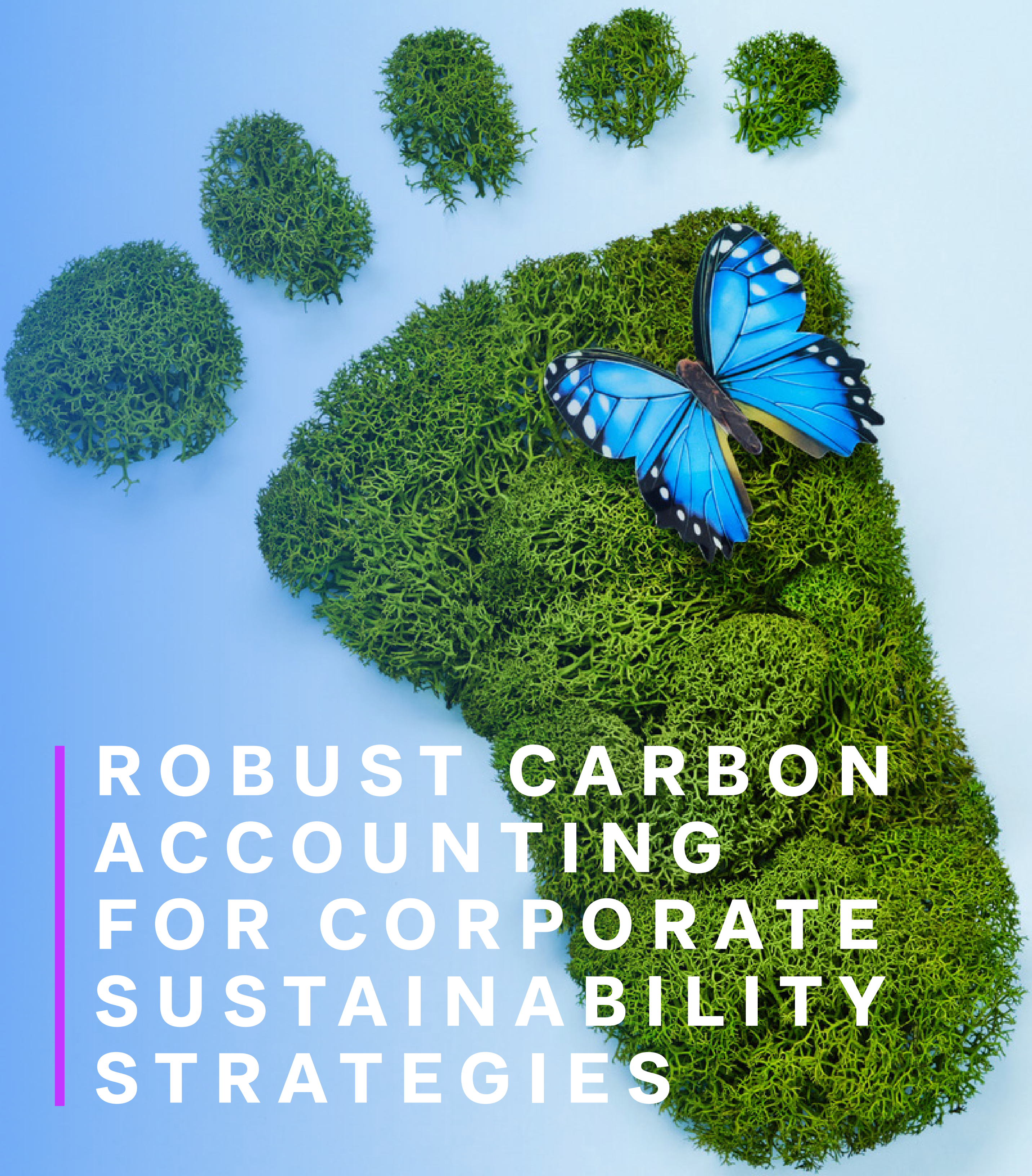

ROBUST CARBON ACCOUNTING FOR CORPORATE SUSTAINABILITY STRATEGIES

Authors

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Clear, transparent, reliable carbon accounting makes good business sense, improving a company's reputation and trustworthiness while providing an opportunity for market differentiation. Unfortunately, there is currently a vast discrepancy in greenhouse gas (GHG) reporting within and across supply chains. Some systems differentiate direct from indirect emissions, some assign scores to various carbon-sequestration approaches, and some focus on alignment with global agreements.

