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# E-LEDGERS CARBON ACCOUNTING

**Robert S. Kaplan**, Harvard Business School

**Karthik Ramanna**, Blavatnik School of Government, University of Oxford

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Robert S. Kaplan, *Harvard Business School*

Karthik Ramanna, *University of Oxford Blavatnik School of Government*

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**Abstract:** In prior publications, we introduced a global system of interconnected E-ledgers that produces – in as close to real time as practicable – accurate, comparable, and verifiable accounts of the cradle-to-gate (net) greenhouse-gas emissions in any product or service that transacts in the economy. In this paper, we delve more deeply into the accounting infrastructure required for the E-ledgers system, including the specific journal entries for recording E-liabilities and E-assets. We explain how the E-ledgers of different entities in the economy articulate with each other and how they connect with jurisdictional E-ledgers that record emissions from end consumers. These entity and jurisdictional E-ledgers can be aggregated into a geological master ledger that tracks anthropogenic GHG emissions and removals, as debits and credits, to a geological carbon equity account. We also provide summary insights from computational technology and pilot studies to guide rapid and cost-effective E-ledgers deployment at scale.

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## I. INTRODUCTION

Many entities around the globe are now attempting to reduce the greenhouse gas (GHG) emissions from their operations. But the emissions from assets they directly own and operate are typically only a small percentage – estimated, on average, at 18% (Cannon, Greene, Blank, et al. 2020) – of their total controllable carbon footprint. The remainder are incurred by suppliers of their products and services.[1] Only companies with substantial direct energy generation from fossil fuels (using external or internal combustion engines), manufacturers of basic materials such as cement and steel, and operators breeding and raising cattle have direct emissions generally comparable to those incurred by their suppliers. Therefore, entities wanting to drive substantial GHG reductions must have accurate information on the embedded emissions in the inputs they purchase (including energy). These entities, however, face a fundamental problem: They cannot, by themselves, accurately measure the actual emissions incurred by their multiple tiers of geographically dispersed suppliers.

This problem is solvable using an approach proposed in Kaplan and Ramanna 2021. The approach develops a global accounting system of interconnected E-ledgers in which emissions are first measured and validated at their source and then communicated to downstream customers via the specific products and services they purchase. Such a global carbon accounting system is accurate and dynamic, reflecting the actual emissions generated by current production, sourcing, and transportation of products and services, and it is also verifiable and comparable across all entities and regions. In this paper, we delve more deeply into the accounting infrastructure required for such a global system of E-ledgers. The infrastructure builds upon a foundation of familiar accounting processes, including

[1] Emissions incurred downstream are usually not "controllable" by an entity (in the accounting sense of the word), since companies in a market economy do not generally dictate how and how much their products shall be used, post-sale, by their customers, their customers' customers, and so on.

accounting for inventory, the capitalization and depreciation of purchased property, plant, and equipment, and the cost accounting assignment of purchased materials and conversion costs to output products.

A simple inductive example illustrates how the E-ledgers accounting system works. Consider a company in the middle of a complex supply chain. It receives information on the embedded emissions (e.g., kg of $CO_2$) in each unit of input product or service (e.g., kWh of electricity) that it purchases from all its direct (tier-1) suppliers. The company also calculates the direct $CO_2$ emissions from its operations that convert production inputs into output products. The company then uses an internal accounting process to assign the emissions in purchased inputs and from own operations to its output products using causal linkages, akin to activity-based costing allocations of shared resource expenses to output products (e.g., Cooper and Kaplan 1998). These steps enable the company to accurately calculate the $CO_2$ emissions embedded in each output product, which it reports to each customer purchasing those products. The customer, receiving a similar report from each of its other tier-1 suppliers, now has all the information to repeat the process described above to assign its purchased and produced emissions to each of its output products, sending that information on to each of its customers. As we will describe, this process continues recursively throughout the economy, improving the E-ledgers system's accuracy over time. At three critical steps – recording of direct emissions, allocation of emissions to products, and transfer of emissions from supplier to customer – the transactions are subject to verification by a qualified third-party auditor at the reasonable assurance threshold. This enables the reliability and representational faithfulness of data for users even many tiers down the value chain.

Other greenhouse gases, such as $CH_4$, are handled in a similar manner, with companies calculating direct emissions and then allocating all direct and purchased emissions to products using causal logic. Information on different greenhouse gases can travel as parallel channels of accounting data in value chains. This description represents the end-state where all substantively significant entities have deployed E-ledgers accounting. Later, we articulate the journey to this end-state, starting with even a small handful of companies.

The remainder of this paper develops the accounting building-blocks needed to implement this algorithm and is organized as follows: Section II introduces the three foundational journal entries for E-ledgers carbon accounting of emissions (i.e., E-liabilities). Section III describes the process for recording consumer and jurisdictional emissions. Section IV introduces the journal entries when E-assets are created by capturing and sequestering atmospheric $CO_2$. Section V describes how a Global Carbon Equity ledger can be created to track the anthropogenic inflows and outflows of $CO_2$ between the earth's geological carbon store and the atmosphere. Section VI discusses the potential role of blockchain tokens in implementing the E-ledgers system at scale. Section VII illustrates the E-ledgers system in action through the experience of piloting entities. Section VIII concludes the paper by showing how a recursive process, with entities progressively supplying primary emissions data at each stage, converges to a system that produces accurate, dynamic, and verifiable emissions data for all relevant products and services in the global economy.

## II. E-LEDGER JOURNAL ENTRIES FOR GHG EMISSIONS

*"What advantages does he derive from the system of bookkeeping by double-entry! It is among the finest inventions of the human mind."*
(Goethe, translated by Thomas Carlyle, quoted from Ijiri 1993.)

The E-ledgers carbon accounting system can be operationalized using the double-entry bookkeeping system of journal entries. Three basic journal entries are needed to account for GHG emissions under the E-ledgers approach. Two of them do not arise in financial accounting: they are novel and unique to E-ledgers carbon accounting. The third demands more accuracy and transparency than its financial accounting counterpart.[2]

**1. Journal Entries for Supplier-Customer Transactions**

Consider first, the transaction that occurs when a supplier sells and transfers an output product to a customer. In this case, the supplier decreases the E-liability amount in the Finished Goods column of its E-ledger by the quantity of $CO_2$ emissions in the product it has just sold. This is accomplished through a Dr (or debit record) entry in the E-ledger. The customer purchasing the product makes a corresponding Cr (or credit record) entry in the Emissions Transferred-in column of its E-ledger. (See Table 1, number 1.) In effect, the customer, as part of the negotiation leading to the sale, has willingly assumed the emissions in the product (or service) it purchases. This seemingly straightforward double-entry record for a purchase transaction departs from traditional financial accounting practice by connecting journal entries on ledgers operated by different entities, the seller and the buyer. Such inter-organizational journal entries are one of the novel features of the E-ledgers system of global carbon accounting.

