


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

**Whitepaper No.2**

The Carbon Accounting Standards Initiative (CASI)

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## Executive Summary

Companies around the world are currently evaluating their capabilities to measure and report greenhouse gas emissions. This whitepaper describes company-level accounting systems that enable Integrated Corporate Carbon Accounting (ICCA). The essential feature of such systems is that an entity's cradle-to-gate product carbon footprints and its corporate carbon footprint are determined from the same data inputs and according to the same accounting standards. To ensure consistency across time periods, the stock variables of the accounting system are organized on a CO2-Balance Sheet. The corporate carbon footprint metric emerges as the corresponding flow variable that reconciles to the balance sheet. Taken together, the resulting carbon statements allow for a comprehensive assessment of an entity's carbon emissions performance and any improvements thereof over time. ICCA systems are shown to be compatible with alternative accounting standards regarding boundaries and allocations, thereby offering a flexible platform for corporate reporting within the overall framework of the Greenhouse Gas Protocol.

## 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 the company's current operational activities including procurement, production and sales. These data inputs also pertain to the company's own direct emissions and the indirect emissions embodied in goods and services acquired from suppliers.[1]

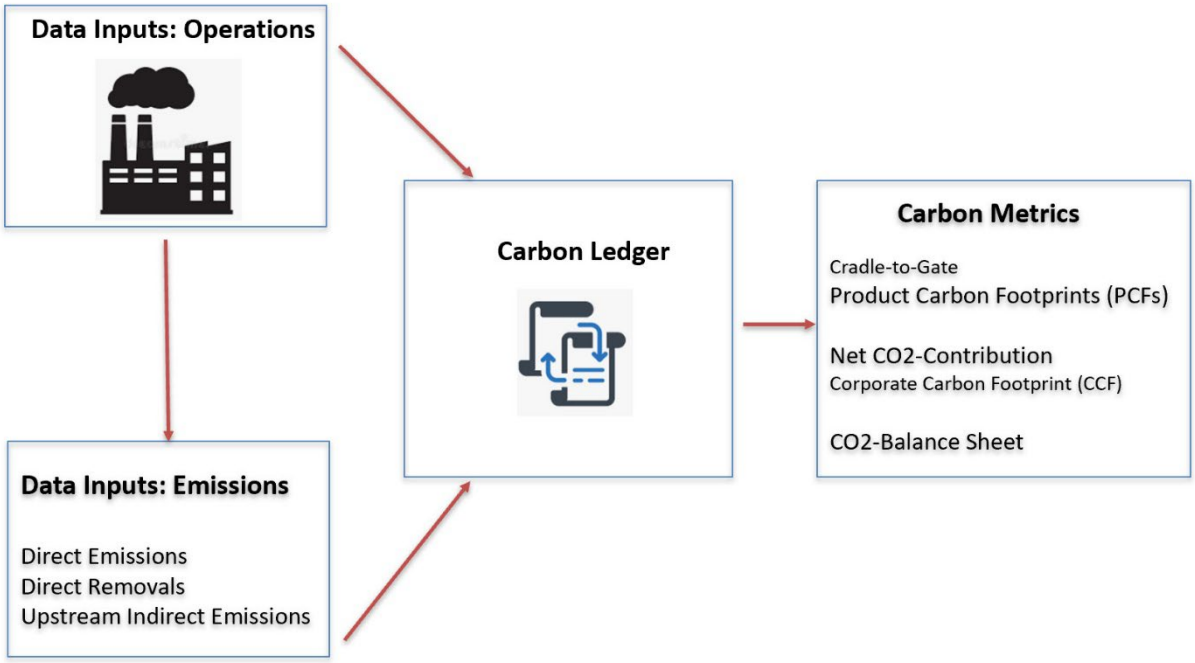



Figure 1: **Structure of ICCA Systems**

CASI 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)* be assessed consistently so that:

i. The CCF and the individual cradle-to gate PCFs are derived from the same data inputs for emissions and operating activities in the current period.
ii. The assessed cradle-to-gate PCFs and the CCF are based on the same carbon accounting standards.
iii. The CCF metric represents 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 $CO_2$ equivalents (or $CO_2e$). Thereby greenhouse gases other than carbon dioxide ($CO_2$) are made comparable to $CO_2$ itself by applying a commonly accepted multiplier which equals one if the greenhouse gas in question is $CO_2$.

