EU Blockchain
Observatory and Forum

Blockchain for Supply Chain Transparency

About this report

This is the tenth of a series of reports that will be published addressing selected topics in accordance with European Commission priorities. The aim is to reflect on the latest trends and developments and discuss the future of blockchain in Europe and globally.

This report has been produced by the EU Blockchain Observatory and Forum Experts Panel and team.

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While we have done our best to incorporate the comments and suggestions of our contributors where appropriate and feasible, all mistakes and omissions are the sole responsibility of the authors of this report.

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Blockchain for Supply Chain Transparency

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Executive Summary

The supply chain is a complex sector with implications for everyday life that applies to a range of products. Generally, the supply chain is an environment where multiple stakeholders coordinate in order to bring products to consumers, and it is not an environment that is stable without any changes. Philosophies change to include new-found requirements and needs, as in the case of the shift from "Just In Time" to "Just In Case". In this environment, works define transparency and the ways to achieve it throughout the supply chain.

The first Chapter of the report details the problems in the supply chain to address and the ways to achieve transparency. As events indicated the value of transparency, legislators take a step toward regulating the way to achieve it. The first chapter concludes with regulations from Europe and around the world on supply chain transparency.

The second chapter stresses the ongoing changes in supply chain management and ethics, including working conditions, environmental issues, and extended supply chains. While local clusters exist for coordination, they differ from globally dispersed suppliers who lean on monitoring mechanisms and the underlying sustainability standards. Firms impose standards in their supply chain to protect their branding reputation. The chapter establishes that transparency requires traceability, and blockchain can be a tool to automate the process. The reasons decoupled within the chapter are the tendency to conceal information, costs of transactions, green-washing, and more reasons for establishing traceability. As blockchain is a reasonable solution for traceability, it is important to focus on the issue of data quality. Using external sources with oracles can ameliorate the phenomena of 'garbage in, garbage out'. Blockchain can incentivise users to share data as digital tokens can retribute the users' efforts.

Readers can be acquainted with specific use cases in the third chapter. The Green Deal is to overhaul sectors to become greener, and policy instruments are in place to lead Europe to a more environmentally friendly future. Blockchain is a fundamental component for establishing platforms in carbon markets where traceability for certificates and transactions needs to occur. Changes in the carbon market can impact supply chains as they can adopt changes to become greener and relieve the environmental pressure. There are applications in production, like sustainable data from the collaboration of the World Economic Forum (WEF). Despite the technologies and updates, governance structures addressing the novel needs and aligning to principles and values are impermanent for the success of blockchain applications. In essence, sustainability requires the creation of a collaborative environment and a clear distinction between governance and management. Governance can be based on real-time data establishing transparency. MRV is an important aspect to consider for using blockchain as options for deploying applications on public and private networks. Moving away from one-dimensional measures of TPS and transactional costs, there are more things to account for. While private and consortium blockchains deal with some public blockchain issues, governance issues rise to jeopardise the consortium's continuum. Public blockchains continue to evolve, and layer-2 solutions can enhance MRV and deliver reports with measures. The improvements to the blockchain leave room for meshing with other technologies like IoT and networks, as blockchain can be a trusted layer for the network's participants. Finally, interoperability between blockchains is in its infant phase, and the predominant solution of bridges (decentralised) has to deal with security issues. Finally, the third chapter concludes with the zero trust journey. There are many technologies offering advancements for the supply chain in addressing weaknesses or offering new capabilities. The recent pandemic indicated all the weaknesses and novel regulations that might be needed for the supply chain. The regulations' success depends on considering the factors of people, processes, and products. Zero trust solutions based on blockchain apply to the supply chain sector as they are industry agnostic.

The fourth chapter aims to promote awareness to the readers about the existing market blockchain solutions as examples taken from real-life. As collaboration and trust between parties are a requirement for the supply chain, the applications of warehouses from the carbon industry are similar projects to review with the likes of the Warehouse, World Bank's Chia, and Carbon Opportunities Fund. The examples are divided into a regional approach, and Africa's cases include affordable energy and carbon emissions. The supply chain project's stakeholders are African Clean Energy, CLINK.earth, and Cartesi. Apart from regional projects, there are worldwide projects based on consortiums and technologies like Hyperledger. Hyperledger solutions facilitate the networks' creation, abstract the identities creations, and offer ways to establish communication. Projects use Hyperledger solutions to deliver environmental services (Climate Action and Accounting, Supply Chain and Trade Finance Special Interest Group), food chain traceability (IBM Food Trust Platform), and traceability in minerals (Rwanda's tantalum, MineHub). The chapter focuses on one of the most notable use cases, IBM Food Trust. Tracing the food supply chain has benefits like reduced waste, faster recalls, and monitoring of expiry date. Traceability can expand further from products and their course, as blockchain can assist cargo management. Documents and other information accompany the cargo through its journey worldwide. The blockchain-based platform, Tradelens, is a solution for automating and decentralising cargo management with partners like Maersk and IBM partaking in the project. Other blockchain-based projects with social impact are Botanical Water Technologies and Aqualedger detailed in the fourth chapter. Finally, obfuscating information is valuable for a blockchain solution for delivering privacy, like the example of True Code.

Chapter 1: Introduction

Section 1.1: Guidance Framework

The supply chain is a complex network of interconnected individuals and companies collaborating with each other in sequential steps to create and deliver products to their customers. The network's complexity increases once globalisation is taken into consideration, as cross-border transactions are common. Additionally, the imperative for achieving uninterrupted supply chain operations cannot be stressed enough. The baseline of the supply chain has changed from 'Just in Time' to 'Just in Case'. Unexpected events may occur, disturbing supply and demand, like the recent COVID-19 disruption, where the demand for healthcare products increased significantly while global trading halted.

For this reason, supply chain management aims to harmonise all the processes, considering the needs of enterprises and customers for the timely delivery of quality products. The goal of supply chain management is to improve the efficiency of existing systems and handle the risks of various events. Information is at the core of every process developed for supply chain management, as decisions and plans are based on accurate and constantly updated information. In this context, the trustworthiness and validity of information become a requirement for building systems within the supply chain.

Supply chain systems extend beyond just storing and keeping information to incorporating channels enabling the information flow. Numerous stakeholders partake in the supply chain, as raw materials start on a journey on which they are processed to finally be integrated into a product to be shipped to customers. Information flows at each step in the chain towards different organisations and requires that efficient and timely communication channels are in place. Moreover, data silos can occur because organisations have to follow business and legal requirements for maintaining their data (safe data storage). Essentially, instances of data duplicated in different databases accessed by individual entities are a case of data silos. A solution is to share information between the numerous stakeholders of a supply chain, making information visible to external users outside of a single entity.

In this complex environment, the role of information and its trustworthiness is backed by the growing trends impacting the supply chain and related activities. Regulations impact the supply chain; regulations are introduced as a means of avoiding past events or impacting future actions. For instance, the Green Deal and Farm to Fork strategy look at the sustainability of the supply chain. Additionally, the supply chain cannot ignore consumers, as they organise in foundations and require information on which to base their decisions. For example, EIT Food[1] includes climate decision-making for consumers. All in all, transparency is a foundational aspect of supply chain management, as it can measure and evaluate information reliability (Ada et al[2]).

The *Harvard Business Review*[3] defines transparency as the requirement for companies to be informed on the supply chain's upstream activities and communicate these details internally and externally. Two elements are essential for achieving transparency according to MIT's Alexis Bateman[4]:visibility and disclosure. Visibility is about accurately identifying and gathering data from all the stakeholders in a supply chain, while disclosure is about communicating the details gathered. According to Ada et al., higher levels of cooperation, collaboration, and coordination (3C) are achievable through information sharing. To reap the benefits of supply chain transparency, frameworks defining actions are suggested throughout the literature.

A handful of works suggest a well-defined path for achieving transparency in the supply chain (*Harvard Business Review*, Deloitte[5], Germany's Ministry for the Environment[6][IP6]). The frameworks can vary in the number of steps, as some suggestions can be more detailed, but the frameworks generally follow a similar pattern. As a first step, information on the environment is necessary to map the supply chain, as transparency involves the whole upstream, and organisations have to have a good grasp of it. In the following step, there is analysis to incorporate the range of risks on the basis of each organisation's global presence, operations, and products. Risks need to be identified and allocated a score while drafting the framework. The score given to each risk can come from a scorecard of multiple factors, like the severity of the impact, how probable it is that the risk will be realised, the risks involved with the internal processes the products undergo, and general risks in the supply chain. It is common to accompany risks with an action plan to mitigate their impact.

Another step advised for organisations to take in drafting a framework involves visualising the chain. There are interrelations with other companies, and there are cases where vendors have to abide by standards set by companies they cooperate with. Companies acknowledge that events in the supply chain can affect their operations, so they seek ways to be proactive. The fourth step is to measure the performance of the transparency and act to close information gaps. Suggesting key performance indicators is a logical route for assessing suppliers' due diligence. Suppliers' data are integral for delivering value for the indicators. Finally, it is usual for frameworks to encourage an ongoing loop to enhance transparency. While indicators can document the progression of the suppliers, risks can arise without warning. Moreover, ethics in the supply chain can be improved along with standards guiding expected behaviour. With that in mind, a loop with accurate feedback can lead to amendments to frameworks, expressing the ever-changing environment.

Software applications and systems complement the drafted frameworks, as they are the encoded representation of the transparency frameworks. Developers are tasked with digitalising and automating the transparency framework using technology. Lately, blockchain has gained traction as the base for supply chain applications, such as Tradelens[7], which are deployed and improved in the field. Additionally, security is a crucial part of software applications, as demonstrated by NIST[8] and NCSC[9]. Information is stored in digital forms, mandating the creation of tools to maintain their security and privacy. Blockchain features can assist the supply chain in achieving transparency and allow it to share information securely among multiple stakeholders.

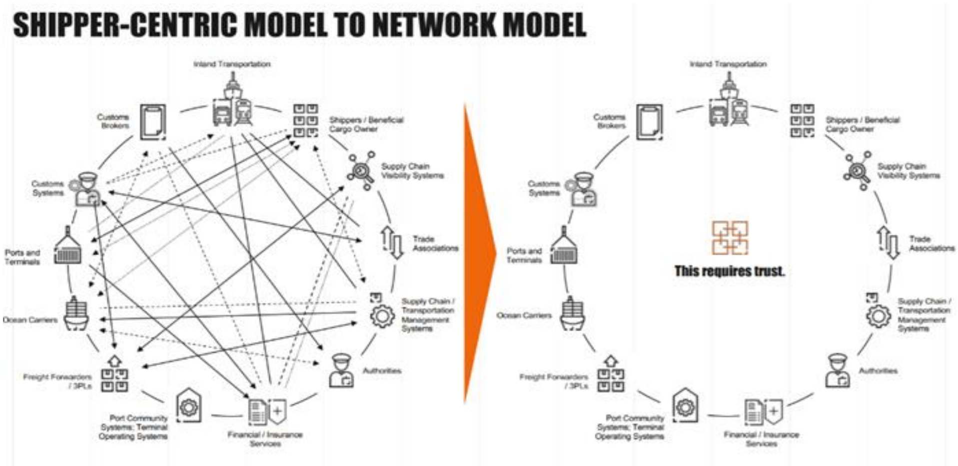

Figure 1: Traditional Vs Blockchain Supply Chain[10]

Section 1.2: Social Elements

The previous section focused on frameworks for organisations to achieve transparency in the supply chain which introduced blockchain as a technology to use. Apart from information flows, there are events which have a social impact on the supply chain. Originally, supply chain tools focused on environmental risks, as described in Deloitte's report[11]. Supply chain tools have expanded to cater for social and governance factors.

Social concerns

Initially, the legal concern focused on the workers' health and involved minimal requirements in procedures and equipment for workers. As legislation built up to provide guidance on workers' health, other issues emerged, such as workers' dignity and slavery. Essentially, ‘modern slavery’ encompasses[12] legal concepts of forced labour and other linked concepts like human trafficking. The complexity of the supply chain can conceal the issue, with organisations exploiting employees at any step of the chain. The United Nations have published guiding principles[13] on business and human rights. These efforts have expanded to national legislation as countries introduce regulations to prevent modern slavery.

One of the first regulations on modern slavery came from California, where the California Transparency in Supply Chains Act[14] (CTSCA) was introduced in 2010. The Act[15] requires companies to disclose information about the potential for modern slavery, without burdening them with additional efforts. Subject to the regulation are retailers and manufacturers with activities in the state of California.

The UK introduced the Modern Slavery Act[16], which came into force on 29 October 2015. The Act includes various sections, ranging from the definition of the offences and their penalties to prevention orders and maritime enforcement. Section 54 of the Act, ‘Transparency in Supply Chains’, impacts organisations, as it requires them to issue statements[17] on slavery and human trafficking. The section includes statement reports that include policies, due diligence, risk assessment, performance indicators, and training for supply chain transparency.

There are more European countries taking steps to regulate unethical labour practices. An example is the Supply Chain Due Diligence Act[18] from Germany, which aims to safeguard human rights along with the environment. The Act covers[19] risks and scenarios involving violation of basic human rights and environmental laws. Compliance with the Act[20] requires the establishment of a risk management system, definition of internal responsibility, regular risk analysis, issuance of a policy statement, planning remedial action, and more, as described in the Act's summary. Another country with an established regulatory framework for transparency is Norway, as the Transparency Act[21] became effective in 2022 and covers respect of human rights and good working conditions. A unique feature of the Act[22] is the right to request information; any member of the public, with examples being trade unions and NGOs, can request information about a company's actions for due diligence.

There are regulations worldwide on modern slavery, like Australia's anti-slavery law[23]. Additionally, there are directives on specific matters of modern slavery in Europe. The European Directive on trafficking[24] introduces measures to prohibit trafficking and protect victims. In 2003, the United Nations[25] included trafficking in a protocol on organised crime.