In this article, we highlight some barriers to robust carbon reporting and provide a seven-factor framework for addressing the gaps. The framework focuses on combining data, standardizing the technical architecture, identifying business drivers, and setting realistic policies. The good news is that recent technological advances make it possible to devise systems capable of carrying out this level of rigor.[1]

Around the world, governments and consumers want businesses to work toward reducing carbon in the atmosphere. A dynamic, transparent carbon accounting system would contribute to this goal.

THE NEED FOR MORE ROBUST CARBON ACCOUNTING

We define carbon accounting as methods for assessing GHG discharges and removals from the atmosphere (industrial or natural processes). In carbon accounting parlance, processes that discharge CO2, such as the flaring of methane at an oil well, are said to be net-positive emissions. Those that remove CO2, such as tree growth, are said to be net-negative emissions. All tracked gases have a global warming potential coefficient that is a multiple of the CO2 warming effect defined by the Intergovernmental Panel on Climate Change (IPCC) — see Figure 1.[2,3]

Emissions accounting is an omnipresent concern for organizations seeking to understand and balance their emissions. For example, high-quality data helps companies integrate their sustainability strategies with their corporate processes, and standardized data measurement techniques enable assessments of disparate processes that would otherwise sit in silos. Adding dynamic verification steps helps ensure transparency and helps observers monitor trends. Data integrity procedures (e.g., ongoing traceability to physical carbon, third-party audits, common metadata) can improve reputational integrity, and having emissions data continuously available opens doors to exchanges and markets (e.g., carbon-offset purchases or sales of carbon credits).

> **GOVERNMENTS & CONSUMERS WANT BUSINESSES TO WORK TOWARD REDUCING CARBON IN THE ATMOSPHERE**

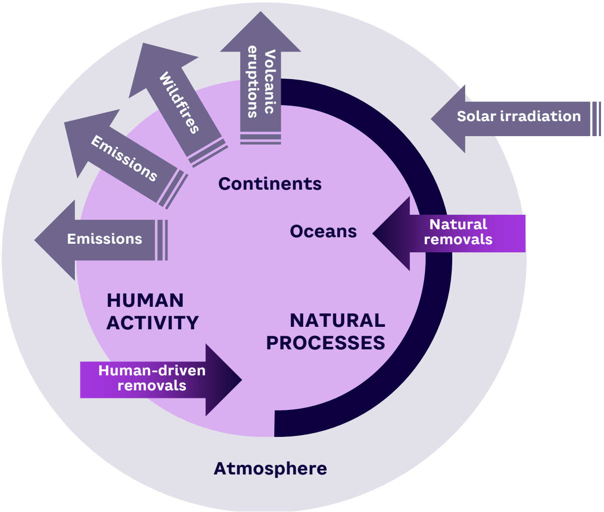


Figure 1. Carbon movement due to human activity and natural processes

The gold standard is to apply the same rigor used in financial accounting to carbon accounting, but with direct ties to dynamic carbon stores. Carbon accounting must reside in business and industrial processes, including tracking carbon movement across supply chains in real time or near real time. Such a system would bring the trust needed to enable GHG transactions, liability identification and delegation, and integration into commodity markets.

ACCRUAL CARBON ACCOUNTING

Imagine a data center operator running a cluster of machines on behalf of a customer. The customer is conducting a computationally intensive machine learning run. For the operator, the direct GHG emissions of that single operation are negligible — but data centers as a whole consume vast amounts of electricity across operators. These emissions can be described as GHG Scope 2 (indirect emissions associated with the purchase of electricity by the data center). They are also Scope 1 (carbon pollution at the utility source) and Scope 3 (peripheral energy consumption by the operator's employees or suppliers).