This whitepaper describes a particular method for integrated corporate carbon accounting, which will be referred to as the *CO2-Statement* approach. As the name suggests, the CO2-Statement approach adopts essential features of financial accounting and financial statements in the context of carbon emissions. The $CO_2$ emissions associated with production and sales transactions are recorded in accordance with double-entry bookkeeping on a corporate carbon ledger. The stock variables of this ledger can be represented on a *CO2-Balance Sheet* as described in Reichelstein (2024).[2]

The principal flow metric emerging from ICCA systems will be referred to as an entity's *Net CO2-Contribution* (NCC). This flow measure represents the 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 atmospheric stock of GHG emissions. As such, the NCC constitutes a measure of an entity's Corporate Carbon Footprint (CCF) in terms of its periodic Scope 1, Scope 2 and upstream Scope 3 emissions. Importantly, the Net CO2-Contribution (NCC) metric reconciles to the CO2-Balance Sheet, ensuring that an entity's carbon emissions are assessed and reported consistently over time (→ CASI Whitepaper No.1).

The Corporate Reporting Standard of the Greenhouse Gas Protocol (WRI, 2004) calls for companies to also include estimates for the future downstream emissions associated with their sales products; see Figure 2 for an illustration. In certain industries, such estimates can be based on statistical information about past usage, e.g., automobiles (Lu et al., 2026). Companies in those industries can then supplement their cradle-to-gate PCF figures with *forecasts* of the emissions to be incurred during the use phase of the products in order to arrive at cradle-to-grave PCF figures. These augmented PCF figures yield a *Comprehensive Net $CO_2$ Contribution* metric. In alignment with the corporate standard of the GHG Protocol, the latter metric becomes a measure of an entity's entire periodic Scope 1 - Scope 3 emissions.

[2] Similar in structure to a financial ledger, the carbon ledger described in this paper refers to a collection of accounts maintained at the company level, wherein all debits are matched by credits on the same ledger. In contrast, Kaplan and Ramanna (2025) advocate for a global inter-organizational carbon ledger. Debits to one company's accounts would be matched with credits to another company's accounts. Further, they envision a "Global Geologic Equity" account to keep track of companies' direct emissions. It appears that the introduction of such an infrastructure would require a complex upfront agreement governing the operation, data sharing and control of this global inter-organizational ledger.