Is blockchain the solution?

Blockchain offers complete and full transparency of data related to the supply chain activities, i.e. blockchains are tamper-proof databases, creating digital ledgers for every single transaction, publicly accessible to everyone and with no centralised controller. This allows automated tracking of all steps within the process, leading to full transparency and no room for unlawful business practices.

There are currently several countries across the world that have initiated the implementation of technology to ensure better transparency on their day to day operations within the supply chains. On the other hand, consumers are also very much interested in contributing to end forced labour, and thus demand more transparency in the companies’ practices.[26]

Below there are some examples highlighting how blockchain can improve transparency and help combat forced labour:

Example 1: In some situations, workers from developing countries do not have an official identity document, which makes it more difficult to track their movement. Biometric information such as fingerprint and iris scans create a virtual identity for workers and eliminates the need for paper documentation. As a result, the reliance on paper documentation and the confiscation of identity would no longer be a means of control. Traditional paper contracts can easily be changed during the transportation process, especially for overseas employees. Blockchain technology could prevent changes such as lower wages than promised or additional fees and work hours. The partnership between the private industry and the non-profit sector could create solutions to this problem. For example, the cooperation of the tuna fishing and processing company **Sea Quest Fiji** with **World Wildlife Foundation**, technology company **ConsenSys**, and technology implementer TraSeable Solutions in Fiji in 2018, resulted in the launch of a pilot project. The goal of the project is to track supply chain management, prevent slave labor, and eradicate illegal fishing. The project uses QR codes to track products on the blockchain. Scanning a can of tuna packaging using a smartphone app shows the journey of the tuna fish, where and when the fish was caught and by which vessel and fishing method. The technology also enables the end user to scan a QR code by using a smartphone app which will tell the story of the tuna fish, such as where and when the fish was caught, and by which vessel and fishing method. Therefore, the consumer can verify the fish they are consuming was legitimately sourced.

Example 2: This refers to the project undertaken by **Diginex** and **The Mekong Club**, and is a cooperation between the private and public sectors to fight forced labor; Diginex is a global blockchain solutions company and The Mekong Club is an anti-slavery nongovernmental organization (NGO). These two have joined forces with data analytics platform Verifik8 to pilot a blockchain-based app called eMin, which has been piloted in Thailand, Malaysia, and Bahrain. The eMin app allows for copies of employment contracts stored on the blockchain and workers can access a secure copy of their contract at any time, bringing transparency to the recruitment process. Companies are also able to audit their supply chains easily, with the comfort of knowing the information is immutable. The eMin app is designed to take a significant step toward improving the lives of migrant workers and to reduce the chances of exploitation, by engaging both the private and public sectors. Over time, the eMin app has turned into a comprehensive management system, complete with functions for securing all documentation using blockchain, beyond the employment contract, as well as grievance management. The Mekong Club promotes the eMin app with companies across different industries in order to include more factories and locations. Matt Friedman, CEO of The Mekong Club, said, “eMin improves the lives of migrant workers, to give them secure access to their documentation, but also is being used to identify issues that otherwise may not have been picked up.”[27]

Challenges

As discussed above, blockchain allows corporate stakeholders to have control and to verify transactions and working conditions in supply chains. Still, to ensure full transparency of the labour conditions, it is necessary to verify transactions throughout the supply chain; the challenge lies on whether there is alignment or conflict on the needs of companies and workers, as per their understanding of what is to be considered “common good”.

Another important point to be taken into consideration is the ability or capacity of workers to actually participated in the blockchain. If access is not possible for all, this would create doubts on the legitimacy of the validation process (this could be due to lack of digital skills, lack of resources, etc.) and would create further divides between the workers.

Finally, the importance of data quality should be stressed; monitoring working conditions' related data and information can be quite challenging and complex. This type of data can be included in the blockchain, but it brings forth a number of privacy issues.

Ethical blockchain solutions offer increased transparency and help eliminate modern slavery and forced labour, but cannot be perceived as the single solution to this very challenging issue.[28]

Chapter 2: Challenges

Section 2.1: Global Challenges in Global Supply Chains

"Supply chain management (SCM) has evolved since the beginning of the 1990s into a coherent body of literature concerning inter-firm relationships. A variety of terms have been used to describe interconnected firms in a productive system, such as 'supply chains', 'supply pipelines' and 'value streams', but the term 'SCM' became the most prevalent" (Burgess et al., 2006). The most commonly used definition of SCM is the one provided by Mentzer et al (2001, p. 18):

> *'The systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole'.*

If 'long-term performance' originally only meant 'long-term *economic* performance', society is increasingly calling for sustainability to be the broader lens through which the performance goals of a firm should be viewed (Carter & Easton, 2011; Gold et al., 2009). Society's understanding of what it means to incorporate sustainability into SCM has led to pressures from multiple stakeholders regarding a diverse range of issues covering decent working conditions, resource consumption, and the carbon footprint of the firms' operations and extended supply chain. As a response, firms have engaged with suppliers, working together to improve sustainability performance (Theißen et al., 2014).

Bilateral projects evolved into multilateral mechanisms in local clusters, for example (Bourlakis et al., 2014a; Meehan & Bryde, 2014). In such clusters, competitors may join efforts to advance sustainability within their practices, which is referred to as co-opetition (Pathak et al., 2014). However, global supply chains differ from local clusters. In order to avoid the risk of reputational damage, buying firms are faced with the challenge of ensuring that their globally dispersed suppliers comply with corporate codes of conduct while preventing environmental and social misconduct at the supplier's premises (Reuter et al., 2010).

When engaging with globally dispersed suppliers, buying firms have favoured monitoring mechanisms to check on suppliers' compliance with selected sustainability standards rather than costly collaboration mechanisms (Delmas & Montiel, 2009; Hoejmose et al., 2012; Lim & Phillips, 2008). Monitoring mechanisms usually include the definition of sustainability standards, the adoption of tracking systems to oversee suppliers' adoption and evaluation routines. They can include penalties for non-compliance (Simpson et al., 2007). Global buying firms such as Nike and McDonald's have explored marketing campaigns based on monitoring programmes and the increased traceability of supply sources (Lim & Phillips, 2008).

Frequently, monitoring mechanisms are accompanied by the buying firm's imposition of standards and targets. Moreover, in most cases, sustainability standards are defined by large buying firms in developed countries, and enforced on suppliers from emerging countries (Turker & Altuntas, 2014). As a result, suppliers often resist adopting the imposed standards (Delmas & Montiel, 2009). Suppliers further upstream in supply networks are even more resistant to the adoption of SSCM practices, as they are less visible to the end-consumers (Hoejmose et al., 2014). In order to expand monitoring mechanisms globally, buying firms have often adopted indirect or third-party solutions (diagonal monitoring) to manage suppliers beyond the first tier (Tachizawa & Wong, 2014). However, even third-party monitoring has proven an incomplete solution, as shown by the example of the Nike case. Throughout the 1990s, Nike's efforts to improve its sustainability image on the basis of third-party monitoring were unsuccessful and only increased public criticism. From the 2000s, after a shift towards a collaborative paradigm, results started to appear, and public pressure diminished (Lim & Phillips, 2008). Hence, while sustainability standards may be easy to draft, supplier compliance with these standards has been elusive (Asif, 2020). The increasing global dispersion of the supply chains has made traditional monitoring mechanisms ineffective.

As public scrutiny sharpens, and global scandals surface, firms struggle to communicate ways in which they differ from one another, and transparency emerges as a goal as important as sustainability in itself. In other words, it is nowhere near enough just to change practices and address sustainability issues, it is now crucial to communicate these changes effectively.

Section 2.2: The Urgency (or Imperative) for Supply Chain Transparency

Transparency is a messy concept and difficult to frame, so identifying its core elements can be useful. Fung (2013) emphasises that transparency is democratic when it allows consumers (and other stakeholders) to act (such as deciding whether to buy a product or not). Young consumers in particular are engaged in responsible consumption, and many would stop buying from companies if they found out that it was involved in scandals. However, transparency is seen by firms as a balance between risks and opportunities. Adding to that perspective, Albu & Flyverbom (2019) contrast the process of developing transparency – defined as managing the tensions emerging from increasing transparency – and the outcome of transparency itself i.e., the quantity, frequency and quality of the information disclosed. A recent report by the Clean Clothes Campaign (2020) has summarised allegations made by fashion brands to justify their lack of transparency: the competitive advantage that results from the confidentiality of purchasing strategies and their list of suppliers and lack of information from intermediaries that manage sub-suppliers. Therefore, in a globally dispersed business environment, transparency is strongly linked to supply chain transparency.

Supply chain transparency refers to the disclosure of information related to the firm's supply chain. Marshall et al (2016) classify the type of information disclosed: supplier membership, provenance of materials, social information, and environmental information. Supplier membership and provenance account for data on suppliers' names, addresses, and the traceability of raw materials. These two dimensions aim to avoid a decoupling between brands and their suppliers, as well as products coming from dubious origins – examples include diamonds and salmon, among others. The other two dimensions comprise social issues (labour conditions, engagement with community) and environmental issues (water, energy, carbon, biodiversity, etc). Therefore, enhancing supply chain transparency often implies extra costs as firms need to monitor their suppliers and collect data regarding their social and environmental impacts (Marshall et al., 2016). Egels-Zandén et al (2015) adds a higher layer of transparency, going beyond traceability (membership and provenance) and sustainability (socio-environmental performance), calling for the disclosure of the buying firm's own purchasing practices. Supply chain transparency therefore also includes disclosing purchasing policy and the conditions imposed on suppliers to conduct their work.

Supply chain transparency is, in conclusion, associated with high transaction costs, i.e., the costs of negotiating, implementing, and monitoring a buying firm's supply contracts (Emery & Marques, 2011). Transaction costs are driven by bounded rationality and opportunism. The former assumes that cognitive competence is a limited resource, so transactions that make large demands of cognitive capacity will tend to be costly and all contracts will be incomplete (Williamson, 2008). The latter assumes that economic actors in pursuit of their self-interest may engage in incomplete or distorted disclosure of information (McIvor, 2009). Transaction costs are barriers to market governance. 'If individuals never engaged in opportunistic behaviour, then the market would suffice for the mediation of all transactions, including those characterised by uncertainty, frequency, and asset specificity' (Lumineau & Oliveira, 2020, p. 74). Therefore, buying firms tend to be attracted by either developing a secrecy strategy, or to look for alternatives such as those offered by new technology that can alleviate transaction costs.

If transaction costs associated with supply chain transparency are too high, stakeholder pressure may actually support a decoupling between policy and practices, as firms justify inaction due to excessively high investments. This means that firms may engage in greenwashing strategies, declaring policies that are not applied in actual practices. Firms eventually respond by including 'buffering' their supply chain practices and protecting them from exposure and outside inspection (Bromley & Powell, 2012). More specifically, multi-sourcing and the development of a multitier supply chain may actually be used as a strategy to conceal misconduct (Kim, Wagner, & Colicchia, 2019). Additional challenges emerge from varied socio-political contexts. For example, firms operating in the Global South face an unstable institutional environment (Silvestre, 2015) and institutional voids, where weak regulations de-incentivise the adoption of sustainable practices or increased supply chain transparency (Marques et al., 2021a).

Conversely, if technology can offer a path to increasing traceability and supply chain transparency while easing associated transaction costs, firms may see value in investing in such technologies. Transparency starts with traceability. Blockchain has promised a scalable traceability system that can enact transparency in global supply chains while reducing transaction costs or even eliminating them completely (Saberi et al.,2019). If blockchain can support secure, reliable and scalable traceability, ensuring procedural justice, we might see the emergence of decentralised and self-organised globally dispersed supply networks (Marques et al 2020) that will offer the supply chain transparency that society currently expects from firms.

Section 2.3: External Data Layers in Blockchain-Based Supply Chain Management

One of the most widely recognised challenges for the wide adoption of blockchain platforms in supply chain management is related to the availability of data that supports supply chain traceability and transparency claims. This challenge can be described in short as 'garbage in, garbage out' – if inaccurate data is entered into the blockchain platform, it will be maintained and propagated in the system.

This is why a reliable external data layer, or a single source of truth in physical supply chains, is critical for providing objective, accurate, and up-to-date data. The function of this data layer is to represent the origin and movement of goods and services or parts and components in manufacturing, which can be verified across different interoperable digital sensor networks (i.e. internet of things (IoT) sensors, data from enterprise resource management platforms (ERP) and tools, remote sensing, and other technologies designed to gather near real time data from supply chain sites, which are often in remote and inaccessible locations).

The ISO reference architecture for DLT platforms specifies this as an 'external data layer' to be provided by dedicated external interfaces linking the DLT systems with external 'non-DLT systems' via APIs. These external data systems are often referred to as 'oracles' or 'off-Ledger data'. Their role is to provide a verified reference layer reflecting the real supply chain events – for example, production or manufacturing data, millions of data points about concessions and production sites, data from suppliers, ownership information, supplier linkages, certification status, data resulting from product processing, distribution, and/or retailing to the customer, and so on. This 'external data layer' is one of the foundations of a record of factual production data and events that happen outside the 'digital" ledger'.

From a data point perspective, the data about these events usually come from another system: an internal web service API, IoT device, ERP system, earth observation sensors, etc. Blockchain usually comes in as a solution that allows different 'master' databases to connect and share data across multiple global partner networks, stimulating transparency, traceability, and efficiency. This mass-participation, sharing and adoption is a key requirement – blockchain solutions usually fail if not all suppliers in the chain want to participate, share, and coordinate their SC databases.

Moreover, it is essential to ensure the trustworthiness of the sources of this 'external data layer'. Trustworthiness of external sources can be both a technical and a non-technical issue. Technically speaking, the use of blockchain is solves the problem of trustworthiness of data because recording something in the ledger creates a 'provenance trail' – the ability to track the entire lifecycle of goods or services in the supply chain. Registration on blockchain can also protect data 'at rest' and 'in motion' by assigning them unique identifiers to demonstrate that data recorded inside the digitally distributed ledger was not leaked or tampered with.

