3.1 tons PCF)	
660 Emissions in sales of Product A produced in 2025 (220 units x 3.0 tons PCF)	
80 Emissions in sales of Product B produced in 2024 (100 units x 0.8 tons PCF)	
<u>42 Emissions in sales of Product B produced in 2025 (60 units x 0.7 tons PCF)</u>	
1,402 Carbon Emissions in Goods Sold (CEGS)	
45 General & Administrative Emissions	
<u>-5 Current Direct Removals</u>	
1,442 Net CO₂-Contribution for the Year 2025	

Table 2: Net CO₂-Contribution Statement

One common interpretation of the commonly adopted “carbon neutrality” or “net-zero” goal is that an entity’s NCC is reduced to zero. This can be achieved either by sufficiently large direct removals that compensate for an entity’s Scope 1 emissions, and/or by acquiring a higher proportion of production inputs with negative PCFs, e.g., biomass, from suppliers.

The final entry of the accounting cycle reconciles the current Net CO₂-Contribution with the CO₂-Balance Sheet. In the GOCASI example, the balance of 1,442 tCO₂e corresponding to the 2025 net CO₂-contribution is added to the Legacy Emissions account shown in Table 3. In direct analogy to retained earnings on a financial balance sheet, the Legacy Emissions account represents accumulated past NCCs. For as long as the entity continues to contribute emissions to the atmosphere, that is, the NCC figures are positive, the entity keeps adding to its legacy emissions.

The total of 396 tCO₂e for the year 2025 on the left-hand side of the balance sheet represents that year's increase in carbon emissions embodied in operating assets. This figure is matched on the right-hand side of the balance sheet by the firm's indirect emissions transferred in during the year less emissions transferred out, i.e., the NCC for 2025.

A few technology firms, including Microsoft and Google, have pledged to undo their legacy emissions by some future date, say 2050. Doing so will require these companies to first become carbon negative, i.e., deliver negative annual corporate carbon footprints (NCCs), which over time might then compensate for the accumulated carbon emissions contributed to the atmosphere in the past.

Buildings						103	Indirect Emissions Transferred In						24,018
Year	prior to 2023	2023	2024	2025			Year	prior to 2023	2023	2024	2025		
	120	-10	-10	3			Scope 2	10,500	600	850	508		
Machinery & Equipment						165	Upstream Scope 3	7,280	1,440	1,550	1,290		
Year	prior to 2023	2023	2024	2025									
	180	-15	-15	15									
Materials						1,040	Direct Emissions						1,757
Year	prior to 2023	2023	2024	2025			Year	prior to 2023	2023	2024	2025		
	0	0	600	440				1,400	125	187	45		
Work-in-Process Goods A						0							
Year	prior to 2023	2023	2024	2025									
	0	0	0	0									
Work-in-Process Goods B						0	Direct Removals						-27
Year	prior to 2023	2023	2024	2025			Year	prior to 2023	2023	2024	2025		
	0	0	0	0				0	-10	-12	-5		
Finished Goods A						540							
Year	prior to 2023	2023	2024	2025									
	80	-80	620	-80									
Finished Goods B						98	Legacy Emissions						-23,802
Year	prior to 2023	2023	2024	2025			Year	prior to 2023	2023	2024	2025		
	40	-40	80	18				-18,760	-2,300	-1,300	-1,442		
Total	420	-145	1,275	396	1,946		Total	420	-145	1,275	396	1,946	

Table 3: GOCASI's Closing CO₂-Balance Sheet for the Year 2025 (in tCO₂e)

In closing this section, we recall that the corporate standard of the GHG Protocol requires companies to report their entire direct (Scope 1) and indirect (Scope 2 and 3) emissions (GHG Protocol, 2004). In contrast, ICCA systems only seek to track emissions that have already been incurred, specifically direct (Scope 1) and upstream indirect (Scope 2 and Scope 3.1) emissions. To bridge this gap, the CEGS metric in Table 2 can be augmented with *estimates* of the emissions that the individual products sold will incur during their use phase. Such estimates will be statistically reliable for industries that sell large volumes of identical consumer products, such as automobiles (Lu et al., 2024). In conjunction with the other periodic emissions and removals

shown in Table 2, the augmented CEGS metric then results in a *Comprehensive Net CO₂-Contribution* metric. As this metric captures an entity's entire periodic Scope 1 - Scope 3 emissions, it becomes an effective bottom line measure consistent with the corporate standard of the GHG Protocol.