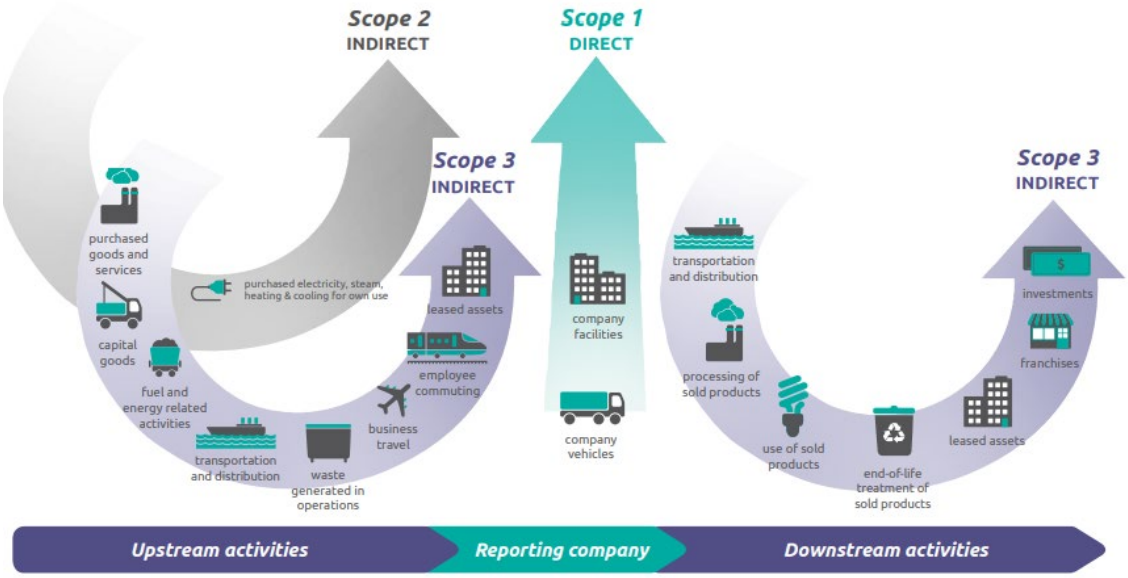



**Figure 2**: *GHG Protocol: Corporate Reporting Standard* Source: WRI (2004)

A commonly expressed concern about current emissions reporting in accordance with the framework of the GHG Protocol is that the reported Scope 3 emissions are typically based on secondary rather than primary data. In assessing those indirect emissions, companies along a supply chain frequently conduct a Lifecycle Assessment Analysis (LCA) to assess the emissions embodied in the production inputs acquired from suppliers. Yet these assessments frequently rely on historic industry-wide emission averages rather than the actual emissions incurred by the particular supply chain (Kaplan and Ramanna, 2021). The chemical company BASF was among the first to develop an in-house PCF measurement system with the aim of credibly communicating to customers the actual direct emissions incurred by BASF in delivering its chemical sales products. (BASF, 2021; Kurtz, 2022; Kaplan, Ramanna and Reichelstein, 2023).

Provided ICCA systems are increasingly adopted along a supply chain, product sales can be accompanied by "carbon tags" indicating the kg of $CO_2e$ embodied in each unit of the product. Importantly, this carbon tag information can enter each customer's carbon ledger at face value, provided it received auditor certification as having been obtained in accordance with recognized accounting standards concerning the boundaries of PCF calculations and the use of allowable allocation rules. The resulting system of assessing PCFs in a sequential and decentralized manner will thus provide buyers of goods and services with audited primary data about the cumulative actual direct emissions incurred by the seller and its upstream suppliers. The emerging shift to primary data will be crucial in providing proper incentives for the parties along a supply chain to decarbonize their operations. Any accomplishments in reducing emissions will be reflected without delay in the carbon tags handed down to customers.

## CO2-Balance Sheets

The carbon stock variables of an integrated corporate carbon accounting system can be represented on a balance sheet, which shares several features with a financial balance sheet. Table 1 illustrates the CO2-Balance Sheet in the context of an example: the

imaginary company GOCASI Ltd. Table 1 shows the company's opening carbon balances 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 | *5,834* | *1,280* | *1,440* | *1,716* | |
| 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* | | | *-16,744* | *-1,850* | *-2,300* | *-1,466* | |
| **Total** | ***360*** | ***60*** | ***-145*** | ***1,275*** | **1,550** | **Total** | ***360*** | ***60*** | ***-145*** | ***1,275*** | **1,550** |

**Table 1**: *GOCASI's Opening 2025 CO2-Balance Sheet (in $tCO_2e$)*

For each account, Table 1 provides line-item information on the recent yearly additions to that account. The accumulated balances on January 1, 2022, are shown in the column emissions "prior to 2022". The next three columns show the annual increases or decreases, thereby creating a three-year trend line for key carbon performance indicators.[3] 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 shows 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 reflect the original carbon footprint assessments of those fixed assets, adjusted by cumulative annual depreciation charges, which, in turn, reflect the anticipated useful life of those assets.

As discussed above, the carbon content of acquired production inputs ideally reflects primary data for the actual direct emissions incurred by GOCASI's suppliers, their suppliers and so forth. The availability of such primary data, however, hinges on the suppliers widely adopting their own in-house carbon accounting system. Until such time,

[3] The balance sheet could, of course, provide additional line-item information by showing the incremental data for more than the past three years.

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 (LCAs) based on historical industry-wide averages (BASF, 2021; Kaplan and Ramanna, 2021; Kurtz 2022; Catena-X, 2023).