However, data that originally enter the chain have to – first and foremost – accurately reflect 'the real world' on the ground, and this is where a big challenge lies for the actors in the supply chain. Their master dataset quality has to be sufficiently high or objectively verifiable to be 'trusted'. Blockchain protocols alone are not designed to validate any information that enters the chain as being legitimate, valid, or accurate. Blockchain function is to provide a network of computers/processors (peer-to-peer nodes) that organises data in a way that the recorded information exists in multiple copies and cannot be altered without a consensus of participating nodes. Token-engineering can be used to create incentives for higher quality of data to be reflected in the chain, in reality, however, even though blockchains have been promoted as 'trustless' systems, a trusted third party is always needed between the 'external data source' and the DLT network. In other words, while the blockchain system's main function is to protect information as it moves through the supply chain, possibly triggering smart contracts and value exchange, third party services are necessary to ensure that the external information is correctly assigned to the digital identity of the event owner. This can add a new potential point of failure, but it also exemplifies that all DLT systems inherently require convergence with other systems as a part of a larger IT supply chain infrastructure implementation.

In this sense, there will be different 'data supply' issues for different dimensions of supply chain transparency, ranging from information about supplier origin, provenance of materials to social information and environmental information. Some of this external data and information is easier to obtain and verify than others. For example, it may be very difficult to obtain specific and localised information about social issues (i.e., labour conditions, child-free labour etc.) without on-the-ground intelligence and reporting. Such working conditions surveys can be expensive or even impossible, in particular if information about the physical environment, work intensity, working time quality, the social environment, or earnings is collected in different countries, under different legislation, or even using different methodologies. Today, however, there is a much easier way to obtain information on supply chain environmental issues (water, land use, biodiversity, GHG emissions etc.) as we have an unprecedented number of independent observations available. They could be utilised as one of the 'low hanging fruits' in supply chain transparency in general, and a cornerstone in solving the data quality problem in blockchain-based supply chain solutions.

In the long run, and for massive adoption, it is essential to base supply chain environmental monitoring on open, publicly funded, data sets. This can and should become a common denominator for all systems requiring that environmental sustainability information is acquired, objectively verified, and recorded on the blockchain networks.

Such data sets and information layers are provided today by global satellite earth observation systems such as Landsat, MODIS, and specifically by the European Sentinel satellites as part of the EU-ESA Copernicus programme. Taken together, they will ensure data availability for at least the next 15 years, at a constant, predictable price (namely free) while having a super persistency of observations (observations close to once a day) and the spatial and temporal (cloud penetrating radar) resolution to detect several key sustainability indicators that are emerging for European and global supply chains. This in particular pertains to sectors such as agricultural supply chains, which are at the top of the EU's priority list regarding corporate due diligence. They aim to achieve certain policy objectives, such as deforestation-free commodities (soy, beef, coffee, etc.), sustainable fisheries, or 'fair trade' support to smallholder farmers. But this capability to objectively and systematically monitor environmental conditions associated with supply chain operations extends to all industries that rely on the use of natural resource extraction: from extractives and mining to cement production, and pulp and paper.

Nevertheless, some sectors of the economy will be taking up traceability solutions faster than others. One such sector is agricultural commodities (so called farm-to-fork). This is for several reasons. The flow of agricultural commodities has long been subject to control, regulations, and different sustainability checks. Today, there is an increasing need to track food from the source to the end stages of consumer outlets, primarily in order to ensure the safety and quality of the produce and to ensure environmental sustainability. For that, information about production, where it originated, how it has been handled, processed, treated, maintained, etc., can shed important light on what its real value is and how the value is added and revenue distributed.

Chapter 3: Can Blockchain Provide Solutions?

Section 3.1: Why Blockchain?

The EU has set up high ambitions in aiming to transform itself into a low-carbon economy by mid-century. This will require an overhaul of the European economy, affecting a range of sectors, from power generation, industry, and transport, to agriculture, construction or finance. To assist in this massive transformation process, several climate policy instruments have or are in the process of being implemented to stimulate the necessary innovations and investments ensure buy-in from stakeholders – both public and private – and change market and consumer behaviour. The European Green Deal, adopted on 20 January 2020 by the European Parliament, is the linchpin of the EU climate strategy, aiming to make Europe carbon-free by 2050, without undermining its economic competitiveness, mobilising a budget of EUR 1 trillion for investment in the green transition, with a focus on energy, industry, building, mobility, and food. The plan also has provisions to assist with the negative effects of disinvestment from carbon emissions heavy economic activity and help people whose livelihood has been adversely affected by the green transition. According to a survey of the European Council of Foreign Relations (ECFR), there is strong support from the business community for the European Green Deal in at least 17 countries, as they see new economic opportunities in the green transition, as well as by state-owned enterprises.

This foundational confirmation process is also aided by a series of other supporting policy instruments, namely:

1. the **EU Taxonomy of Sustainable Finance**, a classification system intended to provide companies, investors and policymakers with appropriate definitions for which economic activities can be considered environmentally sustainable and thus help guide investments towards the implementation of the Green Deal and protect private investors from greenwashing.

2. the **European Carbon Border Adjustment Mechanism (CBAM)**: adopted by the EC in July 2021, is a policy that aims to prevent 'carbon leakage', the offshoring of energy-intensive industry to countries with lower ambitions for emissions reductions or the substitution of EU products with more carbon-intensive imports. Both would cause the EU to miss its goal to reduce global emissions and simply move them from Europe to other parts of the world, while also hurting the competitiveness of European economies. The purpose of the CBAM is to ensure that the price of imports reflects their carbon content, so that foreign products that are nominally cheaper but more carbon-intensive compete on a level playing field, and so that the EU's international partners have incentives to pursue similarly ambitious climate action. The initiative is the first to address explicitly industry emissions in third countries, rather than emissions only from industries within the EU and therefore bring into play the importance of Scope 3 emissions and sustainable supply chain management.

3. **Directive on Corporate Sustainability Due Diligence (CSDD)**: the Commission adopted a proposal for a Directive on corporate sustainability due diligence, aiming to foster sustainable and responsible corporate behaviour. It establishes a corporate due diligence duty (Articles 5-11) and involves identifying, ending, preventing, mitigating, and accounting for negative human rights and environmental impacts in the company's own operations, their subsidiaries, and their value chains. Directors also have a duty of setting up and overseeing the implementation of the due diligence processes and integrating due diligence into the corporate strategy. Corporate due diligence duty applies to certain large EU and non-EU (but active in the EU) companies (Article 2).

The ensemble of these policy instruments is intended to guide and bolster the massive transformation process targeted by the European Green Deal in attaining a carbon free Europe by 2050, by aligning resources and incentives and conditioning the behaviour of economic actors.

Blockchain re-purposed: How to support the Creation of More Transparent Carbon Markets

Despite these climate strategies, international protocols and agreements, and progress in controlling and lowering global GHG emissions is slow. The mitigation plans have been less than effective and private companies and governments alike decry the lack of cost-effective tools in monitoring and evaluating progress. Current measurement, recording, and verification (MRV) systems provide static feedback regarding the performance of the underlying productive activity and are often considered less than trustworthy in terms of verifying the veracity of the due diligence process and therefore an unreliable source for participation in carbon credit markets.

Given the exponential growth in volume of global carbon markets (more than EUR 750 billion in transactions in 2021 for the compliance mandated markets, with Europe accounting for the bulk of those markets), the issue of efficient management of carbon credits and their associated markets is critical. Voluntary credit markets (VCMs), created by independent actors for corporations and institutions to purchase credits for offsets, were relatively small at EUR 1 billion in 2021, but are expected to grow very fast over the next decade. Presently, they are still surrounded by a high degree of uncertainty, limiting their further adoption. Carbon credit scams, poor MRVs, and non-transparent trading practices have compounded the reticence of economic participants and prevented a greater scale up of markets. Measuring carbon emission reductions and effective carbon traceability is key, hence the need for robust VRM systems to ensure the credits can be easily identifiable to regulators.

Here is where blockchain technology can play an important role. As both mandatory and voluntary compliance markets evolve, there is a need for a reliable, trusted platform to which market participants can have access to manage credit origination and trading activity and to provide assurances for accuracy and authenticity. It must be able to track every credit certificate from the day it is created to the day it is retired and provide a record of ownership during its life. VCMs are a space for emerging innovation with new business models, decentralised autonomous organisations (DAOs) and tokenised emission credits.

Blockchain-enabled MRV systems can provide a trusted, cost-efficient, transparent registry where the custody of data travelling through the value chains can be 'verified in real time between network participants and jurisdictional authorities' due to blockchain's immutable, tamper-proof, distributed characteristics.

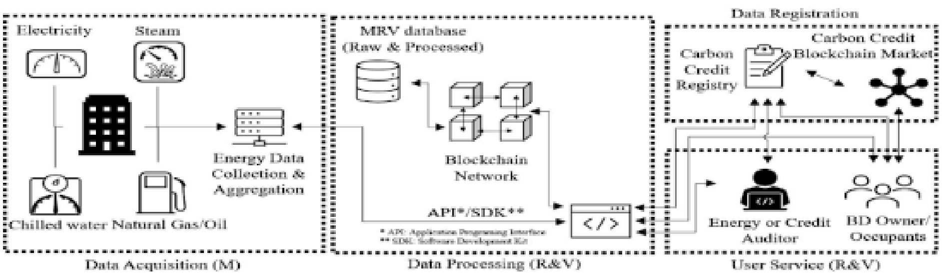

Figure 2: Woo et al.'s data pipeline for carbon credit blockchain market

The combination of blockchain with internet-of-things (IoT) technology, 'smart' devices and machines with the ability to automatically record data and transfer it over a network is decisive in ensuring proper custody of environmental data along the global value chains. ‘That data could then be verified by participants in a public or private network (which may consist of sustainable investors, authorities, regulators, and others) and uploaded into its blockchain, at which point it becomes an immutable and reliable statement of the asset's environmental performance’.

The International Emissions Trading Association (IETA) has noticed the potential engendered by blockchain technology for improving the functioning of carbon markets, both in terms of more effective MRVs, as well as innovative climate asset formation through tokenisation and smart contracts. Early in 2022, its governing council announced the formation of a specific task group to examine the new trends in digital carbon markets and recommend steps to ensure sound governance and environmental integrity in this growing field, particularly in view of the rapid growth of digital carbon assets in the voluntary carbon markets (VCMs). Carbon credits tied to digital tokens accounted for a significant amount of traded volume and high volatility in VCMs in 2021, thereby putting pressure on independent VCM standards and business groups to clarify the terms of use for tokenised carbon instruments. These ‘due diligence’ instruments could be used for a host of other sustainable finance products, such as green bonds or digital renewable energy certificates (dRECs), and even create new environmental asset classes.

Several initiatives underway demonstrate the increasing interest in addressing the need for a robust market infrastructure and more reliable VRM systems. Carbonplace, a blockchain carbon credit settlement platform developed by seven financial institutions with nearly USD 8 trillion in total assets, is an initiative that sold verified credits from a carbon project developer to Visa through Carbonplace's own customer-ready banking platform. It is a glimpse of what bridging these worlds could look like. The platform allegedly satisfies customer needs without forcing it to perform its own counterparty due diligence, thanks to the capabilities of the platform's bank members. This transaction incorporates both of the KYC principles to solve multiple issues. Another such platform Allinfra Climate is also leveraging blockchain technology in an integrated platform to create, track, and trade environmental products. Existing blockchain-based projects vary in scale and objectives, with some offering carbon offsets, while others focus more on ecosystem restoration. Veritree, partnered with Samsung and Cardano, offers various projects with different impacts on climate change from Nepal (habitat and soil restoration) to Madagascar (carbon sequestration with mangrove trees) and Indonesia (carbon sequestration and coastal erosion) has planned a massive reforestation programme, aiming to plant 10 million trees on fallow land in Paraguay. Treecycle sells tokens, ‘TREE’, linked or associated to actual trees, built on a proof-of-stake blockchain. KlimaDAO aims to provide Web3 builders and users the opportunity to participate in the carbon markets through the Klima token, backed by at least 1 tonne of tokenised verified carbon offsets in the KlimaDAO treasury. The intent is for KlimaDAO to act as a distributed ‘central’ bank governing the monetary policy of the new carbon backed currency over an open-source infrastructure. KlimaDAO has already bought 17.3 million carbon credits, which is equivalent to 86,115 hectares of forest. Toucan, WEB3 infrastructure for the tokenisation of carbon assets and a partner of KlimaDao, connects the incumbent voluntary carbon market with a new decentralised financial system. The protocol enables users to tokenise carbon credits issued by respected standards bodies, starting with Verra. Carbon tokens offer many advantages over legacy carbon credits, including traceability, simple retirements, open and democratised access, and enhanced utility as programmable assets.

Blockchain For Greening Global Supply Chains

Providing better functionality for the carbon markets is not an end game; it is part of a bigger puzzle. The greatest potential for blockchain to make a difference in enabling trustworthy systems for the enforcement of climate commitments is in the greening of global supply chains. According to the World Economic Forum, companies can multiply their climate impact by decarbonising supply chains and addressing the most complex of challenges, what are called Scope 3 emissions, particularly for most customer-facing sectors with complex supply chains. Eight supply chains (food, construction, fashion, fast-moving consumer goods, electronics, automotive, professional services and freight) account for more than 50% of global emissions. By engaging suppliers to create a net-zero supply chain, companies can boost their climate impact and have a positive spill over effect in their ecosystem, mobilising action in countries where it would otherwise not be high on the agenda. Given the logistical complexity, asymmetry of information, and lack of 'trust' among economic participants in those global value chains, blockchain can provide a much-needed business application, which may come in the form of a supply chain 'traceability' mechanism and allow customers and investors to obtain reliable, transparent, and timely information about a product and its origins, environmental risks, or human rights and labour violations throughout the supply chain.

