Blockchain and the Carbon Credit Ecosystem: A New Paradigm in Sustainable Supply Chain Management

(1) **Purpose:** Businesses must now track the complicated supply chains of their products, which involve different manufacturers and suppliers. However, because supply chains are scattered across multiple countries and involve many institutions, it becomes an overwhelming practical challenge to ensure transparent recording and reporting of greenhouse gas emissions. The myriad issues necessitate a technological solution that will improve supply chain transparency, assist in managing carbon assets, and allow all parties to obtain credible information on carbon output. As a potential solution, we offer a unique architecture that effectively combines "blockchain technology" with the carbon supply chain of a multi-institution business network.

(2) **Design Methodology:** Our research and proposed framework are based on publicly available reports on carbon emissions tracking, sustainability, carbon trade, and emerging blockchain technologies. We also interviewed industry experts to obtain their input and feedback.

(3) **Findings:** Businesses must support the pledges made by their respective governments towards meeting the objectives of the Paris Agreement. Although the emissions trading system incentivises businesses to move in this direction, it can be challenging for them to efficiently manage their carbon assets owing to issues such as lack of standardised methods for tracking emissions across suppliers and manufacturers and the fragmentation of carbon markets. The carbon supply chain can maintain a record of the chronological flow of carbon emissions and eventually of all carbon assets by integrating a centralised ledger system based on blockchain technology.

(4) **Originality**: Global warming, climate change and carbon emissions are among humanity's pressing problems today. To achieve net zero emissions by the middle of the twenty-first century, emissions must be drastically reduced. Global supply chains have a crucial role to play in this context. Our article provides a blockchain-based technology framework for carbon emissions visibility and tracking. We believe such a platform will provide critical visibility and tracking support to globally dispersed supply chains, moving a step closer toward carbon emissions control and net zero operations.

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"Blockchain could contribute to greater stakeholder involvement, transparency and engagement and help bring trust and further innovative solutions in the fight against climate change, leading to enhanced climate actions."

> Alexandre Gellert Paris, Associate Programme Officer at the United Nations Framework Convention on Climate Change (UNFCCC).

CLIMATE CHANGE & CARBON EMISSION GOALS

Climate change continues to be a major global challenge. As a worsening climate threatens to wreak havoc on people's communities and livelihood, there is growing consensus on the need to move to a more sustainable development paradigm. Conventions such as the Paris Agreement and the Kyoto Protocol have seen governments and businesses pledging ambitious emission reduction goals. The Paris Agreement of 2015, for example, saw 196 nations making emission-reduction pledges that aim to limit global average temperature increase to well below 2°C above pre-industrial levels, and preferably below 1.5°C (UNFCCC n.d.).

Governments and regulators in many countries have put a cap on the amount of carbon dioxide a business in a particular industry can emit if it is to achieve the desired emission-reduction goals. These regulations allow firms to convert the margin below their emission limit into an equivalent amount of "carbon credit" (Kenton, W. 2021) which can then be sold to another firm that requires carbon credits. A single carbon credit allows a firm to emit up to one metric ton of CO2. The funds generated from selling carbon credits is often used to finance environmental projects aimed at fighting climate change.

Several nations have adopted this carbon credit (i.e., emissions trading) system as part of the Kyoto Protocol treaty (1997), and it has since been ratified by several other governments (UNFCCC n.d.). The exchange of carbon credits establishes what is called a

"cap-and-trade" market, which heavily incentivises businesses to reduce their carbon footprint. Businesses whose carbon emission is below the limit can avoid financial penalties that would otherwise increase their overheads. Conforming businesses also make money by selling credits. For example, Tesla, the electric vehicle manufacturer, generated $518 million in revenue in the first quarter of 2021 from the sale of carbon credits alone.