Actors like the data center operator are linked economically in a supply chain defined by a service provider/subscriber relationship. Although there is no immediate cost from the emissions to any of the members of this supply chain, there is a cost to the commons. This type of cost is known in economic terms as an *externality*. Internalizing the externality collaboratively across supply chains using carbon accounting could lead to more predictable and manageable business outcomes.

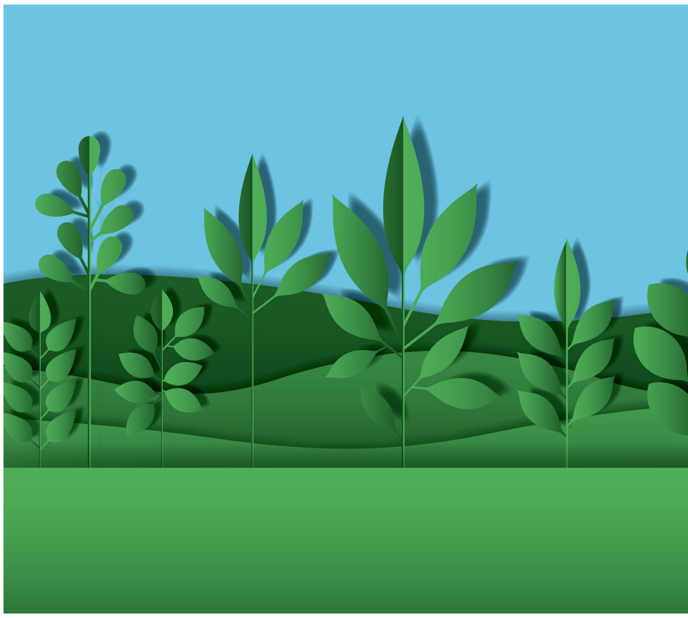
Embedding carbon measurement into business and industrial processes is the carbon accounting equivalent of carrying out financial accounting on an accrual basis, in which revenue is recorded when earned (regardless of when the cash is received), and expenses are recorded when incurred (not necessarily when paid).

Doing it this way presents a more accurate, timely picture of an entity's financial health than a cash-based system. If accrual practices were used for carbon accounting, this could align carbon accounting with financial accounting.

Additionally, offsetting of carbon emissions with the purchase or production of carbon sequestration in the same units and quantity would reconcile the accounts, akin to balancing a checkbook. This would allow the organization or its customers to proactively direct climate-conscious purchases. For example, airline emissions estimates would inform the climate-conscious passenger in advance of a ticket purchase. (This would be even better if, in reconciliation, actual carbon emissions were reported to the passenger.)

Some emissions are *potential* or *pass-through*, in the sense that they are emitted by an actor on behalf of another actor downstream in a supply chain. This goes to the core of the definition of Scope 1, 2, and 3 emissions. Certain actors may be entitled to relief from pass-through emissions. A transparent carbon accounting system could turn this into a dialogue across supply chain participants, possibly with the participation of regulatory agencies. Businesses would benefit from such a predictable scenario in which liability is capped.

However, GHG reporting across participants in a supply chain is not possible without a formal accounting system understood and accepted by the supply chain participants. In such a mechanism, carbon emissions would be treated no differently than other costs among suppliers in a supply chain. (It is important to note that carbon accounting provides data to actors; it does not define or impose policies on its own.)



7 REQUIREMENTS FOR A GLOBAL CARBON ACCOUNTING & TRADING SYSTEM

In this section, we describe the seven essential practices of a cross-industry generally accepted carbon accounting principles (GACAP) system:

1. Interoperability
2. Measuring externalities
3. Verifiability
4. Decentralization
5. Privacy
6. Scalability
7. Traceability

1. INTEROPERABILITY ACROSS SECTORS

A global carbon accounting system requires interoperability between industry sectors and verticals.[4] We can represent emission sources as pie slices, with each source accounting for its emissions or natural removals and developing measurement technologies applicable to their specific processes (see Figure 2).