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 $tCO_2e$ 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 addition to the carbon balances for inputs and production assets received from suppliers, 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 the accumulated indirect (Scope 2 and upstream Scope 3) emissions embodied in goods and services as received from the entity's suppliers.[4] It also shows the entity's accumulated direct (Scope 1) emissions, net of any *negative emissions* that reflect direct carbon removals undertaken (or contracted for) by the entity. As demonstrated below, the account Legacy Emissions 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*:

*Emissions in Assets = Emissions Transferred In + Net Direct Emissions + Legacy Emissions*

is maintained at all times. This equation can be thought of as the carbon analogue of the financial balance sheet identity "Assets = Liabilities + Equity".[5] However, as pointed out above, the left-hand side of the CO2-Balance Sheet does not represent conventional assets. Neither do the accounts Emissions Transferred In and Net Direct Emissions and Legacy Emissions represent traditional liabilities that the entity owes to other external parties.

## Product Carbon Accounting

To illustrate the preparation of CO2-statements, our running example considers a sequence of representative business transactions related to procurement of raw materials and inputs, production and sales. The Appendix shows the journal entries for these transactions, with the corresponding debits and credits to different accounts represented in a Transactions Tableau. The Appendix 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*, a product carbon accounting system must apply allocation rules for assigning overhead emissions to individual products (Kurtz, 2022; Saling et al., 2025). For simplicity it is

[4] Specifically, these accounts record the emissions accumulated after the point in time at which the company adopted an inaugural CO2-Balance Sheet.

[5] The carbon balance sheet proposed in Penman (2026a, 2026b) envisions that carbon assets on the left-hand side of a balance sheet represent investments in future emission reductions.

assumed in the GOCASI example that both Scope 1 and Scope 2 emissions can be charged unambiguously to the two product lines in proportion to each product's required processing times. A further simplifying feature of this example is that there is effectively no allocation issue in connection with materials (Scope 3) as the material requirements and corresponding carbon emission charges for each product line are assumed to be proportional to the volume of production.

Table 2 shows the resulting product carbon footprint (PCF) statement for the two product lines in fiscal year 2025. Accordingly, GOCASI assesses the overall cradle-to-gate-PCFs (carbon intensities) for the two product lines to be 3.0 $tCO_2e$ and .7 $tCO_2e$ per unit, respectively.

| 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 2**: *PCF Statements for Products A and B*

Like product cost data compiled by an internal cost accounting system, the assessed PCFs of finished goods are internal information available in their entirety only to management. When an individual product is transferred to a customer at a particular price, and possibly with certain quality assurances, the seller will be in a position to attach a "carbon tag," providing auditor certification for its carbon intensity, that is, the kg of $CO_2e$ embodied in one unit of the product. Further, as more companies along the supply chain adopt ICCA systems, the carbon tags issued will increasingly convey the actual direct emissions incurred collectively by the seller and its upstream suppliers.

## Net CO2-Contribution Statements

*Net CO2-Contribution* (NCC) statements are periodic flow statements that can be thought of as the carbon equivalent of a 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. General & Administrative emissions correspond to items that are viewed as not sufficiently related to the production process so as to include them in CEGS. Yet, provided these emissions were unambiguously incurred to support the company's operations in the current accounting period, they are included in the NCC measure. In our running example, there were 45 $tCO_2$ in General & Administrative emissions that correspond to carbon

depreciation charges for fixed assets, electricity use related to administration, and business travel by executives.

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

**Table 3:** *Net CO2-Contribution Statement*

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 $tCO_2e$ in 2025, leaving 1,442 $tCO_2e$ that products sold and other periodic activities have in 2025 contributed to the stock of atmospheric GHG emissions.

We interpret the NCC as an entity's *Corporate Carbon Footprint* (CCF) for the total net direct (Scope 1) and indirect (Scope 2 and upstream Scope 3) emissions incurred in order to deliver products and services to customers in the current accounting period. Beginning in the early 2020's, many multinational firms have articulated "net-zero" or "carbon neutrality" goals, frequently with a 2050 horizon. To deliver on these long-term ambitions, the trajectory of an entity's NCC figure will ultimately need to decline over time and approach zero by the target date. 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 $tCO_2e$ corresponding to the 2025 NCC figure is added to the Legacy Emissions account shown in Table 4. [6] In direct analogy to retained earnings on a financial balance sheet, the Legacy Emissions account represents accumulated past NCCs. In Table 4, the annual line items for this account show the entity's NCC figures for the past three years. For as long as an entity continues to contribute emissions to the atmosphere, that is, the NCC figures are positive, the entity keeps adding to its legacy emissions.