As businesses try to come up with ways to reduce their emissions, they also need to showcase such efforts to sustainable investors (also called eco-investors or green investors). This results in “impact investing”, an investment approach where investors consider environmental and social impact alongside traditional investment considerations such as risk and liquidity. Investors and customers also increasingly prefer firms that make products with minimal carbon footprint, and product lineage and provenance matter a lot more for today’s consumers.

BLOCKCHAIN AS A SOLUTION TO SUPPLY CHAIN TRANSPARENCY ISSUES

These massive ecosystem changes have put increased pressure on firms to increase their focus on sustainability. In particular, it has become incumbent on sellers to track their products’ complex supply chains involving multiple manufacturers and institutions. However, with supply chains dispersed across multiple geographies and involving multiple institutions, it becomes an overwhelming practical challenge to ensure transparent recording and reporting of greenhouse gas emissions at each touchpoint in these complex supply chain networks.

To elucidate, in order to reduce the carbon footprint at each touchpoint, one has to calculate it first. But it becomes complicated to calculate the total carbon footprint of a product that is made up of different components manufactured by various manufacturers at different geographic locations. This often results due to a lack of robust data collection processes on carbon emission, implying that there is little reliable data that can be shared

within the multi-institution supply chain network. Eco-investors and customers therefore lack the information needed to credibly verify the provenance and carbon footprint of manufactured products. Moreover, there are no set standards to calculate emission impact and convert savings into carbon credits, with manufacturers in different geographic locations using different formulae. Finally, global carbon markets are at a nascent stage, and the regulatory framework is not robust enough to prevent unethical practices.

These multiple challenges call for a technology solution that can enhance supply chain transparency, help manage carbon assets, and enable all parties to obtain credible data on carbon emission. Here we propose a novel architecture that tightly integrates the carbon supply chain of a multi-institution business network with 'blockchain technology' as a potential solution to this conundrum (Felin and Lakhani, 2018; Klotz, 2018; Schiele et al. 2021). Our proposed architecture seeks to reduce carbon emissions in supply chains to decelerate climate change, at the same time ensuring compliance with government regulations. We also believe that this architecture would encourage green investments, promote environment-friendly products, and generally facilitate data-driven decisions with a sustainability orientation.

AN ILLUSTRATION: OPTIMISING THE CARBON SUPPLY CHAIN OF A BICYCLE MANUFACTURER

Consider a bicycle manufacturer that outsources brakes and tyres, two critical bicycle components. This is the usual scenario industries where independent manufacturers produce the various components. The tyre and brake manufacturers make their products at their respective facilities, and then send them to the final product manufacturer, which assembles these parts with the remaining components to deliver the final product (i.e., the bicycle). All three manufacturers emit a certain amount of CO2, and the carbon credit needs of each manufacturer (upon exceeding the limit) are met by an open marketplace.