CO₂-Statement Analysis

Financial statements enable analysts to derive a range of financial performance indicators. Similarly, CO₂-statements yield a range of *Key Carbon Performance Indicators (KCPIs)* that enable management and analysts to assess a company's past and current emissions performance. Further, the resulting trend lines for individual KCPIs can be extrapolated to gauge the rate at which an entity is projected to decarbonize its operations in the foreseeable future.

Industries such as steel, cement, aluminum, and chemicals deliver carbon-intensive primary products for which Scope 1 emissions constitute the dominant share of the overall carbon footprint. Effective decarbonization in these industries thus hinges on reductions in the annual *net direct emissions*, that is, annual direct emissions less direct removals. Provided CO₂-balance sheets, like the ones shown in Tables 1 and 3, provide line-item information on the recent additions to each account, the right-hand side of the balance sheet immediately generates a trend line for the company's recent *net direct emissions*. For the example in Table 3, this trend line is given by the figures: 115, 175 and 40 tCO₂e.

For industries with significant Scope 2 and upstream Scope 3 emissions, the NCC metric is central to assessing a company's efforts in decarbonizing its operations and sales products. Provided the Legacy Emissions account on the CO₂-balance sheet shows the entity's recent NCC figures as separate line items, the resulting trend line indicates the rate of progress in lowering the entity's CCF. In particular, the corresponding trend line is indicative of a company's ability to achieve any interim emission reduction targets (milestones) towards the long-term goal of carbon neutrality.

As a measure of a company's overall CCF, the NCC metric is an absolute figure, stated in tons of carbon dioxide equivalents. As such, the NCC metric will reflect growth or contraction in a company's operations. One way to standardize the NCC metric for changes in operational size is to calculate an *Aggregate Carbon Intensity (ACI)* metric, given by the ratio:

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

For a car manufacturer, the aggregate *ACI* metric would report the average tCO₂e per dollar of manufacturing cost incurred for the cars sold in the current period. For a cement company with a homogeneous portfolio of different cement recipes, it may suffice to add up the production quantities of the different recipes to calculate an *ACI* metric that captures tCO₂e per ton of cementitious material (Landaverde et. al, 2023). Such aggregate carbon intensity metrics will also enable a meaningful performance comparison of different firms in the same industry.⁶

CO₂-balance sheets can serve as an effective tool for managing compliance with so-called carbon budgets at the corporate and divisional level (Friedlingstein, 2023). Following the

⁶ Similar to the analysis of financial ratios, analysts can examine a variety of other carbon intensity ratios that relate KCPIs to monetary KPIs, e.g. the ratio of an entity's NCC in to the sum of its COGS and G&A expenses for the current period.

recommendations of the Science Based Targets initiative (SBTi), some companies and industries have set upper bounds for the cumulative emissions they pledge not to exceed in the future in order to be consistent with global efforts to stay below certain warming thresholds, such as the 1.5°C threshold. If the carbon budget is stated in terms of Scope 1 emissions, compliance with an industry-specific carbon budget can be checked directly against the balance of a company’s cumulative net direct emissions on the right-hand side of the balance sheet (e.g., the figure 1,730 = 1,757 - 27 tCO₂ in Table 3). Alternatively, if the carbon budget is stated in terms of all Scope 1, 2, and upstream Scope 3 emissions, the relevant budget constraint becomes the balance in the account Legacy Emissions (e.g., the figure 23, 802 tCO₂) in Table 3).