Double counting of emissions is another frequently expressed concern about the framework of the GHG Protocol. As illustrated in connection with the product carbon

[6] Emissions items that cannot be attributed to an entity's ordinary business activities, e.g., emissions embodies in impaired machinery or equipment, can be excluded from the NCC but instead be charged as Other Comprehensive Emissions (OCE). The change in Legacy Emissions then becomes the sum of NCC and OCE; see also Whitepaper No.4.

footprint statements in Table 3, the sequential calculation of PCFs along the supply chain is designed to avoid double counting of any direct or indirect emissions. In contrast, the Net CO2-Contribution involves double counting, and does so by construction as the NCC metric seeks to account for the emissions incurred by an entity's entire supply chain. Scope 1 emissions are the only corporate metric that is truly additive across companies, and ICCA systems report this metric separately on the right-hand side of the CO2-Balance Sheet.

| **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 | *7,114* | *1,440* | *1,716* | *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* | | | *-18,594* | *-2,300* | *-1,466* | *-1,442* | |
| **Total** | ***420*** | ***-145*** | ***1,275*** | ***396*** | **1,946** | **Total** | ***420*** | ***-145*** | ***1,275*** | ***396*** | **1,946** |

**Table 4:** *GOCASI's 2025 Closing CO2-Balance Sheet (in $tCO_2e$)*

The column corresponding to the year 2025 on the right-hand side of the balance sheet in Table 4 shows GOCASI's *Net Carbon Flow* for that year. As introduced in Whitepaper No. 1, the Net Carbon Flow does not distinguish between carbon stock and flow variables but instead records all "incoming" emissions, that is, all Scope 2 and upstream Scope 3 emissions associated with inputs acquired in 2025 plus all net direct emissions incurred during the year. The 2025 year column on the right-hand side of the CO2-Balance Sheet also shows that the difference between the 2025 Net Carbon Flow and the NCC metric amounts to 396 $tCO_2e$. Double-entry bookkeeping ensures that this difference is exactly matched by the increase in carbon emissions embodied in operating assets on the left-hand side of the balance sheet. We therefore obtain the general balance sheet identity:

*Net Carbon Flow - Net CO2-Contribution = Change in Carbon Emissions in Assets.*

Taken together, the combination of CO2-Balance Sheets, NCC statements and individual PCF statements yield a range of decision useful metrics about a company's carbon emissions performance. At the product level, the time series of assessed PCF figures will be informative about an entity's success in decarbonizing a particular product. The line item information shown in Table 3 can identify to what extent any PCF reductions should

be attributed to the company's own direct (Scope 1) emissions as opposed to the indirect (Scope 2 and upstream Scope 3) emissions incurred by the company's suppliers. Further, it may be instructive to assess the PCF contribution made by an individual sales product in relation to the overall corporate carbon footprint, as measured by the NCC. Other instructive performance metrics are obtained by relating PCFs to financial variables, e.g., a product's PCF in relation to its contribution margin.

At the entity level, both CEGS and the NCC metric are bottom line measures that enable companies to operationalize carbon emission reduction goals and net-zero pledges. While individual PCF figures may be affected by the choice of specific allocation rules, the aggregate CEGS and NCC metric are largely invariant to the use of allocation rules, provided there were no significant changes in inventories. For growing businesses it will be informative to relate the absolute CEGS figure to a corresponding financial metric such as Cost of Goods Sold (COGS). The ratio CEGS/COGS becomes a natural measure of the entity's aggregate carbon intensity and any improvements thereof over time.

Some companies have issued so-called carbon budgets at the corporate and/or divisional level, requiring an entity's cumulative CCFs to stay below a certain limit (SBTi, 2026). Compatibility with such carbon budgets can be gauged immediately from the current balance of the account Legacy Emissions on the CO2-Balance Sheet. Finally, select technology firms, including Microsoft and Google, have gone beyond standard net-zero goals by articulating the ambition to undo their legacy emissions by some future date, say 2050 (Comello et al., 2023). Doing so would require these companies to first become carbon negative, i.e., deliver negative annual NCCs, and over time to reduce the balance in the account Legacy Emissions towards zero.