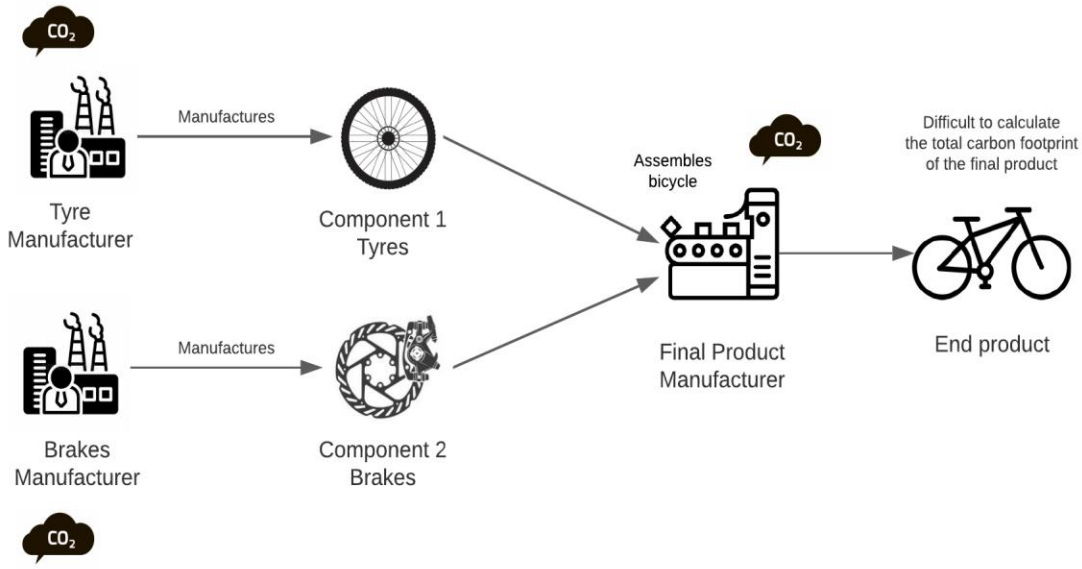

Figure 1: Carbon Footprint in a Traditional Supply Chain

Challenges in the traditional set-up

Since this process of manufacturing components is highly decoupled, it becomes difficult to calculate the total carbon footprint of the bicycle. The difficulty is both in terms of the effort required and the costs incurred. Keeping track of CO2 emissions associated with each product component across multiple manufacturers is usually very expensive. There is no centralised record that shows how much CO2 was emitted in the process of manufacturing a bicycle. As customers and investors increasingly demand supply chain transparency that gives them information about product provenance, and how much CO2 is being emitted at each stage, ensuring such transparency becomes a particular challenge for firms keen to cater to the needs of these green market participants.

What adds to the problem is the absence of common, verifiable standards that stipulate how carbon credits will be generated and verified. The bike and the tyre manufacturer might be using very different formulae to arrive at their emission records, and so there could be inconsistencies in the way carbon credit gets distributed to these two

entities. This calls for institutionalised standards for carbon credit generation that all parties can look up to as the expected norm. In our example, this will allow all three manufacturers (i.e., for the brakes, tyres, and the bicycle) to transact in carbon credits, which will need them to either generate and sell carbon credits, or buy credits to offset their exceeded limits, or even voluntarily buy more carbon credits.

Another challenge to seamless transacting in carbon credit markets is the prevalence of corruption (Bohm S. 2013). There have been instances of industry lobbies influencing the distribution of emission allowances and engaging in unwarranted carbon credit generation. These underhand practices affect both the supply and demand for carbon credits, and hence their price in the marketplace. This calls for greater accountability, transactions that are immutable, and a reliable record of credits that can be traced back to carbon credit creation. Additionally, global carbon markets are fragmented, and market-specific pricing data are usually not available, making it hard for businesses to know if they are paying a fair price for purchasing carbon credits (Blaufelder et al., 2021).

This is where the strength of Blockchain technology can be leveraged to provide a decentralised and distributed energy-tracking system.

BLOCKCHAIN TECHNOLOGY

Blockchain technology is one of the most popular choices for businesses as a solution that enhances supply chain transparency and traceability (Kraf and Zheng, 2021). With no single point of failure, it is a distributed database of transactions, records, and events. Data is stored in the form of immutable blocks being added to the blockchain. Each update on the blockchain is validated by a consensus algorithm, which is dependent on the nature of the blockchain. Businesses can use blockchain technology to re-engineer their carbon supply chains and revamp their carbon credit management platforms, and in turn be more environmentally responsible entities that are compliant with the emission regulations. With

blockchain, it is also possible to digitise physical assets in a supply chain and add an immutable block of information for every step the asset goes through in the supply chain, making it more visible to manufacturers, consumers and investors (Deloitte 2017).

Businesses generally use private/consortium blockchains, where all parties involved need permission to get on board, and the transactions are validated by a governing entity/entity. Detailed features of public, private and consortium blockchains are highlighted in Song et al. (2019). Blockchain enhances trust among the parties involved, as each validated update is immutable, and time stamped. Even if a fraudulent activity does occur in the supply chain, it can be traced back to its source using the blockchain trail. This plays a crucial role in a complex supply chain involving multiple parties and checkpoints, each of which is otherwise highly susceptible to counterfeit activity.