Of course, the sectors do not exist in silos; all emissions go into Earth's one atmosphere. Thus, a federated system is needed, one that accounts for carbon exchanges (emissions or removals) and applies to interactions with the atmosphere and with other industries. A carbon accounting interaction between sectors and various types of emitters and removers introduces the notion of carbon offsetting as a carbon accounting application.

These carbon accounting transactions are included in a GACAP model that applies to all industries, similar to the way traditional business accounting (GAAP) takes place. This model enables distributed, decentralized (yet standardized) carbon accounting, in which each industry sector performs industry-specific scientific or engineering measurements.

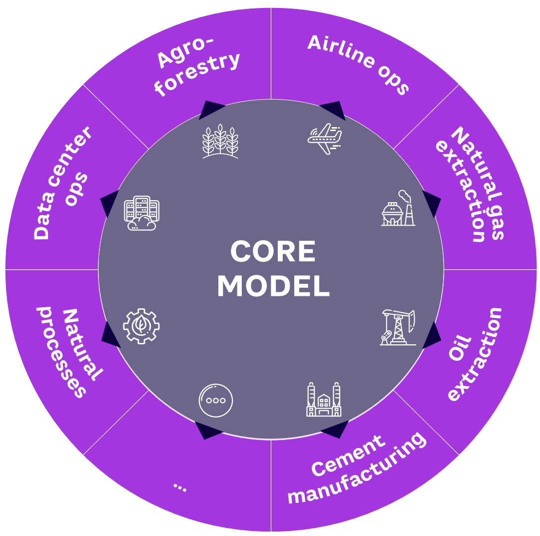


Figure 2. Carbon accounting using a distributed, decentralized model

Merging or integrating data from multiple streams from various sources is efficient, but it requires multimodal measurement in which implementers can balance less expensive, less precise data sources with more expensive, more precise sources. A high-value tract such as a forest with centuries-old hardwood trees, may require measurement on actual specimens or time- and physical-based measurement by ground crews or Internet of Things (IoT) sensors. (Note that the selection of measurement modality, whether event-based or modeling-based, would be determined by policy and affordability.)

2. MEASURING EXTERNALITIES

The main externality for fossil fuels is global warming through combustion (other externalities include contamination from plastic pollution or oil spills from tankers or pipeline breaks). The first step in managing externalities is measurement, formally known as "measurement, monitoring, reporting, and verification" (MMRV). This is required at every stage of a supply chain. For example, supply chain stages for fossil fuels might include exploration and extraction, transportation, refining, distribution, and consumption. Carrying out MMRV at every stage enables carbon-flow assessment and attribution, as well as assignment of emissions liabilities and credits for every player in the supply chain.

One challenge is the impermanence of carbon stored in physical spaces, such as in the agroforestry industry. Improvised mechanisms such as buffer pools are in use in agroforestry-backed compliance markets. Credits from these pools are used after a contingency to restore the credits lost. This mechanism is not foolproof, as losses can be higher than the reserve (e.g., with wildfires), leaving no recourse. As we describe below, various technical verification mechanisms can help with the need to measure externalities.

3. VERIFIABILITY: DIGITALLY TWINNING UNDERLYING ASSETS

Digital twins make audits and tracebacks possible by providing measurement metadata (e.g., timestamps and geolocation). Access to this data should be possible at any moment for technical or legal needs. Stakeholders must be able to track their carbon assets and/or examine the pedigree of any asset being assessed for a transaction. (Blockchain's approach to this is described in the next section.)

For example, the impermanence of forest assets could be treated as variable-price commodities. This would require real-time MMRV, including event-based measurement augmented with historical and predictive growth models.[5] Data-sampling frequency must be based on the underlying business processes. In practice, this means assessing biomass at different intervals depending on the tool (e.g., IoT sensors, light detection and ranging equipment, or satellite infrared remote sensing).