Given the very real demand for a more reliable and transparent system for the 'custody' of sustainability data, the incorporation of blockchain technology into the supply chain is already moving at a rapid pace. A number of applications and experiments are already taking place, some as private consortia within a particular industry and some as public ledgers. However, examples of completely open public blockchains as a source of reliable supply chain data that are still completely public blockchains are still scarce. The World Economic Forum (WEF), in collaboration with Everledger, Lenzing Group, TextileGenesis™ and the International Trade Centre, has launched a public traceability platform capable of visualising blockchain-based supply chain data from multiple companies and sources. The International Trade Centre hosts the platform and assures all parties that their data will not be shared externally and provides data protection under UN neutrality, immunities, and privileges. The Climate Warehouse, led by the World Bank Group, the Government of Singapore, and the IETA, is another initiative aiming to create a global market infrastructure by enhancing transparency and the environmental integrity of carbon credit transactions and international carbon markets. (See Section 4.1).

Section 3.2: The Governance Conundrum

To achieve sustainability and transparency, responsible organisations develop and implement proper governance structures. What does a 'proper governance structure' mean though? Essentially, it means that a company or organisation does all that is required to ensure the decision-making process is in alignment with company principles and values, allowing access to relevant data in a transparent manner.

According to MIT Management School, 'the most obvious, and usually the primary, reason that companies increase supply chain transparency is to comply with internal governance and external regulations. While there are potential business benefits, they are less straightforward and hard to quantify. That makes the return on investment in transparency murky.'[29]

Supply chain governance is the 'coordination of the authority and power relationships that determine how financial, material, and human resources are allocated within and flow within a chain', (Gellynck and Molnár 2009). As mentioned by Morcillo-Bellido & Duran Heras in their article 'Sustainability Governance Mechanisms in Supply Chains: An Application in the Retail Sector' (2020), the governance of a sustainable supply chain requires a collaborative environment, allowing companies to implement their sustainability strategies in close alignment with all supply chain stakeholders.

It is essential to distinguish between the notions of 'governance' and 'management' in a supply chain. Management refers to ensuring the efficient performance of activities (operational-wise) within the chain, leading to safe and quality delivery of products; supply chain governance refers to the overall coordination of the system within the supply chain, taking actions to improve any synergies that would be beneficial for all relevant stakeholders involved. Supply chain governance improves risk management, increases bottom-line profitability, and conforms to the organisation's goals, objectives and strategies (i.e., regulatory standards, social and environmental standards, and values, etc.)

To ensure governance is effective, real-time data is required to help improve decision making, strengthen the supplier network and allow adequate transparency for consumers.

Having an efficient governance strategy, can help improve transparency and reinforce the supply chain, by securing availability of knowledge, capabilities, and resources in every link of the chain. Due diligence achieved through effective governance also improves operational efficiency, prevents any disruptions and enhances a company's reputation and visibility.

Supply chain governance components

The role of governance is to initiate, develop and maintain relationships within the supply chain. Governance mechanisms include contracts, standards, reporting frameworks, social values, and principles, etc. Within the governance process, there are several components intended to support the coordination of financial, material, and human resources within the chain – to allow efficient and effective decision making.

The most important components of supply chain governance include:

- **Collaborative working process**, engaging all stakeholders to help develop and establish policies based on values and principles, guidelines to address minimum requirements and expectations in terms of performance, and risk and impact assessments, including countermeasures and mitigation plans, and finally compliance and performance indicators.
- **Data transparency**, allowing access and visibility to all financial information within the organisation.
- **Monitoring, reporting, and validating progress (MRV)**, and keeping every stakeholder up to date.
- **Continuous improvement**, ensuring monitoring of financial performance and compliance with required standards and principles established in the organisation's strategy.
- **Real-time supply chain data management**.

Supporting technologies

Organisations are expected to ensure that supply chain governance strategies, are implemented through the use of high-end technology, which will allow them to:

- support suppliers to manage and record compliance tasks, corrective actions, and improvements;
- self-assess their performance with regards to corporate social responsibility, environmental impact and health and safety at work (tracking and tracing key performance indicators (KPIs) on corporate social responsibility (CSR) and environmental, social and governance (ESG));
- provide full visibility and transparency to all stakeholders, creating a trusting environment;
- ensure accurate and trustworthy reports, that will prevent any risk from false claims;
- facilitate the maintenance and easy tracking of certificates.[30]

Overall, supply chain governance is the process by which a company takes action on the insights gained through greater visibility in order to manage risks more effectively.31 To conclude, the importance of supply chain governance is increasing, as it helps support the implementation and monitoring of CSR and ESG initiatives, while it improves the brand of the organisation through transparency.

Section 3.3: Blockchain and MRV[32]

When fully programmable public/permissionless networks came live, the possibility of developing and implementing fully decentralised programmes became a reality. Due to design choices, those networks had limitations that shaped the way blockchain solutions and businesses in the Web 3.0 space evolved.

Although the public/permissionless and fully programmable networks were a remarkable technological breakthrough, their limitations gave space to what we call the second phase of the blockchain evolution, the era of private blockchain and its associations. With the enterprise community becoming aware of blockchain benefits, investments started to flow int this sector, and, together with these investments, technological limitations – present in the early versions of these public blockchains, such as Ethereum – came to light.

In general, the discussion on blockchain restricts scalability to transactions per second (TPS) or maximum transaction costs (fees). In fact, scalability goes beyond those two elements, and we can define the following fundamental vectors of scalability:

- Transaction per second (TPS): Probably the best-known scalability factor; It defines the capacity of blockchain technology to process transactions. For any objective, for there to be mass adoption, decentralised systems will have to sustain considerably higher transactions.
- Cost of transactions: In the same direction, the cost of transactions must go down to allow high volume and adoption.
- Computational capacity: This is a requirement mentioned less frequently but equally important. Current solutions have limitations on how complex the code launched into the blockchain can be. To allow further adoption it is paramount that more sophisticated applications are possible, meaning that higher computational consumption requirements are deployed.
- Programmability: This scalability criteria is hardly mentioned but is extremely important. The mainstream market has more than 20 million developers. For real mass adoption, it is vital that blockchain and related techs add support for other programming languages as a fundamental step for the easier onboarding of mainstream developers.
- Privacy: Although it is not an element of scalability, privacy plays a key role in how permissionless and open blockchain tech can be used on mainstream applications. Previously, this was one of the main limiting factors and has been fundamentally addressed over the last few years.

The answer to those issues inaugurated the second phase of blockchain development, which are private blockchains. Among the initiatives, Hyperledger, an open-source initiative led by the Linux foundation and backed by IBM was a fundamental catalyst that drove attention toward this kind of alternative. The picture below shows the number of consortiums for private blockchains, with its peak matching the appearance of limitations on public blockchain nascent technologies

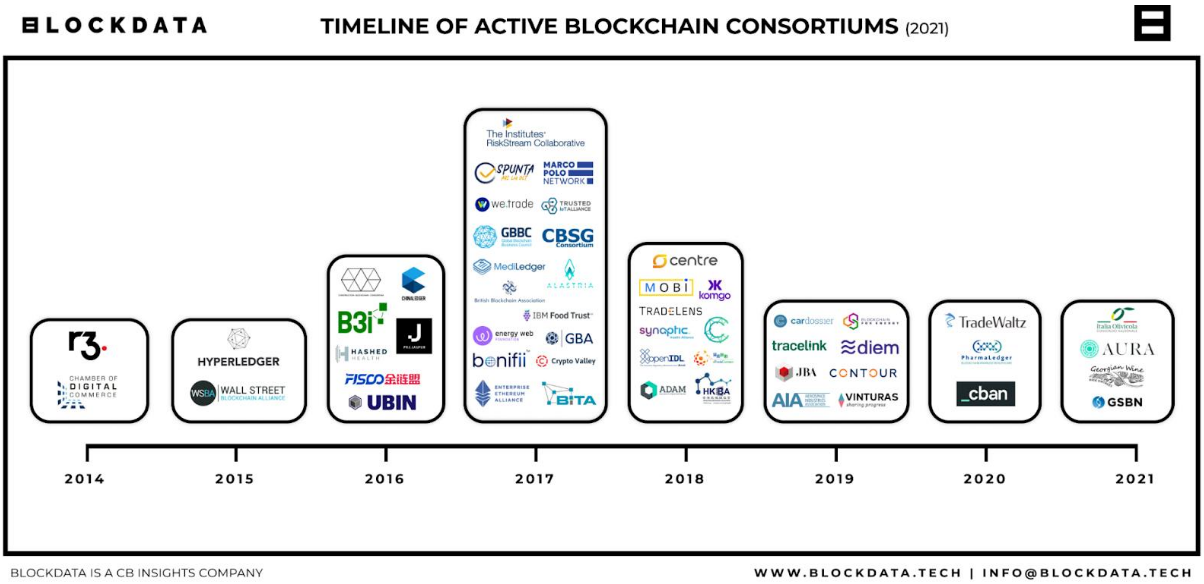

Figure 3: Blockdata timeline

While private networks offered a possible solution to some or all of the main difficulties presented by early versions of public/permissionless blockchains, they also presented, at the same time, their own downsides, including, but not limited to, the lack of permissionless and fully decentralised capabilities. Moreover, consortiums, although highly organised, started to exhibit issues of trust and governance among their stakeholders, which became an obstacle that had to be overcome. This issue was known as the social scalability problem of blockchain consortia.

Meanwhile, public blockchain technology has continued to evolve and mature with more and better infrastructure and tooling, reaching the point where it has regained public attention with a renewed interest in using it as a business platform. The improvements in blockchain architectures led to a point where public and permissionless blockchains found a way not only to scale their capacity, but also to address several other limitations, which were responsible for initially driving attention towards private blockchains.

The development of scalability technologies – including layer-2 solutions, which aim to address the main limitations of blockchain – was the main breakthrough in the blockchain ecosystem. The Ethereum ecosystem is ahead on building its roadmap with a layer-2 centric approach, but it is not alone. Recently, other blockchain projects, like Tezos, have announced they are also converging on the same ‘centric’ strategy.

There are a few technologies that allow the scalability to address the pain points that prevented public and open blockchains being used on a wide range of use cases. We present a summary of these technologies with their pros and cons, and, moving further, we explore how these latest advances can bring MRV´s solutions to a whole new level.

- **State-Channels** participants to transact quickly and freely off-chain. Finality is settled on the mainnet.
- **Sidechains** are independent blockchains running in parallel to the main chain. Sidechains can run their own consensus model and block size. Two-way bridges provide compatibility with the main chain.
- **Rollups** are by far the most popular scaling approach. This is in line with the rollup centric roadmap, proposed by Vitalik B. Rollups perform transaction execution and computation off-chain, and data are

posted on L1 when consensus is reached. Transaction data is posted on L1, meaning that rollups inherit Ethereum security guarantees. There are two types of rollups:

- **Optimistic rollups**: computations are handled off-chain. Transactions are valid by default but can be challenged in the event of a dispute/disagreement.
- **Zero-knowledge rollups**: computations are handled off-chain. A zero-knowledge validity proof is submitted to the chain.

Why is improving the MRV so critical for the future of sustainability markets? The Achilles heel of any system – blockchain-based or not – is that it presupposes having reliable and auditable data to work with. Unreliable data will just generate unreliable outputs, regardless of how sophisticated the data processing layer is.

This is not different in the carbon credit industry. Few mainstream industries have embraced blockchain technology faster than the sustainability carbon credit sector. Several projects aiming to reduce friction in the way this market operates have come into existence over the last 2 years, and more will come. The sector grew more than 150% over the last year, and it is positioned to continue growing at an astounding rate. However, the application of blockchain technology in this industry has not yet tackled the data accuracy challenge, limiting it to 'working its wonders' only once the carbon credit data is available and properly inserted into the blockchain.

Data capture, validation, and handling are still subjected to expensive, long and inefficient processes, very often relying on direct human intervention, which exposes the whole process to considerable risks.

The advances in blockchain architecture and technology can finally help the industry to improve its reliability in data measurements, reports, and verification (MRV), which is a fundamental step towards the implementation of an end-to-end fully verifiable carbon credit issuing system.

The improvement of MRV is not just limited to carbon credit issuing and certification. This is actually just the tip of the iceberg as it can be widely applied to the supply chain as a whole. The need for the data source to be fully automated and verifiable is a prerequisite for any system that relies on database information to produce functional outputs.

The combination of the latest technological developments such as IoT devices with telemetry and precise location and time measurements, together with mobile networks with global coverage and internet availability, opens up the possibility of implementing systems with minimum human intervention. The missing piece of this puzzle was to generate those measurements in such a way that they would be fully verifiable and have data processed by a layer that is tamper proof and can preserve its state. Blockchain technology is the answer to this puzzle.

The technological advances in blockchain architecture and technology allow IoT devices to digitally sign data and send it to the blockchain and maybe even compress files for efficiency purposes. This data can be retrieved by fully automated decentralised applications (DApps), which would verify the data authenticity and proceed with the data analysis/processing required by the specific use case. The output would be fully available in a transparent and immutable format on public blockchains. With this approach, any stakeholder would be able to access the data and fully verify not only its processing but also audit and ensure the data source was valid and had not been tampered with. The diagram below shows a reference block system of a typical use case involving a supply chain.