Financial accounting does not use inter-organizational journal entries because it produces two fundamental statements, the balance sheet and income statement. When a company sells a product (crediting its finished goods inventory account), it debits the accumulated cost of the product to an expense account on its income statement. That expense is then subtracted from the revenue the company recognizes from the sale, generating a measure of net income that is independently informative of the company beyond its balance sheet. Carbon accounting, by

[2] After publication of the first E-liability article, in 2021, several papers have described approaches to recordkeeping in carbon accounting (e.g., Reichelstein 2024 and Penman 2024). These articles do not feature the fundamental distinctiveness of E-ledgers bookkeeping, a focus of this paper.

contrast, requires only a balance sheet or E-ledger. Carbon accounting has no independently informative notion of “income” since all emissions are transferred as incurred, analogous, in financial accounting, to transferring all inventories between entities at cost.

Put differently, the inter-organizational journal entries in carbon accounting provide the necessary transparency into the emissions embedded in an entity’s purchased products and services. A company preparing an income statement and (financial) balance sheet does not have to know the operating costs incurred by any of its suppliers, either tier-1 or further upstream. Nor does it need to know the prices that its suppliers paid when they purchased products and services from their suppliers. But for carbon accounting, as we will see, downstream companies need assurance that the emissions information transferred to them is accurate. Inter-organizational journal entries provide the mechanism by which downstream entities trace and validate the emissions data reported in their purchased products.

**2. Journal Entries for Direct Emissions**

The second new journal entry occurs when the entity records its measured direct emissions. In this case, the entity records the quantity of $CO_2$ emissions as an E-liability Cr entry into the Direct Emissions column of its E-ledger. This treatment codifies an implicit obligation of the entity (and by extension, of the global economy of which it is part) to the earth. It is for this reason that the transaction was labelled in Kaplan and Ramanna 2021 as an E-liability, with “E” standing for environmental or emissions. Double-entry recordkeeping, however, prompts us to ask the question: “On what ledger should we record the equal and offsetting Dr entry?” The answer is that the Dr entry is made to a geological master ledger, more specifically, to the “equity” account of geological carbon on this master ledger.

This equity account keeps track of the anthropogenic outflows and inflows of carbon from the earth's geological store to the atmosphere. When, for instance, carbon is released into the atmosphere from the combustion of fossil fuels extracted from the earth, the transaction represents a drawdown (or debit) from the geological carbon equity (GCE) account. Likewise, when limestone is converted into clinker as part of cement making, releasing $CO_2$, the transaction also reflects a debit from the GCE. Conversely, when atmospheric $CO_2$ is subject to Direct Air Capture and Mineralization, the transaction represents an addition (or credit) to the GCE account. Strictly speaking, "geological" carbon (stored in rock and sediments) can be distinguished from terrestrial carbon (stored in soil and organic matter) and from oceanic carbon (stored in marine bodies), and each of these non-atmospheric stores of carbon can entail different equity accounts on earth's master ledger. But for illustrative simplicity, here we represent all anthropogenic outflows and inflows of non-atmospheric carbon to and from the atmosphere as entailing transactions with a single GCE account.

Thus, returning to the second new journal entry, the offsetting record for an entity's direct emissions (which generates its E-liability credit) is a debit to the GCE account on the geological master ledger. (See Table 1, number 2.) These entries recognize both a decrease in the geological store of carbon and an increase in the entity (and the global economy's) carbon debt to the earth. We will subsequently discuss (in Section V) who might monitor and maintain this GCE account and the earth's master ledger. We will also discuss how a geological master ledger is a desirable but not a necessary feature for adoption of E-ledgers accounting, especially in the early stages of the recursive implementation process. For now, we emphasize this second instance of a carbon accounting journal entry crossing organizational boundaries.

### 3. Journal Entries for Intra-Organizational Allocations

Beyond the two novel inter-organizational journal entries for a global E-ledgers carbon accounting system, a third type of journal entry records the intra-organization assignment of own-entity and purchased emissions to output products. We note the cost accounting inspiration for this entry, akin to when a producing entity allocates shared factory expenses to output products. Cost accounting informs management's pricing and product mix decisions, so accuracy is desirable in such allocations. But costing accuracy at the individual product level is not necessary for external financial reporting. Many companies continue to use simple but arbitrary cost-allocation bases, such as direct labor hours, without triggering any concerns from an external auditor. The auditor is satisfied so long as total expenditures are allocated to production over time and a reasonable split is made between expenditures allocated to the cost of goods sold in the current period and expenditures that are capitalized. Carbon accounting, however, requires an accurate assignment, within a reasonable-assurance threshold, of produced and purchased emissions to output products, since different customers purchase different output products. If the emissions assignment to output products is not accurate, the data in the inter-organizational journal entry (Section II.1 above) between supplier and customer will not be accurate (and thus acceptable to the customer). Accuracy of the intra-organizational emissions-allocation journal entry is a necessary condition for robustly transmitting emissions information down value chains of indeterminate length and complexity.

The journal entries for allocation of emissions from raw materials (and services) to output products is straightforward when there is a one-to-one link between inputs and outputs. The company debits the relevant E-liability amount from the Emissions Transferred-in column of its E-ledger and credits that amount to the E-ledger's Finished Goods column. (See Table 1, number 3.) Likewise, direct emissions – such as those incurred by an entity through fossil fuel-based energy generation in a plant or in its fleet of vehicles – should be allocated to the entity's range of products using defensible and consistent causal logic. The journal entries in these cases entail a Dr of the relevant E-liability amount from the Direct Emissions column of its E-ledger and Cr of that amount to the E-ledger's Finished Goods column. (See Table 1, number 4.)

When an entity purchases inputs used across multiple periods, such as property, plant, and equipment, it can create intermediate columns of account in the E-ledger representing Capitalized Emissions. For instance, when it determines that the emissions associated with a purchased input should be capitalized, the entity debits the relevant E-liability amount from the Emissions Transferred-in column of its E-ledger and credits that amount to the E-ledger's Capitalized Emissions column. (See Table 1, number 5.) Subsequently, in a process analogous to depreciation in financial accounting, the entity allocates a causally defensible and auditor-certified time- or usage-based proportion of the capitalized emissions to its outputs over relevant periods. The journal entries for such "depreciation" entail a Dr of the appropriate mass of emissions from the Capitalized Emissions column and a corresponding Cr to the E-ledger's Finished Goods column. (See Table 1, number 6.)