4. DECENTRALIZATION: NO SINGLE POINT OF FAILURE OR INFLUENCE

A concentration of carbon accounting data or services at any point in the supply chain would not be in the interest of participating entities, due to single points of failure or potential bias. Instead, measurement events must be visible across entities as liabilities and assets are transferred by recording them in a permanent, immutable ledger (blockchain). Additionally, smart contract–enabled blockchains would allow decentralized autonomous organizations to manage the system.[6] Although this blockchain implementation is distinct from cryptocurrency, the high-energy, high-carbon costs of blockchain would need to be included on the liability side of the ledgers.

5. PRIVACY: PROTECTING RIGHTS OF COUNTERPARTIES & ASSET HOLDERS

Carbon accounting data sets must be designed to facilitate audits by participating agencies and entities while preserving the privacy of the underlying asset holder. Cryptographic methods include selective attestation (e.g., authorizing a transaction without revealing the identities of the transacting parties or certain details of the transaction), zero-knowledge proof (e.g., doing a task that reveals the existence of knowledge but not the actor's identity), attribute-based credentials (disclosure of verifiable attributes like location or carbon-asset dimensions, without revealing the disclosers' full identity), and homomorphic encryption (performing calculations on data without decrypting it).

6. SCALABILITY

Global warming affects the entire planet, so the scope of a carbon accounting system should be as broad, with accounting across all sectors. An ability to incorporate most industry sectors, actors, and transaction volumes without restriction would require the implementation of nearly all the factors (interoperability, traceability, decentralization, verification, and privacy).

In addition, scale, in the form of market participation, spreads entities' market risk. High levels of participation signal that the market has confidence that the underlying traded assets are reliable.

7. TRACEABILITY

Supply chains are complex, interconnected systems. They can represent physical materials (e.g., oil or cement in the construction industry), abstract materials (e.g., carbon credits), or both. Transparency and visibility across the supply chain are two of the most pernicious issues plaguing today's opaque, voluntary carbon-offset markets. With such complexity, *visibility* into component parts of a carbon offset coming from different origins or processing streams may be difficult. Meanwhile, a participant might be less *transparent* about an asset whose value is precarious if there were no repercussions to its changing after the sale.

Figure 3 shows a carbon supply chain applicable to the agroforestry industry, with carbon removals (credits) and carbon emissions (debits) for data centers. In this example, each stage in the supply chain represents a data type and an industry actor managing the data type.

Following the agroforestry supply chain stages from left to right, a landowner deals with the forested land, forming the basis for carbon capture in the form of biomass. A carbon consolidator makes the biomass estimates and converts them into bulk carbon figures. A carbon registry takes the carbon figures and issues carbon credits on them. A fintech firm takes the carbon credits to a financial platform to securitize the carbon credits, which are passed to brokerage companies that sell the financial instruments to investors. A similar process can be defined for the data center supply chain (see bottom of Figure 3).

Figure 3 connects both carbon emitters and carbon-capture entities to financial markets, eventually bringing them together. Blocks of carbon emissions or removals can be split and/or combined on exchanges. Carbon records can be pooled or sliced into tranches the same way mortgage-backed securities are today.