As mentioned above, some companies in the technology sector, including Google and Microsoft, have gone beyond the common “net-zero by 2050” goals by pledging to undo their accumulated past direct and indirect emissions by some target date. Attaining this far more ambitious goal will certainly require rapid decarbonization of a company’s supply network. In addition, direct removals must significantly outweigh direct emissions in the years leading up to the target date in order for the cumulative balance in the account Legacy Emissions to approach the value of zero.

Table 3 of the GOCASI example also reveals that the *Net Carbon Flow* metric, introduced in Whitepaper No. 1, emerges directly as the 2025 year column of the liability section of the CO₂-Balance Sheet. By definition, the Net Carbon Flow Metric does not distinguish between carbon stock and carbon flow variables but instead includes all ‘raw’ emissions for the year 2025. Specifically, this metric includes all Scope 2 and Scope 3.1 emissions associated with inputs acquired in 2025 and adds GOCASI’s net direct emissions incurred during the year. The difference between the 2025 Net Carbon Flow and the NCC metric therefore amounts to 396 tCO₂e. As argued above, double-entry bookkeeping ensures that this difference is matched on the left-hand side of the balance sheet exactly by the increase in carbon emissions embodied in operating assets for 2025. The relationship observed in this example holds true in general. Specifically, double-entry bookkeeping always yields the following identity:

$$\text{Net Carbon Flow} = \text{Net CO}_2\text{-Contribution} + \text{Change in Carbon Emissions in Assets}$$

Beyond an entity level analysis, integrated corporate carbon accounting enables management to analyze the carbon emissions performance of individual sales products. The availability of cradle-to-gate PCF figures for the entire product portfolio allows management to assess what each individual sales product contributes to the overall corporate carbon footprint (CCF). Importantly, these product carbon contributions can be compared to the profitability contribution of each sales product.⁷

The CO₂-statements presented here have maintained a historical cost perspective insofar as the accounting system sought to capture the direct and upstream indirect emissions that have already been incurred. Nonetheless, CO₂-statements also lend themselves to extrapolating from the past to the future, as the tCO₂e recorded on the left-hand side of the balance sheet will materialize in future NCC statements. Specifically, analysts will be able to issue forecasts for the near-term future

⁷ Measuring carbon contributions as Scope 1 emissions only, Greenstone et al. (2024) calculate a ratio that relate firms’ profitability to their carbon contributions.

NCCs on the basis of a company's recent direct emissions and the tCO₂e that have been capitalized in operating assets.

The Road Ahead

Our calculations in the GOCASI example have implicitly assumed that the corporate carbon accounting system adheres to certain *carbon accounting standards*. While alternative carbon accounting standards will be the subject of future CASI whitepapers, we note here that one central standard for any ICCA system concerns the *boundaries of PCF calculations*. In the framework of CO₂-statements, the issue of boundaries can be cast in terms of categorizing emission items as either *inventoriable* or as *periodic emissions*. Inventoriable emissions are, by definition, included in the accounts on the left-hand side of the CO₂-balance sheet, while periodic emissions are directly charged to the current Net CO₂-Contribution. The principal difference then becomes one of timing: emissions items deemed inventoriable may be included in future rather than current NCC metrics.

The Product Life Cycle Accounting and Reporting standard of the GHG Protocol specifies relatively narrow boundaries for emission items to be included in PCF calculations (GHG Protocol, 2011). For instance, this standard excludes from PCFs the emissions embodied in factory buildings and manufacturing equipment. Our calculations in the GOCASI example have complied with this standard insofar as the carbon depreciation charges for plant and equipment were treated as periodic emission items and included in the line item General & Administrative emissions. This view obviously contrasts with the general financial accounting standard that treats all costs related to the production process as inventoriable and therefore as part of Costs of Goods Sold.

