Measuring Product Carbon Footprints from Cradle to Gate

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Reliability Issues with the Greenhouse Gas (GHG) Protocol

Concerns about anthropogenic climate-change have led groups such as the Science-Based Targets Initiative to advocate for industry-specific emission reductions paths. Accordingly, many multinational firms have pledged achievement of net-zero greenhouse gas emissions by some target date, usually 2050. Such pledges, however, lack credibility without accurate and verifiable measurement of a company's controllable carbon footprint.

The GHG Protocol, the prevalent carbon accounting standard, classifies a reporting entity's carbon emissions into three categories: Scope 1: Direct emissions from sources owned or controlled by a company; Scope 2: Indirect emissions incurred by external electricity and heat suppliers; and Scope 3: Other indirect emissions incurred by upstream suppliers and downstream customers.[1] The vast majority of companies have indirect emissions that greatly exceed their Scope 1 emissions, with one study estimating the average company having a 5.5:1 ratio of supply chain to Scope 1 emissions.[2]

But the current standard for Scope 3 measurement expects companies to gather emissions data from all their multiple-tier suppliers and customers, a fiendishly complex task. Most companies do not know even the identity of suppliers and customers beyond their immediate ones, much less those entities' attributable carbon emissions. The Scope 3 standard bypasses this measurement problem by allowing companies to use secondary data, based on industry-averages, rather than actual and verifiable supplier and customer data. Allowing the use of secondary data, however, obviates companies' incentives for any actual emission-reductions in their value chains.

At present, companies use limited and idiosyncratic approaches for their Scope 3 reporting. Some hire external consultants to estimate Scope 3 emissions for a small set of categories, such as those from employee commuting or suppliers' vehicles. With regulators so far reluctant to mandate Scope 3 reporting, recent studies have documented companies' inconsistent and selective Scope 3 practices.[3]

A Recursive Process for Determining Product Carbon Footprints

To address the reliability issues inherent in current Scope 3 accounting, Kaplan and Ramanna (2021) introduced E-liability accounting, a method that recursively calculates a product's carbon footprint as it travels down a supply chain.[4] In a process analogous to how the cost of a purchased product reflects the value of all the resources used in its production and distribution, the E-liability method calculates a product's carbon balance from "cradle to gate."

The process originates with the Scope 1 emissions produced from original inputs, such as raw materials extracted from the earth. At subsequent production and distribution steps, each company in a supply chain adds its own attributable Scope 1 emissions to those of its purchased inputs to obtain the carbon footprint for each of its finished products. The process works much as a value-added calculation, except that it is "value-subtracted" to reflect the burdening of the atmosphere from additional carbon emissions. The recursive calculations, done sequentially along a supply chain, are informationally decentralized, requiring only local knowledge at each node of the chain. Also, the sequential value-added approach avoids multiple-counting of emissions, a widely acknowledged drawback of Scope 3 measurement.

The parallels between cradle-to-gate carbon footprint measurement and longstanding inventory and cost accounting practices should enable existing enterprise accounting software to be easily adapted to carbon accounting. As important, and again similar to financial accounting, the reported carbon quantities should be auditable to the same quality standards as companies' financial reports.

Applications in Practice

This section describes how several multinational firms calculate cradle-to-gate carbon footprints for their sales products in accordance with the E-Liability approach.

PTGT (PT, Gajah Tunggal, TbK) is the Indonesian subsidiary of Giti Tire, a global supplier of tires to automobile and trucking original-equipment manufacturers (OEM). PTGT focused a pilot study on the supply chain for its standard passenger-car tire, initially using four of the tire's more than 200 raw materials: carbon black, synthetic rubber, natural rubber, and steel. These four components represented 86% of the tire's weight and provided a starting-point for querying upstream supplier-specific data (see Table 1a, “Current” column). The other major emissions sources were electricity consumed and natural gas used as heat energy for tire compounding and curing (row 1 of Table 1b). PTGT used the data in Tables 1a and 1b to obtain a first-pass estimate of the actual cradle-to-gate carbon content of its standard passenger tire, a quantity it could credibly share with its major OEM customers.