Furthermore, blockchain offers embedded features like smart contracts. Smart contracts are pieces of code integrated within the blockchain, that automatically trigger events upon the fulfilment of certain criteria (McGrath et al., 2021). Smart contracts can be programmed to constantly assess the progress of assets in the supply chain, update and add records onto the blockchain, automatically issue payments to the supplier upon successful delivery, raise exceptions when manual intervention is needed, and so on. This reduces administrative costs and enhances security as there is minimal human involvement.

But data in a blockchain exists only in the digital form, while physical assets flow through the supply chain. Internet-of-Things (IoT)-based telematics devices and smart sensors are widely used to acquire the relevant data from transport, machinery, etc. and increase the energy efficiency in a supply chain. IoT devices are increasingly helping many businesses' individual efforts to reduce their carbon footprint. Leading tech companies like Cisco and Fujitsu are developing industry-specific IoT-enabled tools that help drive energy efficiency. Blockchains can be made more robust by linking them to physical IoT devices and

smart sensors that constantly monitor the supply chain and unite the efforts of all parties on board in optimising the supply chain. For example, if an inventory item in the supply chain needs to be refrigerated, an IoT device can report to the blockchain if there is a temperature fluctuation. This would enable quicker response from the manufacturer, and other parties on the blockchain can also easily anticipate delays in supply of that item due to this event and react pre-emptively.

Finally, present-day industry blockchain solutions offer additional features such as user interfaces for data visualisation and governance tools. The IBM blockchain platform, for example, is an enterprise-ready integrated platform based on Hyperledger Fabric (a private blockchain), and is designed to aid the development, governance, and operation of a multi-institution business network (IBM n.d.). Adapting these solutions provides a user-friendly view to business users, investors, and customers. For example, sustainable fashion brand Covalent uses the IBM blockchain platform so that its customers can track the carbon footprint of the products that they buy.

PROPOSED SOLUTION: BLOCKCHAIN-ENABLED CARBON-TRACKING SYSTEM

Blockchain's distributed nature has the potential to improve governance and sustainability in support of collective action to combat climate change. In contrast to centralised networks, Blockchain precludes monopolistic control of the system. Transparency and traceability are also enhanced by the technology's open and permanent recording of transactions. To resolve supply chain challenges in tracking carbon emissions, we propose an *integrated, private, permissioned blockchain platform* that is built into the supply chain. This central ledger will transform the individual efforts of each manufacturer into a combined effort aimed at recording the overall carbon footprint reduction of the final product, while also increasing the visibility of the carbon supply chain. It will establish an ecosystem of the

multiple institutions involved and eliminate the need to go to an open marketplace to buy/sell carbon credits. The proposed architecture will have the following features:

1. IoT and standardised emission calculation

Each manufacturer will have IoT-based devices in place that drive energy efficiency at the manufacturer's level, and report emissions data to the central blockchain ledger in a cost-efficient manner. Manufacturers can also install point-source carbon capture devices that absorb the emitted carbon dioxide from the atmosphere at major sources of emissions like large-scale industrial plants (Metz et al. 2005). Sensors recording emissions from machinery, transportation etc. will send this data to the blockchain platform, where a standardised method for total emission calculation will be used. This will avoid inconsistencies that may arise among parties due to the absence of a standardised formula to calculate emissions. The digital equivalent of every ton of CO2 emitted by any of the parties onboard will be recorded