While these intra-organizational journal entries are uncomplicated and familiar to financial accounting students and practitioners, the underlying causal logic that supports these entries is more demanding than for financial accounting allocations. The E-liability Proto-Standard (Ramanna, Holloway, Israelit, et al. 2024), produced with inputs from dozens of practitioners and auditors, specifies the principles to which such causal logic must adhere. For instance, causal logic dictates that all emissions embedded in inputs must be (eventually) allocated to outputs: emissions cannot disappear or be "destroyed" in the allocation process (consistent with the first law of thermodynamics, on conservation of energy). Causal logic also implies that similar units of output with similar inputs and production processes cannot have different calculated emissions. The converse is also true: different units of output with different inputs and different production processes, run at different times, are unlikely to have the same calculated emissions (except by chance). Further, causal logic enables the consistent and reasonable allocation of emissions when using a shared input (e.g., a production machine) to produce multiple types of products (or SKUs). Causal logic also provides the guidance for allocating to various products the emissions associated with a common input, such as when crude oil is refined into fuels, lubricants, petrochemical feedstocks, and asphalt.

Beyond unpacking causal logic, the Proto-Standard also specifies accounting principles for measuring and calculating direct emissions, for transferring emissions in and out of E-ledgers, and for the materiality and verification thresholds for such transactions. The Proto-Standard is not intended to be a definitive rulebook but rather a set of guidelines, based off accounting and economic theory, for more formal rulemaking on carbon accounting.

## III. CONSUMER EMISSIONS AND JURISDICTIONAL E-LEDGERS

Thus far, we have shown the E-ledgers transactions needed to track the flow of emissions in value chains up to the point of sale to the end consumer. All the system needs to function to this stage is for entities above a politically determined materiality threshold (including businesses, government organizations, and nonprofits) to keep E-ledgers by recording emissions in products purchased from their suppliers, measuring and recording emissions they produce, and allocating purchased and produced emissions accurately to outputs.

The question then remains, What happens at and after the point of sale to the end consumer? To whom should the embedded emissions in products and services sold to consumers be transferred? And what of direct emissions generated by such consumers? First, and analogous to nutrition labelling, the E-ledgers system produces reliable cradle-to-gate emissions information that can be placed on the labels of products sold to consumers, who can then, depending on their values and preferences, use this information in their purchasing decisions (Kaplan and Ramanna 2024). Second, we do not consider it a necessary component of the E-ledgers carbon accounting system to have the earth's eight-billion individuals keep personal E-ledgers. Instead, consumer emissions can be assigned to the jurisdictional E-ledger of the jurisdiction where the consumer makes the purchase or engages in activities that generate direct emissions.

Jurisdictions here could represent a city, a province, a country, or even a supra-national entity like the European Union. E-ledgers of lower-level jurisdictions can easily be consolidated up to higher-level jurisdictions using standard accounting principles of consolidated reporting across subsidiaries. For illustrative purposes below, we will use a country as a typical jurisdiction. With this definition, when an entity makes a final sale to an end consumer in a given country, then the E-liabilities of that product or service are debited from the E-ledger of that entity and credited onto the E-ledger of the country where that consumer made the purchase. (See Table 1, number 7.) This is, in effect, the terminal transaction, as consumption represents the end-state in a value chain. The E-ledgers accounting treatment for carbon in value chains is similar to how GDP accounting treats consumption. Thus, for instance, if the product is recycled post-consumption and reintroduced into the economy, then only new emissions associated with and after the recycling process will be considered part of that product's second-use E-liabilities. This accounting treatment is consistent with the underlying thermodynamics.

Likewise, if a consumer in a country engages in activities that generate direct emissions, those emissions are recorded on the country's E-ledger. The journal entries are as before, a Cr for the appropriate amount of E-liabilities on the country's E-ledger and a Dr for the equivalent amount to the GCE account. Creating E-ledger entries for such direct consumer emissions may seem burdensome at first, but as a practical matter, the entries can be easily estimated (and verified) to a reasonable level of accuracy. In practice, most direct consumer emissions relate only to combustion of fossil fuels for purposes such as home heating, personal transportation, and operating small generator equipment such as lawnmowers. The quantity of sales of such fossil fuels to end consumers is already known from fossil fuel retailers and the carbon content of those fuels is also known from the fossil fuel refiners. Thus, accurately estimating the direct emissions of end consumers is eminently feasible, a matter of data gathering and simple arithmetic.

Note that outside of fossil fuel use, end consumers do not engage substantially in direct chemical reactions that generate GHG emissions, such as combusting limestone for cement making. Some consumers may raise cattle for private use, but the scale of such activities is negligible from a geological perspective that it can be ignored for E-ledgering purposes. Here, it is also worth pointing out that the emissions from electricity that individuals use to heat or cool their homes, play video games, or ask questions of Generative AI platforms will already be recorded by the utilities producing that electricity. Likewise, the emissions from riding a public bus or flying in a commercial plane are recorded by those transport companies. Those emissions are transferred to a country's E-ledger when the consumer buys that service (electricity or transport) in that country.

As a practical matter, a jurisdiction (e.g., the government of a country) can also maintain a separate E-ledger for emissions, purchased and direct, associated with its own governmental activities, such as public safety, defense, and public education. Such a governmental E-ledger can be useful for its own decarbonization decision-making and accountability purposes but is distinct from its consumption E-ledger, though the two can be easily consolidated to create a single jurisdictional (e.g., national) E-ledger for periodic reporting.

## IV. E-LEDGER JOURNAL ENTRIES FOR REMOVAL AND SEQUESTRATION OF ATMOSPHERIC $CO_2$

Thus far, we have focused on carbon accounting for emissions generated and transferred through the economy, i.e., E-liabilities. But E-ledgers, as the name suggests, also host the journal entries when accounting for carbon removals. These carbon removals, when they meet certain measurement and likelihood criteria described below, constitute "E-assets." Together, E-assets and E-liabilities are the two sides of an entity's E-ledger.

A carbon removal occurs when atmospheric carbon is captured and sequestered in a non-atmospheric sink, such as rock, soil, biological material, or oceans. Different sinks provide different durations of sequestration, with some sinks effectively serving as permanent (or in accounting parlance "indefinite") stores of carbon while other sinks serve as transient stores for just a few months or years. Given that $CO_2$ emissions (E-liabilities) are currently expected to last in the atmosphere for somewhere between 300 and 1000 years (e.g., Buis 2019), the duration of a potentially "offsetting" $CO_2$ removal is a material matter for carbon accounting.[3]

A recent paper has proposed five core accounting principles for carbon removals (Kaplan, Ramanna, and Roston 2023). The first principle states that a carbon offsetting activity can be

[3] The duration that $CO_2$ is expected to linger in the atmosphere itself depends on the amount of $CO_2$ in the atmosphere and thus on anthropogenic efforts to manage $CO_2$.

recognized as an E-asset only when a specific quantity of $CO_2$, already in the atmosphere, is captured and sequestered for a duration comparable to that of existing atmospheric $CO_2$ remaining in the atmosphere (prudently, 1000 years). Stated simply, only actual long-duration removals qualify as E-assets, not activities that avoid the release of some additional quantity of $CO_2$ sometime in the future. Such avoidance activities simply result in lower E-liabilities on the ledger of the entity that would otherwise have released the $CO_2$. This principle may seem obvious from an accounting perspective, but it is necessary to clarify because the vast majority of today's traded offsets are from avoidance not removal activities. The first principle states that avoidance activities cannot create E-assets.