Product boundary issues also arise in connection with direct carbon removals. The GOCASI example recorded direct removals as a separate line-item gain in the NCC statement and as a contra-liability on the CO₂ balance sheet (a negative emissions number). An alternative accounting standard would subtract direct removals from direct emissions and treat the difference of net direct emissions as inventoriable, thereby including this net figure in the calculation of the product carbon footprints. Moving further afield, the accounting standards for direct removals could conceivably leave companies with discretion in assigning tons of carbon removed to select facilities, activities, and even to individual products. The accounting for direct removals, and more broadly carbon credits, is likely to be controversial and of increasing importance in the future. Importantly, alternative accounting standards for the recognition and treatment of carbon removals will generate different incentives for companies' willingness to undertake or acquire carbon removal projects.⁸

The standards for PCF boundaries will ultimately determine the extent to which the reported cradle-to-gate PCFs are complete regarding all Scope 1 emissions incurred in a supply network. As an extreme case, suppose the standards call for "full costing", whereby all emission items are viewed as inventoriable for all companies along a supply network. In principle, the resulting cradle-to-gate PCFs will then amount to an allocated share of the seller's actual direct (Scope 1) emissions, plus an allocated shares of the actual direct (Scope 1) emissions incurred by the seller's Tier 1 suppliers, plus an allocated share of the actual direct (Scope 1) of its Tier 2 suppliers and so

⁸ CO₂-balance sheets allow for the possibility of recognizing carbon removals that are not necessarily irreversible, e.g., reforestation projects. Such "risky" removals could be recognized as "contingent liabilities" on the balance sheet, provided there is ongoing monitoring and verification for possible reversals (Reichelstein, 2025)

forth.⁹ In contrast, a “partial costing” a partial costing approach that views certain emission items as outside the PCF boundaries, will result in PCFs that *undercount* some direct emissions incurred by parties in the upstream supply network.

A key feature of ICCA systems is that incoming direct and indirect emissions are *allocated* (assigned) to different time periods, business segments and products. Industry consortia like Catena-X and Together-for-Sustainability have generally recommended that “allocations are to be avoided”. This may indeed be possible for modular components going into products. For instance, suppose a battery pack is installed in an electric vehicle. The battery’s PCF, as determined by the battery manufacturer and certified by an auditor, can then simply be passed to the PCF calculation of the electric vehicle.

In contrast to modular components, Scope 1 and Scope 2 emissions will frequently be collected in pools of overhead emissions that have been incurred in connection with process steps that support multiple products. Similar to the rules of cost accounting, the allocation of pools of overhead emissions to individual products must then adhere to specific allocation rules. The *Unbiasedness Principle* (→ CASI White Paper No.1) stipulates that allocation rules not be arbitrary and thereby enable selective product greenwashing. In upcoming whitepapers, CASI intends to delineate specific carbon accounting rules that must be met in order for particular allocation rules to qualify as unbiased. Specifically, such rules must comply with the *causal link* principle, that is, the allocation rule reflects the causal relation between emissions associated with specific production activities and the extent to which different products require these activities. The identification of unbiased allocation rules will then determine the extent to which companies can adopt allocation rules such as mass balancing (Saling et al. 2024) or the recognition of clean energy attributes in determining their Scope 2 emissions.

With comprehensive standards in place regarding boundaries and allocations, companies will be in a position to provide their customers with reliable PCF figures, sometimes referred to as ‘carbon tags’. The reliability of this data will be further enhanced if a growing portion of a firm’s suppliers adopt their own in-house ICCA system and the resulting PCF and CCF figures receive assurance from auditors at the individual stages of the supply chain. Such developments will give carbon tags the potential to become a ‘hard currency’ that customers will consider, like product price and product quality, to compare the attractiveness of competing suppliers (Becker, 2025). As cradle-to-gate PCF figures increasingly reflect the actual upstream direct emissions incurred by a product, they generate first-order incentives for companies to decarbonize their own operations by reducing their own direct emissions and to pressure their suppliers to do the same. Such incentives are largely missing today for as long as PCFs are not determined on an actual basis but instead based on historical industry averages.