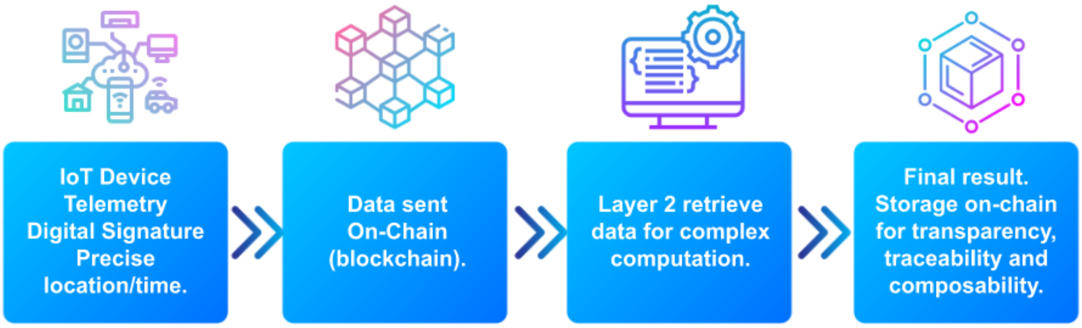

Figure 4: Supply chain traceability with IoT

The end results could be recorded in a typical fungible token or, in a more sophisticated use-case, use the latest development of a non-fungible token (NFTs), which allows a rich set of unique data to be recorded and uniquely associated with a specific owner and asset. Such enhancement is also the result of the latest improvements in blockchain technology and architecture.

From an interoperability point of view, the technology is still far from seamless interconnection among blockchains with bridges dominating the landscape. The current method of bridging blockchains requires manual work and, in general, solutions are seen as the weak security link of blockchain infrastructure, with recent episodes of hacking and security issues such as recently occurred with Solana's bridge and Harmony´s horizon bridge. Instead, some technologies have been created to support multi-chain, meaning they can be deployed on different chains. They are also called agnostic solutions and are flexible enough to be deployed on different blockchain technologies depending on the best fit for the use-case.

Section 3.4: Zero Trust for Supply Chain: A Viable Solution for Addressing Global Supply Chain Ecosystem Deficiencies

Global Landscape

The supply chain has always been a foundational backbone of the economy, however, in this digital era, it has become crucial and disruptions are poised to cause significant economic crises. The recent geographic, social, political, and economic pressures have acutely highlighted the need for redesigning, recalibrating, and reshaping the supply chain.

The global market size for the supply chain has been increasing for most indicators: management, software, analytics, etc. Some of the highest compound annual growth rates (CAGR) have been forecast for digital supply chain market growth, with blockchain and AI consistently ranking at the top of the list of emerging technologies driving the supply chain economy.

Blockchain and other technologies can have a complex positive impact on supply chains by reducing fraud, waste, and abuse; improving compliance with regulatory guidelines; lowering overhead costs; increasing efficiency by increasing transaction speed; improving auditing and transparency, etc. The full portfolio of AI tools has an equally powerful impact by delivering strategic intelligence; enhancing agility to adapt to changing market dynamics via predictive capabilities; dynamically managing inventory; and optimising resilience. However, the most effective combination is the dual power of blockchain and AI capabilities as it can lead to enhanced operational efficiency, maximised ESG-performance, and optimal financial return of investment (ROI).

The World Economic Forum is recommending a global collaborative effort to accelerate action to build a hyper-networked supply chain future, and a recent publication is highlighting the complex relationship between small and medium business retailers and retail giants, as well as the need for logistics platforms that facilitate collaboration[33].

OECD has also recently published on how global supply chain collaborative efforts were able to influence public health outcomes during the pandemic by expediting the delivery of masks, testing kits, and vaccines.[34]

Participants in the United Nations Global Impact have identified supply chain sustainability as one of the major challenges that transcends numerous domains and disciplines, requiring a collaborative effort to revise laws and policies, as well as recalibrate workforce selection, onboarding, and training. The toolkit for sustainable procurement and the practical guide for continuous improvement they have developed can be a valuable resource for business leaders and other key stakeholders in the transformation journey towards increased efficiency and sustainability.[35, 36]

Challenges

The pandemic has exacerbated pre-existing supply chain inefficiencies and has triggered critical shortages affecting public health at a global level. A recent Brookings Institute report[37] has highlighted failed supply chain policies in public health and has called upon key decision makers and regulators to develop novel risk mitigation plans, revise their strategies and a reassessment of technology, suppliers and methodologies to improve existing supply chain vulnerabilities.

The World Bank has published a report that emphasises the importance of new regulatory guidelines, as well as the complexities of the current market structure and dynamics, which are shaping the current global supply chain landscape. The authors are calling attention to the ‘bullwhip’ effect, which they define as caused by an unexpected steep demand rebound and ongoing disruptions due to capacity constraints[38].

Opportunities

Any global collaborative efforts to address the pain points in supply chains must be comprehensive and address people, processes, and products in order to be successful.

People

Building a culture of digital ethics and cyber-resilience are both essential for short and long-term success in securing the global supply chain ecosystem. The current accelerated digital transformation process can assist in addressing some of the supply chain inefficiencies, however, it can also increase the risk of privacy violations and expose cyber-vulnerabilities.

Process

Current processes have proven to be convoluted, fragmented, ineffective, inefficient, not easily adaptable to novel pressures and lacking sustainability. A proactive approach, design thinking, Lean Six Sigma, Kaizen and Agile methodologies can be very helpful when combined with appropriate measures to address workforce shortages and powerful new technologies.

A state-of-the-art ESG-centric strategic roadmap and playbook will have to be developed and deployed globally to address inefficiencies and even uncover the hidden return on investment (ROi) in supply chains.

Recent reports by HSBC[39] and BCG[40] highlight regional challenges and offer concrete solutions that businesses could adopt to enhance their ESG efforts, such as creating transparency, setting clear and attainable targets, engaging suppliers, and activating novel ecosystems.

Product

Converging technology platforms that leverage the novel capabilities offered by technologies such as blockchain, edge computing, cloud computing, and the full AI armamentarium available can address some of the challenges experienced globally in supply chain effectiveness and efficiency.

Zero Trust Rationale

As defined by the IEEE, zero trust is a systemic approach to information security that trusts no user, no transaction or network data exchange unless verified.

Redesigning trust in supply chains has been the focus of a new World Economic Forum's latest initiative, which engages 100+ organisations across 40+ supply chain use cases to offer a platform that can address the residual deficits and facilitate ESG attainment. This platform is showcasing how supply chains powered by blockchain technology can ensure increased transparency, accountability, responsible use of resources, and enhanced auditing functionality.[41]

It has gained significant traction over the past few years, as it is a comprehensive, industry-agnostic solution that is highly adaptive to the increasingly complex demands of the digital era.[42]

To accomplish zero trust, organisations must embrace continuous innovation and embark on an ongoing quality improvement journey, as creating zero trust environments requires a dynamic approach. It involves policy changes, novel operating procedures, redesigned technology architecture, and customised metrics.

To achieve zero trust for supply chains, organisations must design and deploy new criteria to evaluate software security, rewrite best practices, and encourage innovative tools or methods to demonstrate or track zero trust compliance.

A recently updated report published by the National Institute of Standards and Technology addressed cybersecurity labelling of internet-of-things connected devices and software for consumers.[43] This report was produced in consultation with other key agencies such as the Federal Trade Commission (FTC), Environmental Protection Agency (EPA), the Consumer Product Safety Commission (CPSC), Interagency Committee on Standards Policy (ICSP), and the federally chartered Cybersecurity Solarium Commission.[44]

A March 2022 European Commission impact analysis report and proposal for measures for a high common level of cybersecurity at the institutions, bodies, offices, and agencies of the Union provided the political, legal, and regulatory context, identified the problem drivers for supply chain cyber-risks, and suggested a set of concrete measures to achieve zero trust architecture. Two previous reports published report by the European Innovation Council and SMEs Executive Agency (EISMEA) and the European Parliament[45],[46] highlighted the impact of blockchain and other distributed ledger technologies on small and medium enterprises and outlined opportunities for how novel technologies such as blockchain can contribute towards resilience in global supply chains.

Future Directions

A 2021 HBR article emphasised how the combination of blockchain, IoT, and advanced analytics can address challenges to supply chain efficiency. Examples of the combined impact include improved data standardisation, data governance, auditing, transparency, etc.[47]

By deploying the risk management framework recommended by NIST, key players in supply chain ecosystems could accelerate the attainment of a cyber-resilient zero trust architecture.[48]

In the near future, smart global citizens might benefit from the deployment of digital twins for supply chain management and live in smart cities powered by smart, zero trust-enabled supply chains.[49]. They will live, work, shop and entertain themselves in a Web 3.0 digital society, which will demand and be even more dependent on highly efficient, highly effective, secure supply chains. Zero trust supply chain architecture will be the default for generations that are expected to benefit from the immersive, multi-dimensional metaverse and omniverse ecosystems being created currently.

Chapter 4: Use Cases

Section 4.1: The Climate Warehouse

The Climate Warehouse aims to fill a gap in the carbon markets for trustworthy, verifiable data and to provide a bridge for the strong growth in voluntary and compliance carbon markets. 'It offers a unique place in the market by coordinating with government and voluntary carbon credit programmes and may help accelerate the implementation of Article 6 and support international reporting under the Paris rules'. The Climate Warehouse is intended to function as a public good central metadata repository with the primary aims of avoiding double counting and establishing a common set of data specifications for reporting and building additional services (such as reporting or rating functions). It intends to remain agnostic on the choice of any specific set of environmental integrity criteria, instead focusing on a wide capture of cases of double counting across a wider pool of carbon credit programmes. The World Bank has engaged Chia, a crypto platform, to build an open source blockchain that would act as a ledger for carbon offsets. Using a 'proof of time and place' protocol that is allegedly more energy efficient than traditional blockchain protocols, Chia will build global ledgers that can be swiftly updated in an immutable and distributed manner that lets anyone participate, rather than relying on any single, centralised gatekeeper. The pilot is currently in Phase III and undergoing testing with stakeholders and is completing governance consultations with the International Emissions Trading Association (IETA) and the Government of Singapore for the creation of an IETA secretariat with a group of over 70 countries and entities. The Simulation III prototype was tested with 30 participating organisations, including 11 national governments and 75 testers across 58 testing sessions. Participants included governments (37%), independent standards organisations (17%), multilateral organisations (20%), and other private and public market participants (27%), representing a wide number of regions (East and West Africa, Europe, Middle East, North America, Latin America and the Caribbean, South and East Asia).[50] In August 2022, The International Finance Corporation of the World Bank Group, with partners Cultivo, Aspiration, and Chia Network announced the launch of the Carbon Opportunities Fund, a global investment platform for trading carbon credits. The Climate Warehouse will track the fund's verified carbon credits to ensure transparency and market trust.

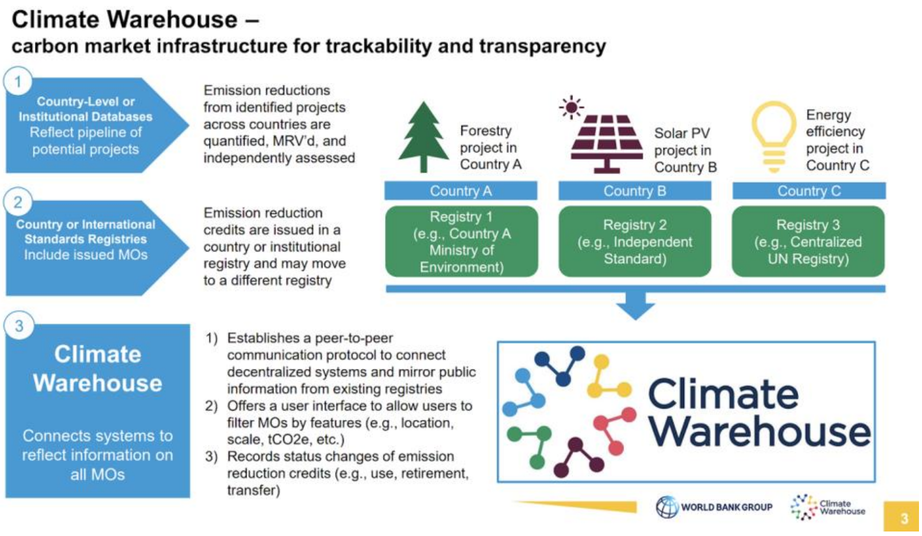

Figure 5: Climate Warehouse by World Bank Group

Section 4.2: A Sustainable Stove for Africa

Supply Side: Affordable Energy Against Poverty

Africa needs affordable energy. Solar energy systems have been used to address the problem. By giving consumers in the developing world access to electricity, solar home energy systems succeed in cutting high expenditure on paraffin, batteries, and phone charging. However, they lack the capacity to support thermal energy generation. So, they do not carry the health, gender, and environmental benefits of a cookstove. Currently, there are over 3 billion people reliant on cookstoves for cooking and water heating, a large share of the African continent. These stoves are often run on inefficient, readily available fuels (sticks, crop waste, dung etc.) which, besides emitting huge amounts of greenhouse gases (GHGs) into the atmosphere, also have huge economic and health consequences for those using the stoves. Improved cookstoves are widely recognised as mitigating the health, gender, and environmental risks associated with rudimentary energy access. They also significantly reduce fuel needs. However, there has been a push within the clean cooking sector for more affordable solutions to this energy challenge, with the result that the majority of clean cookstoves in distribution tend to be cheaply produced and lack future-proof design. They lack the ventilation to produce a clean or powerful enough burn to change negative cooking habits.

Demand Side: Unserved Demand For Carbon Credits

Corporations need to offset their carbon emissions. Improved cookstoves can be a source of carbon credits to offset buyers. And carbon projects are failing to fulfil demand. First, carbon projects move slowly. The time from project inception to credit issuance can take years, killing many projects before they can even get started. Carbon markets are complex and, in most cases, completely inaccessible to the general public. Information on the costs, fees, quality etc., are all hidden, making price discovery on new carbon assets slow and inaccurate. Carbon markets are opaque due to intermediates (brokers and resellers), turning many customers away and slowing the widespread adoption of carbon credits.