The second principle states that E-assets are tradeable, even as E-liabilities are not. In effect, E-liabilities are a fundamental informational property of a good or service, and they can be removed from an entity's E-ledger only when that good or service is itself transferred from that entity's financial ledger (e.g., upon an arm's-length sale). By contrast, E-assets, which are non-duplicable property claims to carbon removals, are tradeable. This is because the entities that efficiently generate E-assets may not be the ones that wish to use them to offset their E-liabilities, and the trading of E-assets enables buyers and sellers to create economic and environmental value. This principle is a simple application of Ricardian theory of comparative advantage.

The third principle establishes that a removal activity can be recognized as an E-asset when the duration and magnitude of the removal are both reasonably estimable and probable (similar to the traditional asset recognition principles in financial accounting). When both conditions have been met, the journal entry is a Dr to the removing entity's E-ledger (creating the E-asset), and a Cr entry to the earth's GCE account, reflecting an increase in the geological store of carbon.[4] (See Table 1, number 8.)

A removing entity has the option to trade its E-asset position (per Principle 2) with another entity that wants to reduce its net E-ledger position. Thus, E-asset recognition (per Principle 3) is also contingent on satisfying, to the reasonable-assurance threshold, the asset alienability criterion – i.e., if separating an E-asset from its originating entity would inherently impair that E-asset, then that asset should not be recognized. The E-asset sale transaction is recorded as a Cr entry for the E-asset in the selling entity's E-ledger and a corresponding Dr entry for the E-asset in the purchasing entity's E-ledger. (See Table 1, number 9.)

Principle 4 establishes the condition under which an entity with E-assets recorded on its E-ledger can use those E-assets to offset (or "net" out) an equivalent value of its E-liabilities.[5] The condition, simply stated, is that the quantity of $CO_2$ represented by the E-asset must have been actually removed from the atmosphere and indefinitely sequestered. This condition is analogous to (and based on) traditional financial accounting's "earned" criterion for revenue recognition. (In traditional financial accounting, revenue is recognized when it is earned and when it is realized or realizable. The latter condition is already embedded in the E-asset recognition criterion described in Principle 3.) The higher standard for netting an E-asset, embedded by the requirement equivalent to the earned criterion, is to ensure, as with revenue recognition, that the act of offsetting or extinguishing a 1000-year E-liability does not forerun the actual delivery of the underlying effort to this end. Conversely, the lower standard for E-

[4] As before, for expositional simplicity, here we use "geological" to refer to all anthropogenic removals of atmospheric $CO_2$ to non-atmospheric sinks, whereas in practice this common GCE account can be disaggregated into separate geological equity accounts for rock, soil, oceanic, and forest sinks.
[5] This transaction is feasible since E-assets and E-liabilities are measured in common units, e.g., kg of $CO_2$.

asset recognition, in advance of full delivery of an indefinite-life removal, is to encourage tradability (and thus financing) of removal offsets.

When an E-asset meets the nettability criterion, the journal entries to recognize the offset to an existing E-liability are as follows: first, a contra asset to the E-asset is created called "E-assets netted" and a contra-liability to the corresponding E-liability is similarly created called "E-liabilities netted." Then, a Cr is made to the contra asset for the relevant offset amount and a Dr is made to the contra liability. (See Table 1, number 10.) Upon consolidating this contra liability with the gross E-liability amount, the entity establishes the (now lower) baseline E-liability amount that it needs to then assign to its outputs, subsequently to be transferred to customers of those outputs. Naturally, the lower E-liability amount makes its outputs more desirable to carbon-conscious customers, promoting a verifiable market for decarbonization.

The establishment of the contra asset and contra liability enables the record preservation of the gross amount of E-asset and E-liability, which is useful for accountability purposes and necessary to enable a previously netted E-liability to be reversed due to an impairment of the underlying E-asset (e.g., if a forest fire prompts rerelease of captured atmospheric $CO_2$). These impairment events are the focus of the final and fifth principle for accounting for carbon removals.

Since the sequestration of carbon removed from the atmosphere must persist indefinitely, the fifth principle establishes the need for ongoing independent monitoring to determine whether some or all of previously sequestered $CO_2$ has leaked back into the atmosphere. This monitoring, particularly for certain oceanic and biological carbon sinks, may also detect an accretion, defined as an unexpected increase in the quantity of $CO_2$ that has been captured and sequestered.

In case of verified accretion of captured carbon, the journal entries are simple: the E-asset can be debited to reflect the higher amount captured and the earth's GCE account can similarly be credited. In the case of impairment of captured carbon, two sets of journal entries must be made on the entity's E-ledger, as follows: first, the E-asset must be credited by the impaired amount and the earth's GCE must be likewise debited, reflecting the decrease in the geological store of carbon due to $CO_2$ rerelease; second, in case the E-asset has already been netted against E-liabilities, the contra asset and contra liability accounts called "E-assets netted" and "E-liabilities netted," respectively, must be debited and credited as appropriate, reflecting the fact the amount that can be considered netted is now lower. (See Table 1, numbers 11 and 12.) Importantly, this accounting treatment clarifies that it is the netting entity, and not its customers who might have already benefited from buying from that entity a product represented as lower E-liability, who must bear the risk of an impairment event. The treatment is analogous to how equivalent events are handled in financial accounting, and it incentivizes the prudential netting of E-liabilities by an entity.

The notion of an E-ledger that recognizes carbon sinks as E-assets raises the question of what to do about historical "natural capital" assets such as ancient rainforests and peat bogs. Some jurisdictions find themselves, through accidents of history or careful environmental management, stewards of considerable reservoirs of such natural carbon sinks. Under a global E-ledgers system, such sinks can be recognized as E-assets. The benefit from capitalizing them on a jurisdictional E-ledger is transparency and the associated incentive to be careful stewards of this E-asset, to prevent its degradation or impairment, such as through deforestation. But such E-assets cannot be sold as offsets against future emissions, as the historical natural carbon sinks already reflect sequestration of past emissions. Any such sales will entail double counting. We concede that this observation may not be received enthusiastically by those trying to monetize such longstanding carbon sinks.[6] That said, any *additional* accretion of emissions by such carbon sinks (e.g., due to newly managed-forest growth) can be recognized as E-assets to be traded (assuming they meet the other principles described above). In such cases, the journal entries would be: a Dr for the E-asset on the relevant government's E-ledger, with the offsetting Cr entry made to earth's GCE account.