Three of the suppliers, after responding to PTGT’s request for data on their products’ emissions, described carbon-reduction possibilities (see last column of Table 1a). The carbon-black supplier could adopt circular production methods to reduce its emissions by 38%. The natural-rubber supplier could save 27% of emissions by switching from a domestic-plantation supplier to one more productive, in Thailand. The steel supplier could lower emissions by replacing virgin-ore steel with recycled steel. PTGT, itself, estimated that substituting on-site solar power for purchased coal-fired grid electricity could reduce operating emissions by 18% (row 2, Table 1b) (a preliminary estimate that did not include the emissions produced by manufacturing and transporting the solar panels). Energy-efficient natural-gas boilers (row 3, Figure 1b) would further reduce Scope 1 emissions by 6% (another upper-bound estimate that did not include the upstream emissions from purchased natural gas).

In summary, PTGT’s E-liability study not only provided more accurate data about the carbon content of a standard passenger tire, it also helped the company identify multiple options that, in aggregate, could reduce the tire’s carbon footprint by 21%.

Table 1a: Standard tire inputs, % weight and quantity of carbon emissions

Input	% Weight of input to output	Carbon footprint (tCO2e/ t input)	
		Current *	***Cleaner inputs ****
Carbon black	27	**1.00**	0.62
Synthetic rubber	26	1.38	N/A
Natural rubber	20	0.41	0.30
Steel products	13	1.63	0.92
Other	14		
	100		

Table 1b: Selected energy-related emissions in producing a standard tire

	Electricity		Natural Gas		Total
	tCO2e/ MWh	MWh/ t output *	tCO2e/ dm3	dm3/ t output *	tCO2e/ t output *
Current	0.891	**<u>1.000</u>**	1.9	0.218	1.305
Cleaner energy	0.654	1.000	1.9	0.218	1.068
Cleaner process	0.891	0.936	1.9	0.208	1.229
Cleaner energy + process	0.654	0.936	1.9	0.208	1.007

*Data in columns marked * are indexed to the camouflaged cell-value identified **thusly**, to protect competitively sensitive information.*

Heidelberg Materials (HM) (formerly HeidelbergCement), in 2020, introduced an internal measurement and reporting system, consistent with E-liability principles, to calculate the carbon footprint of different cement products. Producing cement, according to current IEA data, generates up to 8% of global CO_2 emissions.[5] HM estimates that emissions from converting limestone ($CaCO_3$) into clinker (CaO), the main ingredient in cement, account for about two-thirds of these. HM, like other cement producers, offers products that replace some of the high-carbon clinker content with less carbon-intensive materials, such as fly ash and slag.

HM introduced the new measurement system to provide flexible and timely accounting of the CO_2 content of the company's multiple products, blends, and sourcing options. The system, similar to activity-based costing[6], used a multi-step process to assign an appropriate share of plant-level, energy-related, and purchased emissions to each of a plant's outputs. First, it accessed existing data about upstream emissions of fuels, limestone, and slag, the major purchased inputs other than electricity. It then assessed the plant's direct (Scope 1) emissions, primarily those from the fuel used to heat the kiln for the limestone-to-clinker chemical reaction, and the CO_2 generated from the reaction itself. It next assigned the direct and indirect emissions to two major processes at the plant: "clinker production" and "other" (primarily slag grinding and cement milling). In a final step, the system assigned "clinker production" and "other" emissions to the plant's outputs (see Table 2). The former was allocated proportionately to the clinker content in each cement type; the latter was allocated proportionately to the cement materials' composition.

Table 2: CO_2 content for three cement products

Selected cement types	Clinker content (%)	tCO2e/ t output *
CEM I, 42.5	90	**1.00**
CEM II, 42.5	77	0.85
CEM III, 42.5	38	0.42

*Data in column marked * are indexed to protect company-sensitive information.*

Table 2 presents the data for three representative cement outputs. CEM I and CEM II are structurally and functionally equivalent. CEM II, which replaces some clinker content with slag, has 15% lower carbon content than CEM I. CEM III, which uses much more slag in the cement mix, has a 58% lower carbon rating than CEM I, but also some of its structural performance ratings are lower.