The Stakeholders in the Supply Chain Solution

The **African Clean Energy (ACE)** vision is a world where clean energy and connectivity is for everyone. They aim to eliminate poverty on a platform of clean energy and smartphone technology. As a certified B-Corp, ACE commits to reinvesting most of the profits into its social mission. ACE One is an integrated energy solution to this challenge. With ACE One, ACE uniquely combines future-proof hardware with smart digital infrastructure and responsive physical infrastructure to give isolated, off-the-grid consumers access to clean thermal and electric energy at an affordable cost.

CLNK.earth's mission is to democratise climate action. They aim to set up the infrastructure for change and be rewarded. CLNK is developing the first blockchain-native carbon credits, opening up benefits across the market. They develop blockchain-based solutions to monitor, verify and produce carbon credits.

Cartesi offers an optimistic rollups scalability solution using a breakthrough virtual machine that boots an entire Linux OS. Cartesi's technology is blockchain agnostic and runs initially over the ETH ecosystem, making a perfect match with ACE and CLNK, offering verifiability, as well as all developing the tooling needed to enable a digital measurement-reporting-verification (MRV) solution.

The Solution

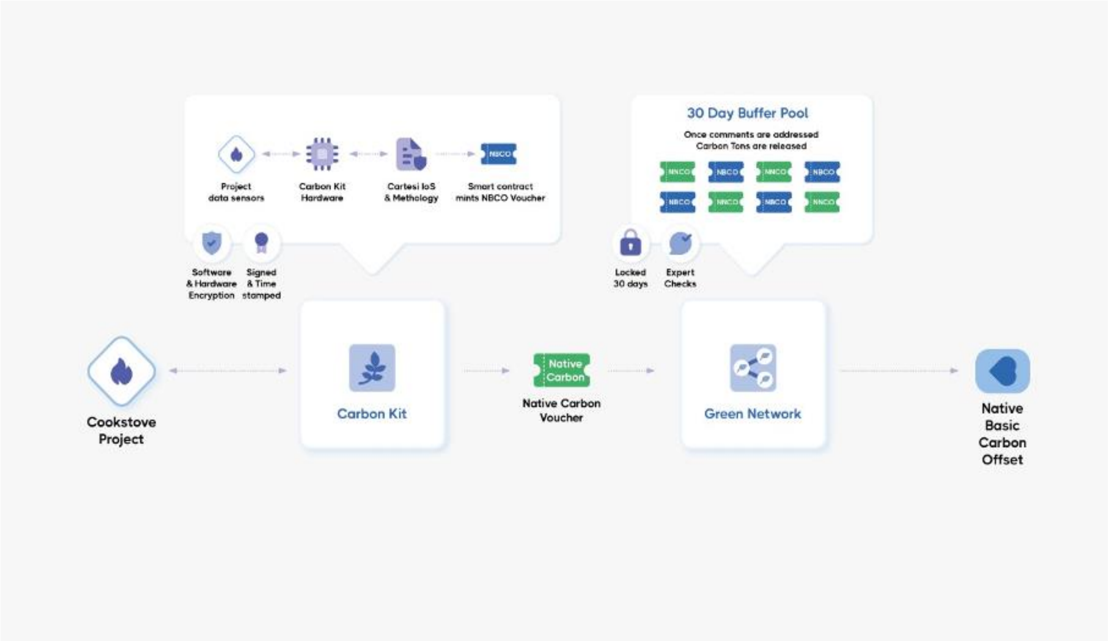

Figure 6: Architecture for sustainable stove with blockchain

A customised IoT device tracks all metrics needed to calculate the carbon savings from the ACE Stove low-carbon biomass solution. Using Cartesi's technology, CLNK can build a digital MRV that includes import checks through digital signatures and all data processing from statistical checks and plausibility checks, with all data and processing fully verifiable and with correct results ensured by rollups with dispute resolution. The 30-day buffer pool allows experts to scrutinise data before carbon credits (mint carbon NFT) are transmitted. The result is blockchain-native carbon that provides benefits across all participants. The supply side gets funding to expand affordable energy and alleviate poverty. The demand side have better access to the carbon market and more transparent information on the credits themselves. The carbon market, as a whole, benefits from better price discovery, easier traceability, and improved trust. There is more transparency, quicker finance, and instant access to the fast-growing on-chain carbon market. The carbon credit timeline is reduced from 8-12 months to as little as 30 days, meaning more green projects across the world.

Section 4.3: Hyperledger Initiatives for Supply Chain Transparency and Sustainability

Hyperledger has many initiatives in regard to supply chain transparency. It is important to note that Hyperledger is not a blockchain technology of itself, instead it is an incubator project from the Linux Foundation to incubate several different enterprise blockchain projects in an open-community, open-source manner[51]. One of Hyperledger's projects is, for instance, Hyperledger Fabric, which is a general-purpose consortium-enterprise blockchain platform driven by, among others, IBM as contributor. Another example is Hyperledger Besu, which is an Ethereum client with ConsenSys as one of the major open-source contributors. As a consequence, Hyperledger supply chain initiatives can be categorised as direct initiatives of the Hyperledger Foundation and indirect applications of the incubated projects.

The most important direct initiatives are working groups. On the one hand, the Climate Action and Accounting special interest group has a special working group dedicated to carbon accounting and certification[52]. They have created an experimental solution for tracking and reducing oil and gas methane emissions. The solution is based on NFT tokens combined with external oracle protocols to report, track, and aggregate methane emissions and create emission profiles for different industrial actors, like oil and gas producers, power plants, and refineries[53]. Another community group is the Supply Chain and Trade Finance special interest group, which focusses on various topics related to blockchain, supply-chain, logistics, and trade-finance[54].

Indirect initiatives are all the projects and solutions that are implemented by one of Hyperledger's incubated technologies but might not be directly driven by the Hyperledger Foundation. Probably one of the most famous such examples is the IBM Food Trust platform. The platform provides a common blockchain for monitoring and auditing movement of different food components across the whole supply chain, including participants such as growers, processors, shippers, retailers, regulators, and consumers. The platform provides the following benefits for the different participants.

- Increasing the efficiency of the whole supply chain, increasing delivery time, decreasing stocks.
- Helping in food safety and making it easier to ensure regulatory compliance.
- Guaranteeing food freshness.
- Eliminating food fraud and errors.
- Minimising food waste.
- Building better brands for local food suppliers.
- Providing better sustainability characteristics.

The platform is implemented on Hyperledger Fabric and used, among others, by Walmart[55].

Another known example is a mine-to-manufacturer traceability platform for conflict minerals. The African country of Rwanda is the world's biggest supplier of tantalum: a rare mineral used to make capacitors found in devices like smartphones and laptops. The goal of the project is to prove that every bag of tantalum ore from Rwanda was mined, transported, and processed under OECD-approved conditions, without any child or slave labour. The system is implemented with Hyperledger Fabric. It provides a more efficient and cost saving solution for regulatory compliance[56].

A similar approach is realised by MineHub to improve efficiency in the metal and mineral mining industry. In the field, there are nearly USD 1.8 trillion of metals and minerals moved across the world every year from mines, through ports, along transport lines, to processing plants and, ultimately, to the end users, involving hundreds of companies and millions of transactions. The implemented solution is a blockchain-based collaboration platform that replaces the inefficient partly manual processes, providing a reduced cost and a much better efficiency for the whole segment[57].

Section 4.4: IBM Food Trust

From the farmer, processor, retailer, to the consumer, IBM Food Trust™ uses trust to build transparency. The blockchain solution is working to ensure that transparency enables the expanding food system.

With capabilities to enable safer food, longer product shelf lives, reduced waste, faster traceability, and better access to shared information, IBM Food Trust empowers you to meet the new standard for transparency and trust.

The solution provides authorised users with immediate access to actionable food supply chain data – from farm to store and, ultimately, the consumer. The complete history and current location of any food item, along with certifications, test data, and temperature data can be readily available in seconds.

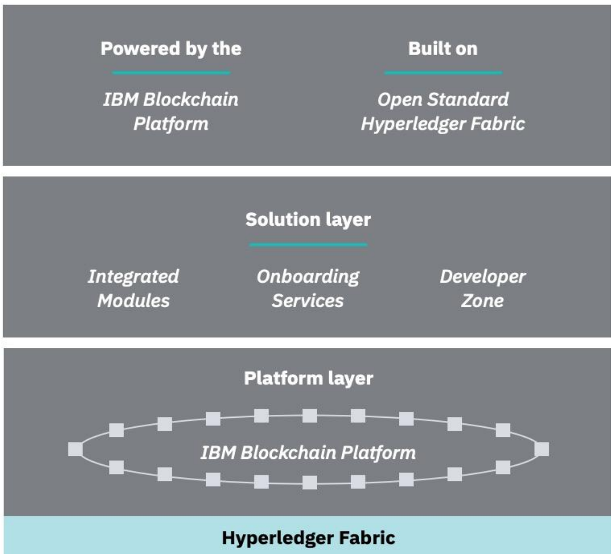

Figure 7: Data Types on Food Trust Network[58]

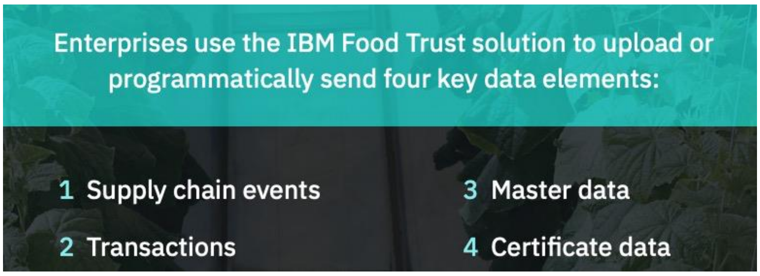

Figure 8: IBM Food Trust Data Entry

Trust Anchors are participants in the Food Trust network, such as retailers and food suppliers, who are collectively responsible for maintaining the integrity of the shared ledger and assisting in meeting security, as well as privacy and permission guarantees. Every organisation owns and controls their own data including data sharing.

- Food Trust Governance Council
- Companies.

IBM Food Trust Benefits for Stakeholders

Food Trust provides your organisation with a set of integrated modules to address the increased complexity and build trust in the industry.

- Supply chain efficiencies: Operate using smarter processes across a shared food system by identifying process inefficiencies, leveraging data insights for demand forecasting, scaling with automation, and optimising your business for continuous growth.
- Food safety: Securely trace products in seconds to mitigate waste, cross-contamination, and spread of foodborne illness.
- Food fraud: Enable full transparency by digitising transaction records and storing them in a decentralised and immutable manner, eliminating the opportunity for fraud across the food system.

- Reduce waste: Share and manage data across the food supply chain, helping to increase efficiency, reduce product loss, and optimise your ecosystem.
- Food freshness: Gain unprecedented visibility into supply chain data for valuable insights and analysis, identifying inefficiencies and ensuring quality of goods sold.
- Brand story: Empower consumers, retailers, manufacturers, suppliers, and producers with confidence and trust in companies that they purchase and consume their food from.
- Sustainability: Digitise essential certificates and documents to optimise information management, certify provenance, and ensure authenticity.

Section 4.5: TradeLens

TradeLens is focused on cargo owners, exporters, importers, freight forwarders, port operators, shippers, government authorities, and financial services in the supply chain. More efficient logistics improves the value of the supply chain for producers, manufacturers, distributors, retailers, and consumers. TradeLens was originally founded as a joint initiative between IBM and Maersk.

TradeLens is an open, neutral, supply chain platform using blockchain for parties to share information and collaborate, improving supply chain efficiency and reducing trade friction, particularly in international trade and shipping containers. Existing processes were complex and slow with inaccurate data.

Based on open standards, TradeLens allows parties to manage their source data, directly improving information quality and reducing information silos. The TradeLens platform uses the supply chain reference data model from UN/CEFACT, which defines three interrelated 'objects' as the basic units of global trade: shipments, consignments, and transport equipment.

TradeLens can be understood as comprising three components: the ecosystem, the platform, and the applications and services marketplace. The marketplace allows 3rd parties to publish add-on services as well. The platform is built on the open-source, high performance Hyperledger Fabric blockchain. The ecosystem members interact directly on the platform, processing over 1 billion shipping events annually and more than 10 million documents, automating shipping processes and decision making.

The platform is highly secure with permissioned access for registered parties. It supports both private data and shared data controlled by parties directly. Based on roles, different dashboards make the visibility of the state of the supply chain easy. Organisations can easily set up subscriptions for events to improve visibility. TradeLens conceptual architecture diagram below:

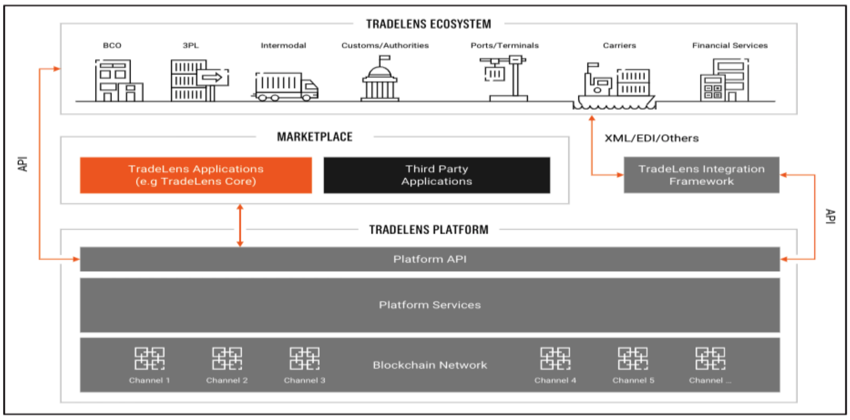

Figure 9: Tradelens Architecture[59]

Section 4.6: Botanical Water Technologies

Summary: Delivering a New Source of Water

Every year, 3 trillion litres of water become a redundant side product of food production. It is the equivalent of 1 million Olympic swimming pools, a simply astounding loss. Botanical Water Technologies (BWT) uses its standard shipping container-sized technology to harvest, filter, and purify water during food production.