## V. THE EARTH'S GCE ACCOUNT AND ITS CONNECTION TO A GLOBAL CONSOLIDATED E-LEDGER

The E-ledgers method entails "the earth" as a transacting entity in the carbon accounting system. This is intuitive as E-ledgers are created to track anthropogenic GHG emissions and removals through value chains, and the earth – in particular the earth's geological store of carbon – is the principal counterparty for such emissions and removals. Thus, the earth's GCE account is the principal account with which all direct emissions and removals interface, as we have shown in the journal entries described earlier.

The primary purpose of the GCE account is to keep track of anthropogenic GHG transactions. While, in principle, the GCE could also keep track of all natural emissions and removals – for instance, GHG emissions from volcanic activity or GHG removals from ocean absorption – doing so is not necessary for the E-ledgers system to serve its main objective of recording changes in the earth's geological store of carbon due to human activity. Thus, once the E-ledgers system is operational, if the GCE account as of a given date is found to be, for instance, negative – i.e., the account shows the earth as having a negative equity balance of geological carbon – this does not mean that the earth itself is in a negative position on

[6] Indeed, such a practice has already been attempted (e.g., Andreoni and Brito 2025).

geological carbon (which is physically impossible); rather, it simply means that the impact of anthropogenic activities on the earth's geological store of carbon is negative at that date.

The GCE account is a "trueing-up" equity account on a geological master E-ledger that consolidates all arm's-length entity E-ledgers (across all businesses, governments, and nonprofits worldwide) and all arm's-length jurisdictional consumption E-ledgers. A core feature of the E-ledgers approach is that, on a net basis, anthropogenic direct emissions and removals appear once and only once across all arm's-length E-ledgers in the system. Thus, these individual arm's-length E-ledgers can be aggregated (under standard accounting rules for consolidation), and the total shown on the E-assets side of the geological master ledger will equal the total shown on the E-liabilities side plus the GCE account balance. (See Table 1, Panel D.) This feature of the E-ledgers system preserves the fundamental accounting equation, Assets = Liabilities + Equity, and it ensures a check on the system to identify instances of incomplete accounting, whether due to negligence, error, fraud, lack of capacity, or otherwise.

A policy question that then arises is who or which institution should maintain the GCE account and the geological master ledger. We recommend that a purpose-built international organization be established to this end, with members selected from related fields such as accounting, climate science, data science, and statistics. This international organization can also draw from existing collaborations across central banks worldwide, including from OECD countries and so-called Global South countries. Central banks are relatively independent of everyday retail politics, and they have expertise in data acquisition and collection from diverse sources, complex statistical modeling, data analysis, and macroeconomic bookkeeping, which will all be relevant to maintaining the GCE account and geological master ledger. The Bank of International Settlements, sometimes referred to as the global “central bank for central banks,” could serve as an incubator for the purpose-built international organization that maintains the geological master ledger and continually updates the GCE account.

A second policy question is how to initialize or calibrate the GCE account. If this account is to represent the impact of anthropogenic activities on the earth’s geological store of carbon, must we go back to the dawn of human civilization and backfill records for this account to function? Invoking the accountant’s principle of the “irrelevance of sunk costs,” we argue this is unnecessary. While doing so can improve the precision of the system, backfilling records to antiquity is not critical for the E-ledgers system to accomplish its objectives going forward. Tracing anthropogenic emissions and removals back to the origin of human civilization or even to the beginning of industrialization is likely not a cost-effective exercise. While the GCE account does need a start date, a practical option could be to set the start date in the recent past (such as 2024, when the Paris Agreement’s reporting framework came into effect) or in the near future (e.g., at a date when a critical number of economies agree to use the E-ledgers approach). This approach of setting aside anthropogenic net emissions prior to the start date has a basis in current scientific understanding, where findings suggest that “no substantial further $CO_2$-induced warming or cooling of the climate system will occur as long as” anthropogenic net emissions *going forward* are reduced to zero (Allen, Frame, Friedlingstein, et al. 2025).

Ultimately, though, on these policy questions, we defer to the political process, since neither the choice of institution to maintain the GCE account nor the initialization date affects the journal entries for E-ledgers carbon accounting, the focus of this paper. Moreover, as a practical matter, the E-ledgers system can be deployed at the level of individual commercial entities without a formal GCE account. In such a setup, when an entity directly releases GHG into or removes GHG from the atmosphere, the recordkeeping is single entry: the entity simply represents the corresponding increase in its E-liability or E-asset balance. In this sense, E-ledgers accounting can be as simple as recordkeeping in a checkbook. Such a single-entry setup would allow for the initiation of E-ledgers accounting in supply chains where it is most material, even as international negotiations occur on the form and governance of the GCE account. This phased, pragmatic approach could even facilitate the eventual establishment of a GCE account that otherwise might evoke resistance from some activists, entities, and jurisdictions.

## VI. INFORMATION TECHNOLOGY FOR IMPLEMENTING E-LEDGERS AT SCALE: THE POTENTIAL ROLE OF TOKENS

As we have seen above, the principles for asset and liability recognition, charge-off, and transfers are based on common financial accounting principles, meaning that hundreds of thousands of trained accountants and auditors are already familiar with these concepts. However, on one key dimension, E-ledgers accounting is distinctive: inter-entity transactions (both when direct emissions and removals are recognized and when inventories are transferred down a value chain). This situation poses a practical challenge: how to ensure secure and verifiable communication, at reasonable cost, of the true and fair emissions embedded in any entity's output products to all downstream users of those products (over many tiers). Even as recently as a few years ago, the compliance costs of implementing a system to accomplish this objective could have made the E-ledgers approach uncompetitive.

Take the example of a manufacturer of lithium-ion batteries for electric vehicles. The battery contains a multitude of elements, including lithium, cobalt, nickel, manganese, graphite, aluminum, copper, and iron. Each element could be purchased from multiple suppliers, with each supplier having its own deep supply chains involving different country locations, extraction and refining machinery, energy sources, and downstream transportation methods. Each step of that supply chain involves direct emissions and the allocation of input emissions to products. When the battery manufacturer receives information from its tier-1 suppliers on the embedded emissions of its purchases (in units such as kg of $CO_2$), the battery manufacturer must be able to trust that those numbers are "representationally faithful" (in the accounting sense of that term) all the way up through the value chain. One way to do this is for the battery maker to have sight, at a qualitative level, of the full richness of the production methods and emissions-accounting decisions of all its tier-1 suppliers, their suppliers, and so on. The trouble with this approach is that it is costly, cumbersome, and potentially invasive of the trade secrets of companies in the supply chain.