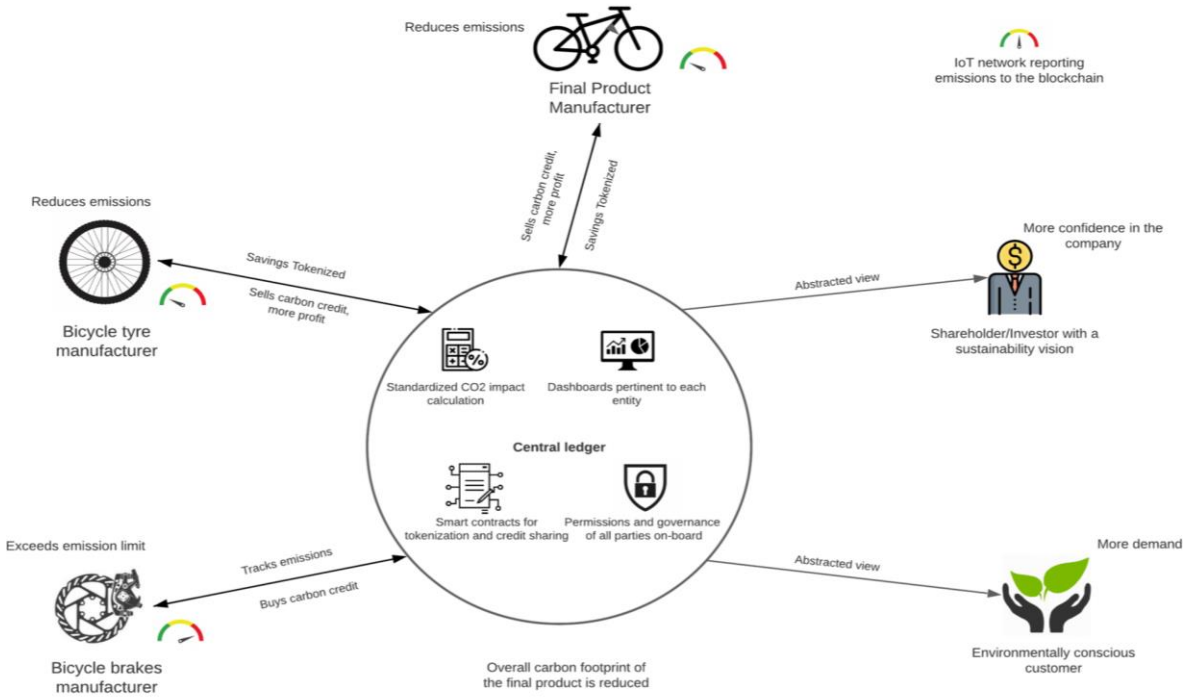

Figure 2: Central ledger for integrating blockchain into the carbon supply chain

on the blockchain. This is important, because to qualify for carbon credits, businesses will need a clear and robust record that traces back to the original emission source. For example, STRATO blockchain, an enterprise CO2 tracking solution by Blockapps, provides RESTful Application Programming Interfaces (APIs) to the businesses, which allows a direct connection of IoT devices to the blockchain network (BlockApps 2020).

2. Carbon credit generation, management, and sharing

All the member institutions will follow the same central ledger, and the process of carbon credit generation and sharing will be driven by smart contracts. If the tyres and final product (bicycle) manufacturers undertook measures to reduce CO2 emissions and managed to stay below the limit, their savings will be automatically tokenised into carbon credits which will be credited to their carbon credit wallets. In contrast, assuming the brakes manufacturer exceeded the emissions limit, it can buy these credits directly from the tyre manufacturer or the final product manufacturer, eliminating the need to go to a carbon marketplace/exchange. This precludes the many challenges that have been discussed earlier with respect to carbon marketplaces. This being a localised carbon marketplace, there will be more trust among the parties transacting, and less scope for unethical practices. Furthermore, the parties can easily negotiate a fair price, instead of being bound by the price monopoly of a carbon exchange platform. Finally, there will be no need to pay a transaction fee to a third party.

3. Dashboards and emission tracking

The central ledger will provide relevant dashboards and data visualisations to the parties on board that will allow them to pinpoint their major sources of emission, and accordingly take data-driven corrective actions. Although this feature can be implemented at the manufacturer's level, tracking emission data along with viewing carbon credit information (which will be available in real time at the central ledger) makes more sense from a business perspective. This will also enable sharing of a product's emission data across manufacturers

in the product supply chain, something that is essential to achieving the target carbon footprint reduction. The platform will also provide an abstracted view through which each entity will be able to view various information based on the nature and level of its authorisation.