HM's customers can reduce the E-liability of their cement purchases by selecting CEM II as long as they can accommodate its lower early strength when used in a concrete mix. Customers with applications that do not need the high early structural strength of CEM I or CEM II can select CEM III and obtain even lower carbon emissions. Customers can, therefore, make informed purchasing decisions based on each product's carbon content along with price and performance data.

HM has, for many years, has been producing Environmental Product Declarations (EPD) to meet regulatory disclosure requirements. Such declarations estimate and independently verify the CO_2 emissions for one specific product, produced at a specific plant, at a specific point in time. The EPDs often become obsolete since they take considerable time to complete for each product, and any change in the product's production process, design, or sourcing requires a new EPD to be produced and validated. In contrast, the new measurement system allows HM to continually report credible and timely product-level emissions to customers and end-users, based on a product's actual production process, recipe, and sourcing.

In a third application, the chemicals company **BASF** developed a digital tool, SCOTT (Strategic CO_2 Transparency Tool), to calculate the carbon footprints of its 40,000 sales products.[7] Several of BASF's largest customers, selling directly to end-use consumers, wanted accurate cradle-to-gate carbon emissions data for each of BASF's products. BASF determined that a traditional approach of manually generating EPDs for each of its thousands of products would be too slow to respond to changes in suppliers' processes, leading to outdated estimates. By developing and licensing the SCOTT tool with suppliers, BASF could not only obtain current and accurate emissions information of its purchased products but also incentivize suppliers to continuously reduce the emissions in products sold to BASF. The system also standardized some emissions-allocation rules used by suppliers, for example, by preventing them from using unverified removal offsets in their product-level emissions data. BASF has not mandated use of the software, and, in the first year, only 10% of suppliers adopted it to report primary data. But BASF expects usage to increase quickly.[8]

Several IT organizations are currently developing blockchain solutions that allow the product-level emissions data, calculated by the E-liability method, to be stored and validated at each node of a supply chain.[9] When fully implemented, the solutions will enable accurate and verifiable carbon accounting to be implemented for even the most extended and complex supply chains.

Policy Implications

E-liability accounting for product carbon footprints holds businesses accountable for their direct emissions and the upstream emissions accumulated through purchased products and services. Each entity assigns carbon balances to its final products relying only on knowledge of its own direct (Scope 1) emissions and those embodied in purchases from immediate suppliers. Any reductions in a company's actual direct emissions or the emissions of the company's suppliers will correspondingly lower the carbon balances of products sold and distributed to customers. Since the aggregate of all carbon balances of a firm's outputs are a verifiable measure of a company's overall carbon footprint, external analysts and regulators can readily assess whether companies are on a trajectory consistent with their net-zero pledges.

The decentralized nature of E-liability accounting entails strong network synergies. As more companies at each node of a supply chain record their actual emissions, the entire chain's carbon accounting become more reliable. The PTGT example shows how such information motivates continuous emission reductions at every node of the supply chain, an incentive missing when companies use industry-level data for Scope 3 reporting.

Consistent with the GHG Protocol, companies can certainly supplement cradle-to-gate carbon footprint measures with estimates of the emissions anticipated from customers' product use. Unlike the verifiable measurements of *actual* upstream emissions, however, downstream Scope 3 calculations must rely on estimates, often quite speculative, about customers' subsequent use of a product.

Regulators considering mandates for carbon footprint reporting can increase accuracy and auditability by mandating that secondary data be replaced by the actual emissions produced and accumulated along a supply chain.

References:

[1] World Business Council for Sustainable Development and World Resources Institute (2004) *The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard, Revised Edition*, p 25.

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[7] Partnership for Product Carbon Footprint Methodology, https://www.basf.com/global/en/who-we-are/sustainability/we-drive-sustainable-solutions/quantifying-sustainability/product-carbon-footprint/partnerships.html (accessed September 13, 2022).

[8] Authors' interview with Alessandro Pistillo, BASF, September 13, 2022.

[9] Authors' correspondence with IBM and SAP, June 23, 2022 and April 8, 2022, respectively.