Recent advances in blockchain and distributed ledger technology offer another way to transfer representationally faithful emissions information down value chains. Under this approach, direct emissions, when recognized on an E-ledger, would be tokenized into indestructible atomistic units of digital "currency" that are then indelibly linked to relevant units of inventory. For example, if two tons of $CO_2$ emissions are produced by mining one ton of copper at a given facility on a given day, those two tons of $CO_2$ emissions would be tokenized into, say, two-billion emissions tokens (the unit of digital emissions currency) that are now forever linked to that ton of copper. Then, as that copper makes its way down a value chain, and becomes embedded into thousands of different products (based on various product-allocation decisions by entities along the value chain), the proportionate amount of tokens (proportionate to the copper) also becomes embedded into the E-liability calculations of those products. The tokens' metadata, at any point in the value chain, contains information such as the date and place where the original token was created, the various E-ledgers through which the token has passed up to that point, and the auditors who have assured the token's transactions across and within E-ledgers, including assurance of all the input-to-output product-allocation decisions.

As the token itself is fungible with the tokens associated with all other products and services moving down a value chain, E-ledgers calculations using tokens are simple. And, as long as the token metadata appears in order, with all the appropriate and expected audit checks, the user of the token at any point in the value chain can be assured of its true and fair representation of embedded emissions without needing to unpack, at a qualitative level, the underlying production methods and emissions-accounting decisions of all associated upstream E-ledgers. The token-based technology also preserves the trade secrets of the intermediate entities in the supply chain. In effect, blockchain and distributed ledger technology offer the promise for simple, private, secure, and practical deployment of the E-ledgers system.

Two challenges for widespread implementation of this technology remain. First, the technology must be interoperable across multiple token suppliers from different jurisdictions and over time. Second, using this technology must not generate more emissions than it saves through entities' informed decarbonization decisions. These are important considerations for policymakers and the technology suppliers to assess and address as they consider widespread adoption of tokenization to implement E-ledgers accounting at scale.

## VII. LESSONS FROM PILOT APPLICATIONS OF THE E-LEDGERS SYSTEM

Since E-ledgers were first introduced in 2021, a number of entities in high-income and developing countries have implemented elements of the system in pilot projects. These entities include businesses, governments, and nonprofits, and they cover various sectors such as agriculture, mining, manufacturing, and services. Several important lessons have emerged from the pilot studies, which we briefly summarize below.[7]

First, the processes to obtain dynamic, facility-level direct emissions are not as burdensome as one might imagine (Ramanna and Holloway 2025). For instance, in a recent pilot at BMW, which entailed calculating the E-liability of the iconic kidney grille on the automaker's electric cars, the manufacturer first started with a process map that identified all chemical reactions involved in the production process at the pilot facility. The underlying information was, of course, already known to BMW's production engineers, so the process map was easy to generate. Next, the team focused on major sources of emissions across those chemical reactions, then identifying those (nongaseous) inputs and outputs from the reactions whose mass could be easily determined (e.g., because those input or output masses are listed on financial-inventory records or bills of sale). Then, using basic chemistry knowledge, they were able to impute the mass of direct emissions generated from the reactions on a dynamic basis. This process of imputing direct emissions using production knowledge, basic chemistry, and existing inventory recordkeeping has been used at other pilots as well.

Second, the intra-organizational assignment of direct emissions and those embedded in purchased products and services to an entity's output products has also been relatively straightforward. Across pilots, this process has involved several generalizable steps. (1) The pilot entity identifies the range of products generated by the facility in question and then identifies emissions-intensive raw materials and processes to allocate to those products. (For instance, in a pilot at a major UK hospital, the entity identified various types of hip-replacement surgeries as the output "products" and identified the artificial hip and operating

[7] Disclosure: Our time has been provided pro bono to these pilot projects. In return, we have asked for the ability to publicly share the broader learnings from the pilots.

theater usage as the most emissions-intensive input and production process.) (2) The pilot entity determines the usage of those inputs and production processes in generating each unit of the selected outputs. (Continuing with the hip-replacement example, the hospital dynamically measured the minutes of operating theater usage per hip-replacement surgery, where one artificial hip is usually needed per surgery.) (3) The pilot entity calculates emissions per unit of usage for the selected production processes. This is generally based on dynamic, facility-level direct emissions measurement. (In the hip surgery pilot, the hospital calculated the emissions per minute of operating theatre usage based on energy consumption and amortization of embedded emissions in the capital equipment.) (4) The emissions per unit of selected input (e.g., the artificial hip in the hospital pilot) are obtained from the relevant supplier. (5) Using simple arithmetic akin to that used in cost accounting, the entity then calculates the emissions per unit of output (e.g., the emissions for each type of hip-replacement surgery). Throughout these steps, pilot managers are advised that the emissions from waste or scrapped materials should also be allocated to outputs, unless those discarded materials can be used for other output products.

Third, where complications sometimes arise in pilot studies is with tier-1 suppliers being unable or unwilling to provide dynamic, batch-level data for the products they supply to the pilot entity. In the case of the BMW pilot described earlier, the automaker addressed this challenge by working with its smaller suppliers to help build their requisite carbon-accounting capacity. In the case of other pilots, the piloting entities have worked around the problem by limiting the pilot scope to a handful of key emissions-intensive suppliers that were able and willing to cooperate (Kaplan, Ramanna, Gour, and McAra 2022). In still other cases, pilot entities have also reverted to use of emissions factors as starting values in the pilot process, counting on the recursive adoption path for E-ledgers carbon accounting to have more suppliers, in the next iteration or two, provide primary, real-time emissions data (Kaplan, Ramanna, and Jha 2023). Even in cases where pilots have included cooperative suppliers providing primary data, the pilot process does need careful supplier management. This is because pilots usually entail the discovery of new information on emissions intensity of specific products, beyond what is assumed from (and sometimes contradictory to) conventional sustainability reporting based on industry-average emissions: not surprisingly, this new information can become the basis for defensiveness and anxiety amongst supplier companies.

The fourth and perhaps most impactful lesson from the pilot projects is that seemingly similar "commodity" products can have large differences in their embedded emissions. For instance, the pilots have revealed that two bags of cement with the same structural properties and similar functional uses can have vastly different embedded emissions when made by different facilities or even the same facility at different times (Kaplan, Ramanna, and Reichelstein 2023). The same is true for bars of steel or even barrels of oil. The most vivid example comes from a pilot study with Hitachi Energy, to calculate the emissions embedded in the large transformers that the company manufactures (Ramanna and Kirk 2023). Copper is a key material in transformer manufacturing, and copper mining entails substantial emissions. Hitachi Energy was thus under some pressure from environmental advocates to use recycled rather than virgin-mined copper in its supply chain. What the E-ledgers pilot revealed, however, is the variance in emissions across Hitachi's copper sourcing – some recycled copper has higher embedded emissions than virgin-mined copper, even as other virgin-mined copper is vastly dirtier than recycling. The pilot's key lesson is that rhetoric such as "recycling is green" and "mining is brown" can be misleading – the E-ledgers approach allows for improved decarbonization decision-making by replacing qualitative and somewhat simplistic heuristics with accurate, comparable, and verifiable quantitative data. In effect, the E-ledgers approach, by providing a universal accounting system for emissions, commoditizes $CO_2$ and de-commoditizes all other commodities, unleashing new forms of value creation through incentives for decarbonization.