## Alternative Product Carbon Footprint Boundaries

While Carbon Emissions in Goods Sold (CEGS) is arguably the core of an entity's NCC, Table 3 also shows General & Administrative emissions corresponding to depreciation charges for fixed assets, electricity use related to administration, and business travel. The corresponding emissions were not recorded as inventoriable but instead as periodic emissions attributed to the current year and charged directly to the current Net CO2-Contribution. The conceptual justification for such a partial-cost PCF methodology is that emission categories should be charged to products only if there is a discernible causal link between the incurrence of these emissions and the underlying production and transportation processes. For the same reasons, the 5 tons of $CO_2e$ removed from the atmosphere in 2025 by GOCASI were recorded as a periodic revenue rather than a credit applied to PCFs.

Various standard setting organizations and industry associations have advocated for relatively narrow product carbon footprint boundaries, thereby opting for a partial-cost PCF methodology. For instance the Product Life Cycle Accounting and Reporting Standard of the Greenhouse Gas Protocol (2011), Catena-X (2023) and Together-for-Sustainability (TfS, 2024) suggest that the emissions embodied in machinery and equipment (Scope 3) not be included in cradle-to-gate PCF calculations. Consistent with CASI's core principle of *completeness*, CASI Whitepaper No.4 (2026) advocates for the emissions embodied in fixed assets used in the production process to be capitalized on

the CO2-Balance Sheet, with the subsequent periodic amortization charges applied to products. For long-lived assets not associated with production or transportation processes, e.g., buildings used for administration, CASI Whitepaper No.4 also calls for capitalizing the embodied emissions but leaves open the possibility of recording the subsequent amortization charges as part of the General & Administrative category.

The obvious drawback of partial-cost PCF calculations is the *undercounting* of some direct emissions incurred by an entity's upstream suppliers. One simple and transparent alternative for obtaining full-cost PCF figures is to use the partial-cost figures as the allocation base for charging any residual periodic emissions lacking a causal link to products. To do so, all partial-cost PCF figures are marked up by a common multiplicative factor given by the ratio:

$$\frac{NCC - CEGS}{CEGS}.$$

In the GOCASI example this ratio is given by 40/1402 = .02853. Each partial-cost PCF shown in Table 3 then receives the mark-up factor 1.02853 resulting in the following revised NCC statement.

**Net CO2-Contribution Statement**

| | |
|---|---|
| 638 | Emissions in sales of Product A produced in 2024 (200 units x 3.19 tons/unit) |
| 679 | Emissions in sales of Product A produced in 2025 (220 units x 3.09 tons/unit) |
| 82 | Emissions in sales of Product B produced in 2024 (100 units x 0.82 tons/unit) |
| 43 | Emissions in sales of Product B produced in 2025 (60 units x 0.72 tons/unit) |
| 1,442 | **Carbon Emissions in Goods Sold (CEGS) - Full Cost** |
| 1,442 | **Net CO2-Contribution for the Year 2025** |

**Table 5:** *Net CO2-Contribution Statement: Full Cost PCFs*

By construction, the above "bootstrapping" step from partial to full-cost PCFs leaves the bottom line Net CO2-Contribution unchanged. Further, this step does not result in double counting of emissions. In principle, each resulting cradle-to-gate PCF reflects an allocated share of the seller's actual direct (Scope 1) emissions, plus an allocated share of the actual direct emissions incurred by the seller's Tier 1 suppliers, plus an allocated share of the actual direct emissions of its Tier 2 suppliers and so forth.[7]

[7] For an economy consisting of B2B and B2C companies, full-cost PCFs imply the following accounting identity: The aggregate PCFs of products sold to consumers over the entire life cycle of the economy are equal to the aggregate CEGS figures of all B2C companies, and this total is equal to the sum of all direct emissions incurred by all companies in the economy. (Reichelstein, 2024).

We recall that the corporate standard of the GHG Protocol calls for companies to report their entire direct (Scope 1) and indirect (Scope 2 and 3) emissions (GHG Protocol, 2011). 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) emissions. To bridge this gap, the CEGS metric in Table 5 can be augmented with *estimates* of the emissions that the individual products are projected to incur during their use phase. Such estimates may be difficult for primary products like chemicals or steel, but may be reasonably predictive in industries that sell large volumes of identical consumer products, e.g., automobiles or appliances. In the context of the GOCASI example, suppose each unit of the A line is projected to incur on average 2 tons of $CO_2e$ during the use phase while each B unit is projected to incur 3 tons. Adding these use phase emission estimates to the full-cost PCF figures yields the following augmented Net CO2-Contribution.