BWT positively impacts water scarcity by providing a new source of drinkable, sustainable, plant-based water for communities and environmental projects. It harvests water during sugar milling and vegetable processing seasons for the company's retail brand, AquaBotanical. A water harvesting unit (WHU) used to extract the water from the existing supply chain comes as a standard shipping container. Through transportability, the harvesting of water in existing supply chains is optimised. The end product, botanical water, is distributed for retail (AquaBotanical), wholesale (ingredient for beverage companies), and social and environmental impact initiatives (water impact credits).

Fujitsu builds a Hyperledger Fabric based solution and supports the ecosystem that enables the secure trading of water.

Introduction

When fruit, sugarcane, and vegetables get pressed to extract the juice and then evaporated to make concentrate or sugar they produce a large volume of water. BWT uses its patented technology to filter and purify this water, potentially saving trillions of litres annually. **An estimate of three trillion litres is available**. However, BWT needed to be able to harness this potential. Tracking and certifying water production and connecting suppliers with customers globally became a critical focal point.

The Botanical Water Exchange (BWX) platform relies on the Fujitsu Enterprise Blockchain - Track and Trust service, which uses Hyperledger Fabric to ensure end-to-end transparency and traceability of processes, including the refinement, sales, purchase, delivery, and usage of the product. BWX enables greater transparency and security in water trading and ultimately creates an open market in which companies – including but not limited to juice concentration facilities, sugar mills, alcohol distilleries, and beverage manufacturers – can trade in water purified by the patented BWT process.

BWX is an ecosystem that allows for the harvesting, purification, and delivery of botanical water. It provides a frictionless way to donate water for environmental and philanthropic projects. It also incorporates sustainable solutions for regional and global fast moving consumer goods (FMCG) food producers to reuse or utilise this water as an ingredient or throughout the production process.

The Three Streams for Harvested Water

The BWX global water trading platform efficiently connects buyers and sellers to utilise the three main uses of potable plant-based water. The ingredient water is a sustainable replacement for current practices and is used in a compound or used as a component of the end-product of food and beverage manufacturers. Impact water makes a difference in schools, groundwater recharge, marine and wildlife restoration, rivers, agriculture and irrigation, municipal water, private households, and communities. Impact water is purchased through partners and distributed across the globe to impact people and the planet positively. Water reuse provides alternatives to existing water supplies. Water reuse is applied to enhance water security, sustainability, and resilience.

Tapping into the supply chain with water harvesting units

WHUs turn any juice concentration facility or sugar mill into a sustainable potable new water source. The WHUs are manufactured, tested, commissioned, and serviced. They also operate independently of existing equipment at the processor. To ensure transportability, a WHU is a repurposed standard shipping container. The unit is moved to where it is needed, for as long as it is needed.

With over 170 measurement points providing live monitoring and adjustments, the non-invasive and low power consumption WHUs create a circular water economy to positively impact people and the planet. The aggregated data from the units is also stored on the blockchain platform, supporting the different trades and ensuring the immutable keeping of ESG and sustainability evidence.

Water is not transported across large distances, as production is balanced using the information from the WHUs and the data on the platform, bearing in mind the locality, needs, and regulatory obligations.

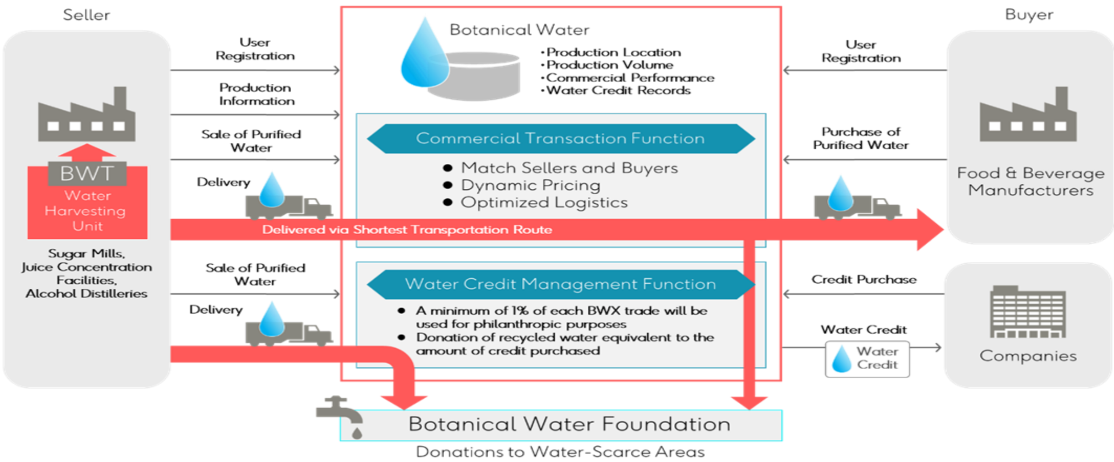

Figure 10: Botanical Water Technologies architecture

Sprinkling Aid Through the Botanical Water Foundation

The BWF exists to deliver botanical water to people who need it most, at no cost. BWF works with vetted charitable organisations and impact partners across the globe with existing infrastructure to provide free water to the world's poorest people. A minimum of 1% of all transactions traded on BWX gets donated to the Botanical Water Foundation.

A Vast Ocean of Benefits

In summary, and as an overview of some of the benefits:

1. With 85% of consumers becoming 'greener' the ability to manufacture and produce more sustainable products is crucial. With BWT, access to the world's first plant-based water will create significant opportunities previously impossible.

2. With water scarcity already affecting every continent on the planet, we offer the ability to utilise this new sustainable water source and restore environments that have suffered due to increasing water demand.

3. Water is an essential ingredient and, in some cases, the main element in many food and beverage products. Through a partnership with BWT, partners can utilise this water source throughout their practices, creating a sustainable process.

4. Along with implementing community-owned projects, the ecosystem can help facilitate the delivery of water to some of the world's most vulnerable people.

5. ESG and sustainability are fundamental practices in all industries. With BWT, this is embedded right to the core of who we are. BWT offers the ability to reach your sustainability goals by purchasing water impact credits to offset your water usage.

6. With 10,000+ fruit, vegetable, and sugar cane processors and potential member of the global ecosystem, BWT can optimise inventory levels, increase processes, and improve supplier/third-party relationships.

7. Zero impact on existing manufacturing operations as the WHU sits external to all production and is connected at the point where condensate liquid is sent to waste.

8. Processors are facing limitations on the water they can draw from municipal sources. They can be provided millions of litres to be used as production water, which reduces or sometimes eliminates the need to take from municipal sources and deplete reserves.

Section 4.7: True Code[60]

This is a new traceability initiative which started with an idea at the Consumer Goods Forum (CGF) End-to-End Value Chain (E2EVC) 2019 Steering Committee meeting and currently involves many of Europe's largest meat retailers and suppliers. True-Code is connecting the food supply chain by facts verified using blockchain-based zero knowledge proof technology. At the core, True-Code provides a method for one end of the supply chain (retail, consumer) to ask essential sustainability questions to the other end of the supply chain (first mile, farmers, smallholders). One of its pilots focussed on questions regarding assurance about deforestation-free soy used to feed animals and food safety. Together with feed mills and the soy trader, the meat processor demonstrated that it is possible to give traceability answers up to the level of the soy cooperatives in Brazil. To date, these traceability claims were based on self-reported datasets. In a pilot currently implemented with the European Space Agency and Satelligence, new TrueCode locations will be generated using objectively verified satellite data that can substantiate the claims made about deforestation (with close to daily monitoring of soy and cattle ranges at 10m spatial resolution). TrueCode is rolling out a commercial verification module where Satelligence's satellite-based insights can become the blockchain ZKP verification 'gold standard'.

Section 4.8: AquaLedger

Another example is a project called AquaLedger, which demonstrates enhanced traceability and tracking in aquaculture and fisheries supply chains through the use of blockchain and satellite earth observation of marine environments. AquaLedger aims to harness earth observation and advanced analytical techniques to collect valuable information about the marine environment and activities related to aquaculture management while enabling its integration with blockchain networks to verify producer's claims, which are recorded in the shared database.

Monitoring the quality of the water where aquaculture is developed is crucial for ensuring the security of the seafood that reaches the consumer. Water quality monitoring is required also for hatcheries that pump water from the ocean, especially because of certain species (i.e., fish larvae) that are very sensitive to water quality. Aquaculture also needs monitoring because it may significantly affect the surrounding environment (i.e., nutrient and organic matter enrichment, contamination by hazardous substances, sedimentation, physical disturbance). The environmental impacts of aquaculture are regulated under a range of EU legal requirements that address broader issues including water quality, biodiversity protection, and sustainable development and planning. The key EU environmental policies that aim to ensure safe and healthy aquatic environments, on which aquaculture relies, are the Strategic Guidelines on Aquaculture, the Marine Strategy Framework Directive (MSFD) and the Water Framework Directive (WFD).

To support the growth of efficient and sustainable aquaculture production, the AquaLedger project focused on providing the aquaculture supply chain with user-relevant and timely information based on the most up-to-date earth observation data and API interfaces to integrate it into the blockchain-based (hyperledger) system that connects the producers with processing plants, distributors, retailers, and end-customer. The pilot was implemented together with Greek fish producer SKALOMA, which is one of the aquaculture farms hosted in the Thesprotia Region. It was established in 1998 and is currently able to produce 500 tons of mainly sea bream, sea bass, and other Mediterranean aquatic species. The unit where the AquaLedger will be deployed is located in a maritime area of 30ha along the Sagiada Lane coast.

European food law specifies that food companies should be able to specify the origins of their products. Dedicated information should accompany each product to enable traceability at the different stages of the supply chain, and consumers should be able to trace the fish back to the farm as well as to know the conditions, methods (i.e., harvesting date, packaging date, etc.) and the environmental footprint of the production.

The classical set of EO-derived water parameters was developed for this use case and integrated into a custom-made blockchain traceability solution that connected all the parties in the supply chain.

- **Temperature** is a water quality parameter which can directly affect the quantity of oxygen that can be dissolved in water but also the growth of organisms and bacteria. A rise in temperature will decrease the dissolved oxygen content in water, which will successively increase the metabolic rate of fish and therefore the demand for oxygen. This information is also important for the farmer in order to adjust the feeding rate (i.e., in case of a drop in temperature, feeding should be reduced so as to avoid financial losses).

- **Dissolved oxygen** is considered an important measure of water quality as it is a direct indicator of an aquatic resource's ability to support aquatic life. It should be noted that high temperatures and drops in oxygen are usually linked to fish disease.

- **Chlorophyll-a (Chl-a)** is a critical parameter to monitor the impacts of eutrophication as well as the health risks associated with harmful algal blooms (HABs). HABs are caused by the rapid growth of algae and cyanobacteria. They are hazardous and sometimes fatal to human and animal populations, either through toxicity or by creating ecological conditions, such as oxygen depletion, which can lead to fish deaths. General conditions that favour algal blooms are rising seawater temperatures and high nutrient loading from fertilisers.

- **Total suspended matter (TSM)** includes organic and mineral suspended solids that affect the transparency of the water and therefore the depth that light will penetrate. Light is necessary for photosynthesis, a process that produces oxygen.
- **Coloured dissolved organic matter (CDOM)** constitutes a mixture of organic molecules that can be a proxy for carbon context. The concentration of CDOM can have a significant effect on biological activity in aquatic systems. CDOM diminishes light intensity as it penetrates water. Very high concentrations of CDOM can have a limiting effect on photosynthesis and inhibit the growth of phytoplankton and oxygen production.
- **Turbidity** determines water clarity.
- **pH** is a measure of the acidity of the water. The pH of the water affects the concentrations of dissolved substances and the physiological functioning of aquatic organisms.
- **Salinity** is commonly defined as the concentration of dissolved salts. The aquatic organisms in ponds have a tolerance to a specific range of salinity.