## VIII. CONCLUSION: RECURSIVE E-LEDGERS ADOPTION

Global adoption of the E-ledgers system will likely not occur in a single stage. The pilots have shown the complexities of getting even tier-1 suppliers to participate in the E-ledgers process. But implementing the E-ledgers algorithm recursively enables the system to be adopted over time (Ramanna, Angel, Wang, and Zuber 2024). Recursion is a computational process in which a seemingly unsolvable problem becomes solvable by breaking it down into iterations. In carbon accounting, the "problem" is getting accurate product-level emissions data on a dynamic basis for all products that transact and cycle through the economy. This problem can be solved recursively through multiple iterations as follows.

In the first iteration, a small handful of key companies start using E-ledgers (perhaps due to a government reporting mandate, emissions-based tariffs as being considered in Europe, or even as part of a voluntary collaborative). The early adopters identify their salient direct emissions (as BMW did) and a handful of tier-1 suppliers with high direct emissions. They obtain batch-level primary data for these direct emissions for a given reporting period. For all other emissions associated with inputs and production, they can use existing and public data, for instance, drawing from databases like Argonne National Laboratory's GREET. A combination of these primary and secondary data, together with the accounting processes described in this paper, allows the companies to generate a first pass at an E-ledger and product-level emissions calculations for their outputs. The data from this stage are more accurate than existing product-level emissions data obtained from industry-level estimates but far from the accuracy required for reasonable-assurance audits.

In the second iteration, the emissions calculations from the first iteration can be used as inputs into emissions calculations by those entities that are customers to the iteration-1 companies. Given the circular nature of supply chains, some of these customers will be suppliers (tier-1 to tier-n) of the iteration-1 companies. By using slightly more accurate data, the product-level calculations for all companies involved in iteration-2 become more accurate. And, as iteration-2 increases the number of companies involved in using the E-ledgers system, more outputs will benefit from this increase in accuracy.

This process can continue over further iterations until all material products and services in the economy have accurate, dynamic emissions. A recent study of recursion's iterative calculus predicts that reasonable-assurance levels of accuracy can be achieved in as few as five iterations, assuming geometric growth in company coverage (von Kalckreuth 2024). The recursive process would be turbocharged if policymakers introduced a progressive penalty (say, over five years) for companies that continue to use secondary instead of primary data for their own material direct emissions, as the E-liability Proto-Standard recommends. The recursive process was previously used in the post-World War II period to scale bottom-up microeconomic data to an integrated global system of reasonably accurate GDP accounts, providing a historical case study of its practical potential.

The E-ledgers carbon accounting system integrates best practices from centuries of inventory accounting and from decades of cost accounting with more recent developments in tokenization technology. It offers a simple, dynamic approach to calculate emissions embedded in all goods and services that transact in the economy to an accuracy standard that is representationally faithful and can be reasonably assured. The system, which should be instinctively familiar to accountants and business managers, enables competitive differentiation of products based on their emissions efficiency, helping align market incentives with decarbonization objectives. This paper, which develops the accounting fundamentals of the E-ledgers system, can seed further research into the theory and practice of robust carbon accounting for decision-making and accountability.

**References**


Myles R. Allen, David J. Frame, Pierre Friedlingstein, et al. 2025. "Geological Net Zero and the need for disaggregated accounting for carbon sinks." *Nature*, Vol. 638, pp. 343–350. Available from: https://doi.org/10.1038/s41586-024-08326-8.

Manuela Andreoni and Ricardo Brito. 2025. "Brazil prosecutors try to block $180 million carbon credit deal." *Reuters*, June 4. Available from: https://www.reuters.com/sustainability/climate-energy/brazilian-prosecutors-seek-block-180-million-carbon-credit-deal-2025-06-03/.

Alan Buis. 2019. "The Atmosphere: Getting a Handle on Carbon Dioxide." *NASA*, October 9. Available from: https://science.nasa.gov/earth/climate-change/greenhouse-gases/the-atmosphere-getting-a-handle-on-carbon-dioxide/.

Charles Cannon, Suzanne Greene, Thomas Koch Blank, Jordy Lee, and Paolo Natali. 2020. "The Next Frontier of Carbon Accounting: A Unified Approach for Unlocking Systemic Change." *Rocky Mountain Institute*, June. Available from: https://rmi.org/insight/the-next-frontier-ofcarbon-accounting/.

Yuji Ijiri. 1993. "The Beauty of Double-Entry Bookkeeping and it Impact on the Nature of Accounting Information." *Economic Notes*, Vol. 22, pp. 265-285.

Ulf von Kalckreuth. 2024. "Harnessing the power of Input-Output analysis for sustainability." *Irving Fisher Committee on Central Bank Statistics,* December. Available from: https://www.bis.org/ifc/publ/ifcwork24.pdf.

Robert S. Kaplan and Robin Cooper. 1998. *Cost and Effect: Using Integrated Cost Systems to Drive Profitability and Performance*. Boston: Harvard Business Review Press.

Robert S. Kaplan and Karthik Ramanna. 2021. "Accounting for Climate Change: The First Rigorous Approach to ESG Reporting." *Harvard Business Review*, Vol. 99, No. 6, November–December. Available from: https://hbr.org/2021/11/accounting-for-climate-change.

Robert S. Kaplan and Karthik Ramanna. 2024. "Disclosing Downstream Emissions." *Harvard Business Review*, Vol. 102, No. 4, July-August. Available from: https://hbr.org/2024/07/disclosing-downstream-emissions.

Robert S. Kaplan, Karthik Ramanna, Vibhuti Gour, and Sarah McAra. 2022. "What Does an E-Liability Pilot Look Like? The Case of Giti Tire." *Oxford Case Centre for Public Leadership*, November 7. Available from: https://e-ledgers.institute/wp-content/uploads/2025/06/What-does-an-E-liability-pilot-look-like-The-case-of-Giti-Tire-1.pdf.

Robert S. Kaplan, Karthik Ramanna, and Stefan Reichelstein. 2023. "Getting a Clearer View of your Company's Carbon Footprint." *Harvard Business Review Online*, April 3. Available from: https://hbr.org/2023/04/getting-a-clearer-view-of-your-companys-carbon-footprint.

Robert S. Kaplan, Karthik Ramanna, and Piyush Jha. 2023. “Update on E-liability Accounting.” *Accountability in a Sustainable World Quarterly*, Vol. 4, September, pp. 96–116. Available from: https://online.fliphtml5.com/jdbmp/jqen/#p=98.

Robert S. Kaplan, Karthik Ramanna, and Marc Roston. 2023. “Accounting for Carbon Offsets.” *Harvard Business Review*, Vol. 101, No. 4, July–August. Available from: https://hbr.org/2023/07/accounting-for-carbon-offsets.