**Comprehensive Net CO2-Contribution Statement**

| | |
|---|---|
| 638 | Emissions in sales of Product A produced in 2024 (200 units x 3.19 tons /unit) |
| 679 | Emissions in sales of Product A produced in 2025 (220 units x 3.09 tons/unit) |
| 82 | Emissions in sales of Product B produced in 2024 (100 units x 0.82 tons/unit) |
| 43 | Emissions in sales of Product B produced in 2025 (60 units x 0.72 tons/unit) |
| 1,442 | **Carbon Emissions in Goods Sold (CEGS) - Full Cost** |
| 840 | Estimated Use Phase Emissions of Product A (420 units x 2 tons/unit) |
| 480 | Estimated Use Phase Emissions of Product B (160 units x 3 tons/unit) |
| **2,762** | **Comprehensive Net-CO2-Contribution** |

**Table 6:** *Comprehensive Net CO2-Contribution Statement*

The Comprehensive Net CO2-Contribution provides a measure of an entity's periodic Scope 1 - Scope 3 emissions on the basis of an entity's cradle-to-grave PCFs. As such, it becomes an effective corporate carbon footprint measure that complies with the corporate standard of the GHG Protocol.

## Concluding Remarks

While this whitepaper has referred to specific carbon accounting standards, our primary concern here has been with the structure of a carbon ledger that enables integrated corporate carbon accounting. 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.

Our running example, GOCASI Ltd., was intentionally designed to sidestep allocation issues frequently encountered in practice. However, Scope 1 and Scope 2 emissions are frequently collected in pools of overhead emissions that have been incurred for process steps that support multiple products. The Unbiasedness Principle stipulates that allocation rules not be arbitrary and thereby enable selective product greenwashing. Future CASI whitepapers seek to delineate specific carbon accounting rules that meet the criterion of unbiasedness. Such rules should again 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 determine the extent to which companies can adopt specific rules such as mass balancing (Saling et al. 2025). Closely related issues concern the recognition of Environmental Attribute Certificates (EACs) attributes, for instance, in connection with the accounting for Scope 2 emissions.

Carbon credits, in particular direct carbon removals, present a controversial and increasingly important subject for generally accepted carbon accounting standards. Our GOCASI example recorded direct removals as a separate 'revenue' item in the NCC statement and in a contra account on the right-hand side of the CO2-Balance Sheet. A plausible alternative standard subtracts direct removals from direct emissions and includes the net direct emissions in the PCF calculations. Moving further afield, the accounting standards for direct removals could conceivably leave companies discretion in assigning tons of carbon removed to select facilities, activities, and even to individual products. Such more lenient standards are likely to have a tangible incentive effect in terms of companies' willingness to undertake or acquire carbon removal projects.[8]

From a cost-benefit perspective, the CO2-statement approach laid out in this whitepaper 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 $CO_2$ 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 data that have already received auditor assurance (Becker, 2025; CASI Whitepaper No.1).

On the benefit side, we expect a tangible network effect as a growing share of a firm's suppliers adopt their own in-house ICCA system. The resulting reported PCF and CCF figures can then become a 'hard currency' that like product price and quality, customers will consider in comparing the attractiveness of competing suppliers (Becker, 2025). Also, as cradle-to-gate PCF figures increasingly reflect the actual upstream direct emissions incurred by a product, they provide first-order incentives for companies to both reduce their own direct emissions and to pressure their suppliers to do so. Such incentives are largely missing today for as long as PCFs are not based on actual emissions incurred but instead on historical industry averages.

[8] CO2-Balance Sheets allow for the possibility of recognizing carbon removals that could conceivably reverse at a later point in time, e.g., reforestation projects. The potential reversibility of such removals could be reflected in contingent liabilities on the balance sheet, provided there is commitment to record any reversals that actually do occur without delay on the entity's carbon books (Reichelstein, 2025b).