4. A view for the customers and investors

The central ledger provides an unhindered view to environmentally and socially conscious customers and investors who seek details on the provenance and carbon footprint of the products. For example, customers can track how the manufacturing of their bicycle progresses along the supply chain and view the amount of CO2 emitted at each stage. This feature will enhance demand from customers interested in green products. Impact investors will also have more confidence in the venture if they get a similar view of the business. This will increase the ESG score of the business, potentially bringing in more investments.

5. Governance and security

For better integration, the central ledger will have administrative and governance capabilities, in addition to the already secure blockchain (due to its distributed and immutable nature). There will be a governing party which will decide who gets to be a part of the blockchain network, allow permissions, decide levels of abstraction for the different entities, and validate changes made by others. This is important in a private blockchain as it is not as secure as a public blockchain and is more susceptible to attacks. Bad actors in a private blockchain can endanger the entire network.

CONCLUSION

Blockchain is the foundation of the much anticipated “Web 3.0”: an internet built on the design principle of decentralised storage and computation of people’s data. While we are still far from this complete overhaul, one can look at our proposed architecture as an inspiration from the tenets of Web 3.0. With investments pouring into the decentralised

applications space, these technology solutions will become cheaper and economically more viable over time, along with the added benefit of setting the users free of any third-party entity governing the network.

Vechain, a Web 3.0 project focusing on using blockchain for supply chain, has already partnered with giants such as Shokay (the world's leading socially responsible yak fabric brand, and a partner of H&M) to verify products along their supply chain (VeChain, 2020). The proposed architecture provides a framework for businesses to integrate the future of sustainable solutions and the web into their supply chains. The constraints in implementing this solution lie in the installation of IoT devices keyed to the network, as technologies such as carbon capture and emission sensors are currently expensive and can only be economically viable at scale.

Achieving goals of the Paris Agreement will require businesses to embrace the pledges made by their respective nations not only to comply with government regulations, but because it is their corporate social responsibility. The emissions trading system incentivises businesses to take a step in this direction, but challenges such as emission tracking across manufacturers/suppliers, the lack of standardisation in emission calculation, and the fragmentation of carbon markets, make it difficult for businesses to effectively generate and manage their carbon assets. Integrating a central ledger system based on blockchain into the carbon supply chain will allow recording the chronological flow of supply chain carbon emissions, and eventually carbon assets.

Smart contracts will enable tokenisation and sharing of these assets. Additional capabilities like dashboards and emission-tracking user interfaces will enhance transparency, help the business users in making data-driven decisions, and instil confidence among customers and investors. All offerings will be complemented by a private blockchain's robust security and governance features that will enhance trust in a multi-institution business

network. These features make the proposed architecture a viable option for businesses looking to cope with the sustainability shift. Adapting sustainable solutions on a large scale serves the primary goal of helping us slowly reduce our emissions and buy time for us to figure out alternative energy sources that do not release greenhouse gases into the atmosphere. Making clean energy breakthroughs might take decades and till then we need to adapt our processes and practices to minimise environmental damage.

From a firm's perspective, integrating the proposed architecture into its supply chain is not only an environmentally conscious choice, but also a prudent business decision. It will help companies cope with the sustainability shift and cater to the emerging green market, raise greater investments from eco-investors, enhance revenues by optimising carbon asset management, and provide a transparent view of their supply chains. Efforts to reduce carbon footprint practices should also result in reduced operating costs for businesses, greater employee satisfaction, and a strengthening of the company brand (Center for Climate And Energy Solutions n.d). In the years to come, rather than being a choice, incorporation of sustainable supply chain practices will become a necessary condition for a corporation's survival.

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