⁹ Since the “full cost” standard views all emission items as inventoriable, a company’s Net CO₂-Contribution reduces to its CEGS under the full cost standard. Further, in a closed network economy the total emissions incurred throughout its entire lifecycle will always conform to the following identity: the aggregate PCFs of all consumer products sold are equal to the aggregate CEGS figures for all suppliers in the network, and this total is equal to the sum of all direct emissions incurred within the network (Reichelstein, 2024).

Appendix

Preparing CO₂-Statements: An Example

This appendix provides details regarding the transactions undertaken by GOCASI Ltd. during the fiscal year 2025. GOCASI's opening CO₂-balance sheet in Table 1 shows the emissions embodied in all stock variables carried over from the previous year. On the left-hand side, it records the emissions embodied in the company's operating assets: buildings, machinery, materials in inventory and finished products. These emissions have been incurred and have not yet been charged in NCC statements.

The right-hand side of the balance sheet shows the entity's accumulated carbon emission liabilities and its accumulated legacy emissions. Liabilities are partitioned into indirect (Scope 2 and upstream Scope 3) emissions, direct (Scope 1) emissions and negative direct emissions, represented as carbon removals. These are recorded with a negative sign, making them effectively a counter-liability account. The balance in the Legacy Emissions account shows GOCASI's accumulated past NCC figures. Since GOCASI has consistently contributed additional emissions into the atmosphere over the past three years, the balance of the Legacy account has grown in each year.

Product Carbon Accounting

GOCASI produces and sells two product lines, A and B, each one of which is manufactured in two process steps. Batches leave Step 1 as 1 Work-in-Process (WIP) and are turned into finished goods in Step 2. The following table summarizes the calculation of the product carbon footprints (PCFs) for the two product lines. The figures pertain to fiscal year 2025, with the 2024 figures shown only for comparisons. Emissions are recorded separately for each product at each of the two production steps. In the first step, purchased materials with a carbon footprint of 800 tCO_{2e} are transferred into work-in-process (WIP). Of these 800 tCO_{2e}, 720 are allocated to the A (product) line and 80 to the B line. The split reflects the production volume for the two products as well as their per-unit material requirements. Similarly of the 40 tCO_{2e} embodied in electricity used in step one, 36 are charged to the A line, with the remaining 4 tons going to the B line. These allocations reflect the known power requirements for each A and B unit, as well as the production volume of 400 As and 200 Bs.

In Step 2, both product lines are burdened with further emission charges arising from consumed electricity. The charges of 420 and 36 respectively reflect the required kWh for electricity for each A and B unit. Finally, Table 4 shows GOCASI incurred direct emissions in the amount of 44 tCO_{2e} caused by the combustion of natural gas to generate process heat. The split into 24 and 20 tCO_{2e} reflects the processing time needed by each A and each B unit.

PCF Calculation				
Product	A		B	
Year	2024	2025	2024	2025
Emissions in Step 1				
Scope 1	0	0	0	0
Scope 2	40	36	4	4
Scope 3.1	1,020	720	96	80
Emissions in Step 2				
Scope 1	40	24	30	20
Scope 2	760	420	30	36
Emissions total	1,860	1,200	160	140
Units produced	600	400	200	200
PCF	3.10	3.00	0.80	0.70

Table 4: Product Carbon Accounting

Journal Entries in 2025:

The following 14 journal entries (JE) reflect GOCASI's transactions related to procurement, production, sales and other operating activities.

JE1: The company purchases materials with a total PCF of 1,240 tCO₂e.

JE2: In Step 1, a fraction of these materials corresponding to a total PCF of 800 tCO₂e are transferred to WIP A and WIP B. Of these, 720 tCO₂e are charged to Product line A and 80 tons to Product line B. This split reflects i) the amount of materials each product requires and ii) that 400 A units and 200 B units were processed in Step 1 as WIP in 2025.

JE3: 36 tCO₂e are charged for electricity consumption to WIP A and 4 tCO₂e are charged to WIP B.