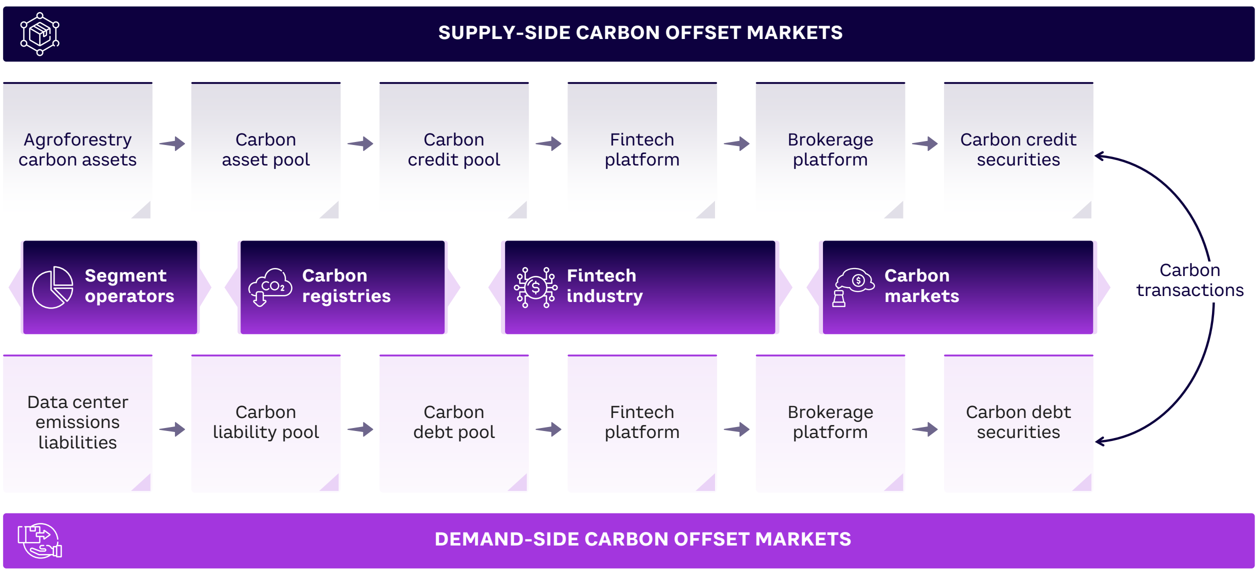


Figure 3. Supply-side and demand-side supply chains for carbon-offsetting securities

AN OPEN SOURCE COMMUNITY

To construct the carbon accounting protocol to meet these seven criteria, we propose an open source community where members codevelop the framework and deliver applications such as gathering data from various parts of the supply chain and sending data horizontally from stage to stage.

The community should adopt reuse as a governing principle. The objective is to connect supply chain blocks representing carbon assets, which, in turn, correspond to blocks in the target supply chain. Reuse would minimize implementation cost and leverage a standard three-tier architecture.[7]

For example, the bulk of the work involved in putting together an agroforestry solution is at the physical (or bottom) layer of the architecture, where the sensor and control structure of a digital twin resides. The digital twin represents the forest's carbon assets and is developed as an API to a carbon registry (carbon-asset pool, at the next layer), which can be aggregated as carbon credits traded by investors (at the top layer).

CONCLUSION

A carbon accounting system could harmonize carbon management across participants in a supply chain, industry sectors, and natural systems while expanding trust in carbon markets. It would require new collaborations among technical, financial, physical science, and business domains but would finally add the type of robustness that has been missing from carbon accounting. Ultimately, this would enable businesses to offer more innovative products and services and make good on their sustainability promises.

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Enrique Castro-Leon is CTO and a founding member of OptimiLabs, a start-up focused on systems integration and technology innovation. He currently leads SCOOP, an open source project developing an IT framework for universal greenhouse gas (GHG) accounting, supporting both GHG emissions and removals and offering secure, high-quality data suitable for financial transactions. Dr. Castro-Leon is also Vice Chair of the IEEE P7802 standards working group, focusing on measurement, monitoring, reporting, and verification for climate action projects. Previously, he worked at Intel, driving the transformation of traditional engineering labs into cloud-based, lab-as-a-service environments. Dr. Castro-Leon also led efforts to integrate power monitoring and control capabilities into data center solutions and worked as an enterprise architecture consultant, advising executives on technology integration and strategy. He served as Adjunct Professor at Portland State University, Oregon Graduate Institute, and the University of Costa Rica. Dr. Castro-Leon has authored and coauthored four books, contributed to IEEE publications and *Amplify*, and holds three patents. He earned a bachelor of science degree in electrical engineering from the University of Costa Rica, a master of science degree in electrical engineering and computer science, and a PhD in electrical engineering, both from Purdue University, USA. He can be reached at enrique@optimilabs.com.

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