Stephen H. Penman. 2024. “Accounting for Carbon.” Unpublished Manuscript, January 1. Available from: https://ssrn.com/abstract=4721974.

Karthik Ramanna, Niels Angel, Michael Wang, and Maria T. Zuber. 2024. “Accelerating the Implementation of Accurate Product-Level Carbon Accounting.” Unpublished Manuscript, August 20. Available from: https://ssrn.com/abstract=4957351.

Karthik Ramanna and Lauren Holloway. 2025. “How BMW Started Auditing Emissions Across Its Supply Chain.” *Harvard Business Review Online*, February 26. Available from: https://hbr.org/2025/02/how-bmw-started-auditing-emissions-across-its-supply-chain.

Karthik Ramanna, Lauren Holloway, Max Israelit, Chloe W. Zhang, and Robert S. Kaplan. 2024. “A Proto-Standard for Carbon Accounting and Auditing using the E-Liability Method.” *E-ledgers Institute*, September 12. Available from: https://ssrn.com/abstract=4957358.

Karthik Ramanna and Harry Kirk. 2023. “Why Recycled Materials Don’t Always Generate Greener Products.” *Harvard Business Review Online*, November 30. Available from: https://hbr.org/2023/11/why-recycled-materials-dont-always-generate-greener-products.

Stefan Reichelstein. 2024. “Corporate carbon accounting: balance sheets and flow statements.” *Review of Accounting Studies*, Vol. 29, pp. 2125–2156. Available from: https://doi.org/10.1007/s11142-024-09830-y.

**Table 1**

This table shows E-ledger journal entries for representative transactions for a sample entity (Panel A, "Luca Pacioli Corp."). Certain transactions are intra-entity (numbers 3, 4, 5, 6, 10, 12); while other transactions are inter-entity, with Pacioli Corp.'s supplier (Panel B, numbers 1 and 9), with its customer when that customer is an end consumer (Panel C, number 7), and with the geological carbon equity (GCE) account on the geological master ledger (Panel D, numbers 2, 8, and 11).

Additionally, Panel D shows how the changes in the "NET TOTAL" E-assets and E-liabilities accounts of various entities and jurisdictions in the economy (e.g., the three representative E-ledgers in our stylized setting) consolidate into the geological master ledger's E-assets and E-liabilities accounts. Panel D also shows how transactions by entities with the GCE account reconcile that account to changes in the geological master ledger's E-assets and E-liabilities accounts, so that the fundamental accounting equation "Assets = Liabilities + Equity" is preserved.

The values in the table can be considered units of GHG emissions and removals (e.g., kg of $CO_2$) and are entirely fictionalized for illustrative purposes. This table is not intended to be standalone and should be read in conjunction with the text of the article.

**A. E-ledger of Luca Pacioli Corp.**

| | | E-assets | | | E-liabilities | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Removals Purchased & Generated | (E-assets Netted) | NET TOTAL | Emissions Transferred-in | Direct Emissions Generated | Capitalized Emissions | Finished Goods | (E-liabilities Netted) | NET TOTAL |
| | Beginning balance | 0 | 0 | 0 | 0 | 0 | 150 | 10 | 0 | 160 |
| *1* | *Inter-entity transfer of emissions* | | | | *40* | | | | | |
| *2* | *Direct emissions generated* | | | | | *10* | | | | |
| *3* | *Allocating purchased emissions to FGs* | | | | *-20* | | | *20* | | |
| *4* | *Allocating direct emissions to FGs* | | | | | *-10* | | *10* | | |
| *5* | *Capitalizing purchased emissions* | | | | *-20* | | *20* | | | |
| *6* | *Depreciating capitalized emissions* | | | | | | *-5* | *5* | | |
| *7* | *Sale to end consumer* | | | | | | | *-35* | | |
| *8* | *Recognizing generated removals* | *20* | | | | | | | | |
| *9* | *Inter-entity transfer of removals* | *10* | | | | | | | | |
| *10* | *Netting emissions with removals* | | *-10* | | | | | | *-10* | |
| *11* | *Impairment of removals* | *-5* | | | | | | | | |
| *12* | *Reversing the netting of impaired removals* | | *5* | | | | | | *5* | |
| | Ending balance | 25 | -5 | 20 | 0 | 0 | 165 | 10 | -5 | 170 |

**B. E-ledger of supplier to Luca Pacioli Corp.**

| | | E-assets | | |
|---|---|---|---|---|
| | | Removals Purchased & Generated | (E-assets Netted) | NET TOTAL |
| | Beginning balance | 100 | 0 | 100 |
| 1 | *Inter-entity transfer of emissions* | | | |
| 9 | *Inter-entity transfer of removals* | *-10* | | |
| | Ending balance | 90 | 0 | 90 |

| | | E-liabilities | | | | | |
|---|---|---|---|---|---|---|---|
| | | Emissions Transferred-in | Direct Emissions Generated | Capitalized Emissions | Finished Goods | (E-liabilities Netted) | NET TOTAL |
| | Beginning balance | 0 | 0 | 0 | 100 | 0 | 100 |
| 1 | *Inter-entity transfer of emissions* | | | | *-40* | | |
| 9 | *Inter-entity transfer of removals* | | | | | | |
| | Ending balance | 0 | 0 | 0 | 60 | 0 | 60 |

**C. Country's consumption E-ledger for end consumer of Luca Pacioli Corp.**

| | | E-assets | | |
|---|---|---|---|---|
| | | Removals Purchased & Generated | (E-assets Netted) | NET TOTAL |
| | Beginning balance | 0 | 0 | 0 |
| 7 | *Sale to end consumer* | | | |
| | Ending balance | 0 | 0 | 0 |

| | | E-liabilities | | |
|---|---|---|---|---|
| | | Emissions Transferred-in | (E-liabilities Netted) | NET TOTAL |
| | Beginning balance | 10,000 | 0 | 10,000 |
| 7 | *Sale to end consumer* | *35* | | |
| | Ending balance | 10,035 | 0 | 10,035 |

**D. Geological master E-ledger**

| | | E-assets NET TOTAL | = | E-liabilities NET TOTAL | + | Geological Carbon Equity |
|---|---|---|---|---|---|---|
| | Beginning balance | 10,000 | = | 1,000,000 | + | -990,000 |
| *2* | *Direct emissions generated* | | | | | *-10* |
| *8* | *Recognizing generated removals* | | | | | *20* |
| *11* | *Impairment of removals* | | | | | *-5* |
| *A* | *Change in Luca Pacioli's Net Total* | *20* | | *10* | | |
| *B* | *Change in Supplier to Luca Pacioli's Net Total* | *-10* | | *-40* | | |
| *C* | *Change in Country Consumption Net Total* | *0* | | *35* | | |
| | Ending balance | 10,010 | = | 1,000,005 | + | -989,995 |