JE4: In Step 2, 400 units of WIP A is converted into 400 units of Finished Goods A, requiring an additional 420 tCO₂e for electricity and 24 tCO₂e for allocated direct emissions.

JE5: In Step 2, 200 units of WIP B are converted into 200 units of Finished Goods B, requiring an additional 36 tCO₂e for electricity consumption and 20 tCO₂e for allocated direct emissions.

JE6: GOCASI sells 420 A units during fiscal year 2025. Of these, 200 units were produced in 2024 with an assessed PCF of 3.10 tCO₂e per unit (see Table 4). The remaining 220 units were produced in 2025 with a PCF of 3.0 tCO₂e per unit (as calculated in JE1-JE5 and summarized in Table 4).

JE7: GOCASI sells 160 B units in 2025. Of these, 100 units were produced in 2024 with a PCF of .8 tCO₂e per unit (see Table 4). The remaining 60 units were produced in 2025 with a PCF of .7 tCO₂e per unit (as calculated in JE1-JE5 and summarized in Table 4).

JE8: New machinery with an assessed PCF of 30 tCO₂e is purchased from a supplier.

JE9: GOCASI constructs a storage facility. The building materials have emissions of 10 tCO₂e embodied in them. Construction of the facility requires electricity with an assessed PCF of 2 tons. GOCASI incurs 1 ton in direct CO₂ emissions due to fuel combustion.

JE10: Travel by GOCASI's executives in 2025 resulted in 10 tCO₂e.

JE11: GOCASI has signed an offtake agreement with a direct air capture company. According to the contract, 5 tCO₂e were removed in 2025.

JE12: Straight-line depreciation charges are applied to long-term operating assets: 10 tCO₂e corresponding to buildings and 15 tCO₂e to machinery.

JE13: Electricity use for General and Administrative activities, including R&D, results in emissions of 10 tCO₂e.

JE14: The balance in the carbon flow account Net CO₂-Contribution is closed out to the balance sheet account Legacy Carbon Emissions.

The following table shows the debits and credits for the above journal entries. All accounts shown in this table correspond to balance sheet accounts except for the NCC account, which is a carbon flow account with a beginning and ending balance of zero.

Business transactions tableau overview:

	Carbon Emissions in Assets						Net CO2- Contribution	Carbon Emission Liabilities			Legacy Carbon Emissions
	Buildings	Machinery & Equipment	Materials	WIP A	WIP B	Finished Goods A	Finished Goods B	Indirect Emissions Transferred In	Direct Emissions	Direct Removals	
Beginning Balance	100	150	600	0	0	620	80	22,220	1,712	-22	-22,360
JE1			1,240					1,240			
JE2			-800	720	80						
JE3				36	4			40			
JE4				-756		1,200		420	24		
JE5					-84		140	36	20		
JE6						-1,280					
JE7							-122				
JE8		30						30			
JE9	13							12	1		
JE10								10			
JE11										-5	
JE12	-10	-15									
JE13											
JE14								10			-1,442
Changes in 2025	3	15	440	0	0	-80	18	1,798	45	-5	-1,442
Ending Balance	103	165	1,040	0	0	540	98	24,018	1,757	-27	-23,802



Net CO2-Contribution Statement

620 Emissions in sales of Product A produced in 2024 (200 units x 3.1 tons PCF)

660 Emissions in sales of Product A produced in 2025 (220 units x 3.0 tons PCF)

80 Emissions in sales of Product B produced in 2024 (100 units x 0.8 tons PCF)

42 Emissions in sales of Product B produced in 2025 (60 units x 0.7 tons PCF)

1,402 Carbon Emissions in Goods Sold (CEGS)

45 General & Administrative Emissions

-5 Current Direct Removals

1,442 Net CO2-Contribution for the Year 2025

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About CASI

The Carbon Accounting Standards Initiative (CASI) is a coalition of academics and company representatives from the fields of accounting, corporate reporting, and decarbonization. CASI's mission is to advance rigorous and decision-useful carbon accounting at the company level.

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