# Appendix

## Journal Entries for the GOCASI Ltd. Example

This appendix provides details on 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.

GOCASI produces and sells two product lines, A and B. Both products are manufactured in batches that pass through two process steps. Batches leave Step 1 as Work-in-Process (WIP) and are turned into finished goods in Step 2. Emissions are recorded separately for the two products at each of the two production steps.

**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 $tCO_2e$.

**JE2:** In Step 1, a fraction of the purchased materials, corresponding to a total PCF of 800 $tCO_2e$, are transferred to WIP A and WIP B. Of these, 720 $tCO_2e$ are charged to Product line A and 80 tons to Product line B (this split reflects the amount of materials each product requires and that 400 A units and 200 B units were processed in Step 1 as WIP in 2025).

**JE3**: 36 $tCO_2e$ are charged for electricity consumption to WIP A and 4 $tCO_2e$ are charged to WIP B (this split reflects the known power requirements for each A and B unit and the production volume of 400 A and 200 B units).

**JE4:** In Step 2, 400 units of WIP A is converted into 400 units of Finished Goods A, resulting in an additional 420 $tCO_2e$ for electricity used and 24 $tCO_2e$ for allocated direct emissions (the charge of 420 tons again reflect the required kWh of electricity for each A unit; similarly the charge of 24 tons in allocated direct emissions reflects the processing time that each A unit requires on a natural gas combustion unit).

**JE5:** In Step 2, 200 units of WIP B are converted into 200 units of Finished Goods B, resulting in an additional 36 $tCO_2e$ for electricity consumption and 20 $tCO_2e$ 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 $tCO_2e$ per unit (see Table 3). The remaining 220 units were produced in 2025 with a PCF of 3.0 $tCO_2e$ per unit (as calculated in JE1-JE5 and summarized in Table 3).

**JE7:** GOCASI sells 160 B units in 2025. Of these, 100 units were produced in 2024 with a PCF of .8 $tCO_2e$ per unit (see Table 3). The remaining 60 units were produced in 2025 with a PCF of .7 $tCO_2e$ per unit (as calculated in JE1-JE5 and summarized in Table 3).

**JE8:** New machinery with an assessed PCF of 30 $tCO_2e$ is purchased from a supplier.

**JE9:** GOCASI constructs a storage facility. The building materials have emissions of 10 $tCO_2e$ embodied in them. Construction of the facility requires electricity with an assessed PCF of 2 tons. GOCASI incurs 1 ton in direct $CO_2$ emissions due to fuel combustion.

**JE10:** Travel by GOCASI's executives in 2025 resulted in 10 $tCO_2e$.

**JE11:** GOCASI has signed an offtake agreement with a direct air capture company. According to the contract, 5 $tCO_2e$ were removed in 2025.

**JE12:** Straight-line depreciation charges are applied to long-term operating assets: 10 $tCO_2e$ corresponding to buildings and 15 $tCO_2e$ to machinery.

**JE13:** Electricity use for General and Administrative activities, including R&D, results in emissions of 10 $tCO_2e$.

**JE14:** The balance in the carbon flow account Net CO2-Contribution is closed out to the balance sheet account Legacy 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, by definition, is a carbon flow account with a beginning and ending balance of zero.

**Business transactions tableau:**

| | Buildings | Machinery & Equipment | Materials | WIP A | WIP B | Finished Goods A | Finished Goods B | Net CO2-Contribution | Indirect Emissions Transferred In | Direct Emissions | Direct Removals | Legacy Emissions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Beginning Balance** | 100 | 150 | 600 | 0 | 0 | 620 | 80 | 0 | 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 | | 1,280 | | | | |
| JE7 | | | | | | | -122 | 122 | | | | |
| JE8 | | 30 | | | | | | | 30 | | | |
| JE9 | 13 | | | | | | | | 12 | 1 | | |
| JE10 | | | | | | | | 10 | 10 | | | |
| JE11 | | | | | | | | -5 | | | -5 | |
| JE12 | -10 | -15 | | | | | | 25 | | | | |
| JE13 | | | | | | | | 10 | 10 | | | |
| JE14 | | | | | | | | -1,442 | | | | -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 | 0 | 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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