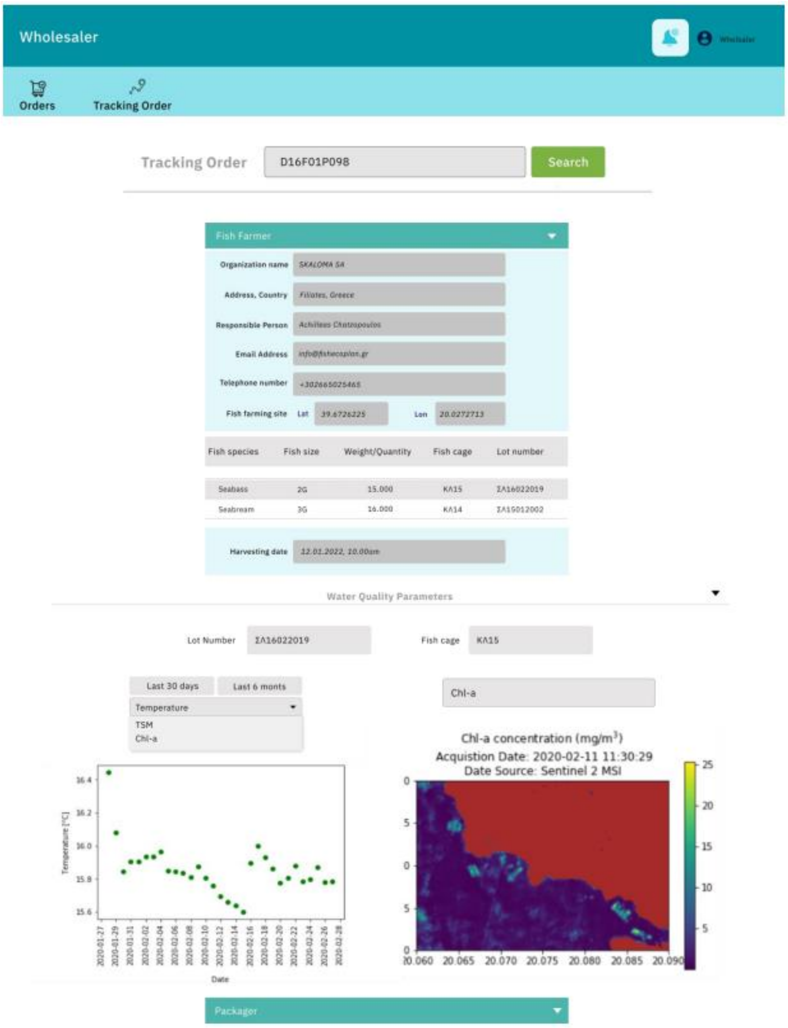

FIGURE 18: INTERFACE ALLOWING THE VISUALISATION OF AGGREGATED INFORMATION ABOUT THE ORDER AND THE ACTORS INVOLVED

Figure 11: AquaLedger's interface for visualisations

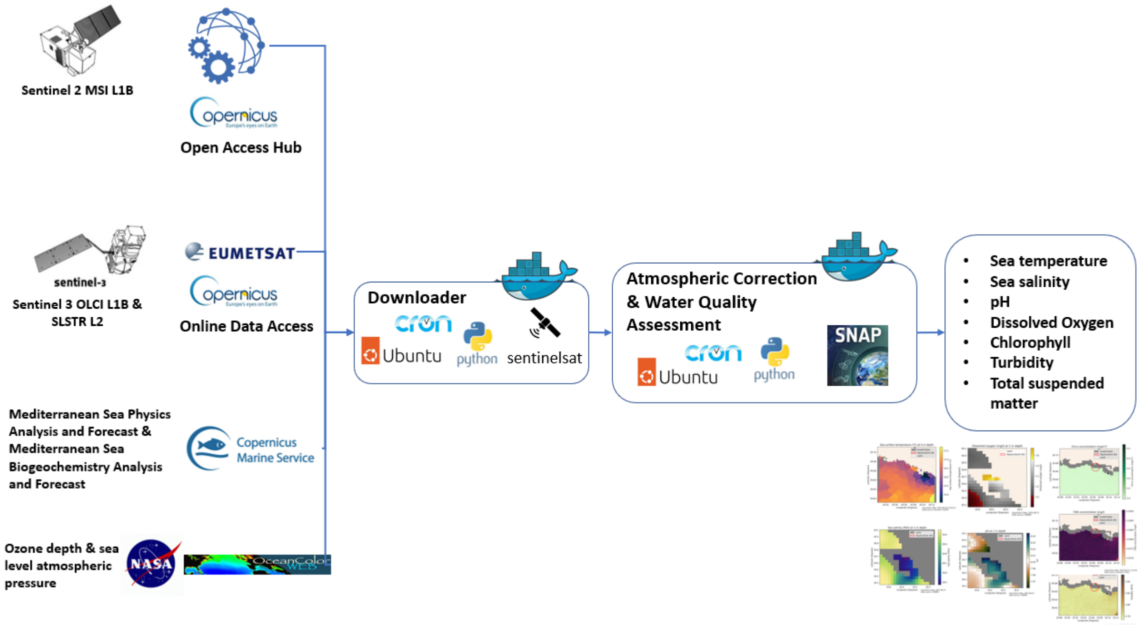

Figure 12: Earth Observation data architecture in the AquaLedger project[1].

[1] These data layers were integrated in the custom blockchain traceability solution which hosts the smart contracts that calculate metrics regarding the water quality of the production of orders. The goal is to enable the indication and characterisation of the ecological quality and status of the aquaculture food products as a part of the value chain tracking.

Chapter 5: Lessons and recommendations

Policymakers can play an important role in addressing several present challenges to greater investment adoption of DLT-based climate mitigation/ transparency promoting solutions.

There is still lack of frameworks, guidelines, specifications and best practices for blockchain applications designed for climate action and specifically Digital MRV systems, making it difficult for potential adopters to make educated decisions and to implement solutions. While multiple stakeholders (both from private and civil society sectors) have been experimenting to define the appropriate solutions, policymakers should advance their own thinking and positioning in order to have a catalytic effect on the market.

The different regulations are providing incentives for companies and other organizations to account for their carbon footprint. In the absence of concrete tools to ensure a cost-effective mechanism for reporting and tracking carbon data, however, there is a clear danger of increased greenwashing. The **main driver** for companies, when focusing on Sustainability, remains **regulatory pressure**.

The focus may lie on a number of policy areas, e.g., climate data, climate modelling projections, sectoral impacts, asset-based risks, metrics, finance, and digital Measurement, Reporting and Verification (MRV)[2]. Furthermore, guidelines regarding blockchain data structures, token standards, and even recommendations on the legal nature of tokenized carbon credits would help to further accelerate the implementation of blockchain projects.

It essential to ensure that more research and investment is directed to developing robust MRV platforms both from a carbon accounting mechanics perspective but also from a user perspective, whether financial intermediaries, corporates or sovereigns. There is a critical need to bridge the gap between the European Green Deal and climate tech Innovators by targeting European funds towards climate tech solutions and in particular in DLT supply chain management and carbon data custody solutions, such as MRVs.

In addition to this existing complexity, there is a digital divide between the global North and South that should be addressed with adequate support from policymakers and multilaterals, to ensure that developing economies that are considered to be a critical climate change link in the global value chains are also onboarded.

Finally, the challenge faced by DLT technologies as a whole are also a challenge in their use in climate change use cases and regulatory clarity and coherence among different initiatives is imperative. The push through regulatory pressure to advance a Green transition is a compelling tool in hands of European policymakers. However, bottlenecks and markets failures will be inevitable unless there is now a commensurate and directive strategy on harmonizing existing initiatives and investing in innovation to deliver cost-efficient toolkits and instruments to implement the policies on the ground.

Policy makers also have a role of convoking and mobilizing representatives from diverse areas of the supply chain, to co-design and co-develop in order to break silos and provide common protocols of use. “International and inter-industry cooperation and collaboration are essential to create global DLT-based infrastructure that not only accounts for the multiple facets of climate action, but also remains flexible to anticipate and incorporate the benefits of rapidly developing emerging technologies”[3].

[2] Blockchain for sustainable energy and climate in the Global South: Use cases and opportunities. Social Alpha Foundation, 2022.

[3] Ibid.

Annex – Insights from the experts

Questions for Mariana de la Roche Wills, IOTA, INATBA

The European Blockchain Observatory and Forum interviewed Mariana de la Roche Wills, for some insights into the work of INATBA's Social Impact and Sustainability Working Group.

EU OBSERVATORY: In the recently published INATBA report titled *Blockchain and the Climate Adaptation Imperative*, it's mentioned that 'the blockchain community has, likely unintentionally, ignored climate adaptation.' How can the blockchain community raise awareness of the benefits of adopting blockchain technology toward a more sustainable future?

MARIANA DE LA ROCHE: The blockchain community is already raising awareness of the benefits of adopting DLT for a more sustainable future. For example, in the context of supply chains, the support of a fully trusted, immutable, and interoperable data system – implemented with DLT – can improve the speed of automation and innovation. This enables new adaptive business models to move faster to the circular economy.

Often, data used to measure impact is limited to a narrow aspect of the supply chain, such as material production. This fails to calculate the real impact, and other measurements, such as the carbon footprint of production and transportation, are not considered. DLT offers the possibility of collecting, analysing, and reporting data concerning all aspects of the supply chain. By digitalising the total lifecycles of products and supply chain, these solutions also support enterprises to track and optimise the real impact they generate in society and facilitate the process of manufacturing sustainable products. There are many organisations currently developing different use cases regarding supply chains in different sectors, the IOTA Foundation being one of them.

However, as pointed out in the report Blockchain and the Climate Adaptation Imperative*, we have found that when scanning the blockchain ecosystem for use cases about environmental and climate issues, the main focus is on mitigation rather than adaptation. The focus on mitigation is due to the positive mindset that we still have to stop climate change; however, as we have seen in the past few years, rising temperatures are already impacting communities in multiple regions. Mitigation actions are still needed to prevent situations from becoming even worse. Still, the severe fires and droughts that dry up lakes and rivers, the flooding of entire cities, and the melting of the polar ice, among other catastrophes, are clear signs that we also need to invest in adaptation measurements and solutions that help us to respond to the consequences of climate change. As we pointed out in the report, this has already been recognised by the World Economic Forum.*

While mitigation can help us prevent significant damage to the environment, adaptation can help us mitigate the consequences of climate change, such as the increase in refugees fleeing infertile areas or floating cities and the negative impact on the agriculture industry and hence an increase in hunger, among others.

DLT stands out for having excellent applications in climate mitigation regarding data transparency and the tokenisation of carbon credits. These applications can also be re-purposed for climate adaptation. For example, integrating climate risks into supply chain use cases can help identify the impact of these risks on the production and supply of goods. Moreover, trust in the generated data can enhance the willingness of donors to adapt projects by showcasing where their donations are going and the impact of the actions implemented by the project, generating more security on the side of the donor and incentivising the continuation of their support. Moreover, there are already use cases that support climate adaptation. However, this might have been a grateful unintentional outcome as long as they did not consider this impact during their design.

Furthermore, several blockchain/DLT organisations seek out a more sustainable future – for example, by seeking out partnerships with business/industrial entities and institutions to work on use cases that develop sustainable solutions based on DLT/blockchain. The technology can achieve its biggest impact and scale when it is interoperable and applicable across borders and jurisdictions. Take the challenge of making supply chains more efficient and therefore more sustainable: DLT offers a fully trusted, immutable, and interoperable data system that can speed up automation and innovation across a supply chain, enabling new adaptive business models to move faster to the circular economy. For example, the IOTA Foundation is part of the Dig_it project, a European consortium that digitises the mining supply chain to create a more sustainable mining industry. These kinds of cross-industry collaborations are an ideal way of raising awareness of a sustainability benefit that many people perhaps wouldn't automatically associate with blockchain/DLT.

EU OBSERVATORY: The same report refers to the necessity of a 'toolkit' that will provide resources for analytical, financial, and operational technologies related to climate adaptation. Who would be the stakeholders to be involved in the development of such a 'toolkit'?

MARIANA DE LA ROCHE: In my view, the stakeholders should be a coalition of climate researchers, institutions, and technical experts taken from the public, private, and non-profit/third sectors. Ideally, the stakeholder's configuration will also have a participatory approach that involves communities and actors operating at the local level, who are most vulnerable to climate change.

Community involvement helps us understand short-term priorities, so that the actions designed with the interventions can directly impact the current context and aim to generate longer-term solutions. Moreover, considering the variety of stakeholders involved, defining where to prioritise and how to reward good adaptation is essential. These rewards should be based on efficiency, effectiveness, and quality of adaptation actions.

It is also essential to have representatives from the technology, policy, and financial sectors to ensure that the implementation will fit the context and that the technological solution will have the proper resources to be deployed and scale.

EU OBSERVATORY: What measures does the European Commission need to take to promote the added value of blockchain in sustainability and supply chain?

MARIANA DE LA ROCHE: Besides the regulatory support offered by the current crypto regulations, the European Commission should promote the correct environment for the proliferation of these solutions and incentivise their development. For example, it can help create spaces (online or onsite) to present solutions that can be replicated, as well as by incentivising the proliferation of the solutions via grants and subsidies.

The European Commission can also organise dialogue tables among different sectors working on supply chains, including technology, industry, and policy, to promote cooperation in deploying and scaling up solutions.

As a relatively new industry, the blockchain sector struggles with education gaps. Knowledge of the main advantages offered by blockchain applications tends to stay among people working in the industry and people with specific knowledge. This is demonstrated by the wide-spread misconception that all blockchain technologies are inherently resource-intensive and harmful to the environment. To raise awareness of the added value of blockchain in sustainability and supply chain and harness its unique qualities to tackle problems in the field, it is essential to bridge that knowledge gap. To address this, the European Commission could increase educational initiatives about blockchain outside the bubble of nerds, geeks and crypto freaks.

EU OBSERVATORY: Which are the best-known supply chain blockchain-based applications?

MARIANA DE LA ROCHE, BARA GREPLOVA, ASA DAHLBORN: There are multiple examples across sectors. To mention one that relates to climate adaptation, the Trade Logistics Information Pipeline (TLIP) project is a cooperation between the IOTA Foundation and TradeMark East Africa, an organisation working on *improving trade conditions in East Africa to grow prosperity in the region. The project aims to establish a digital infrastructure for exchanging guaranteed data between government agencies and other actors involved in cross-border processes. TLIP is an integrated solution built on the IOTA DLT that ensures information is shared from the source. Thanks to the underlying DLT's immutability and transparency, TLIP ensures the authenticity of digital certificates and prevents them from being tampered with. Also, TLIP's IOTA DLT provides visibility and traceability in the supply chain, avoiding tedious paperwork processes, cutting costs and delays, and removing the need to rely on third parties. By improving the flow of trade information, the project has excellent potential to increase the competitiveness of East African goods on the international market and thus create jobs and improve livelihoods in the region.*

Another initiative that demonstrates the advantages of DLT in supply chains is Well Adapted Coffee Supply (WACS). Developed by Adaptation Ledger Ltd., WACS is an adaptation ledger specific application (ALSA) in the Adapt IT™ suite of climate adaptation tools. These tools are used in the agricultural supply chain to better study measures taken by coffee producers to reduce their vulnerability to the climate crisis. WACS can be integrated with other supply chain applications with different functionalities, which provides several opportunities such as using tokenised vulnerability reduction credits (VRCs™) to reward projects that demonstrate climate-resilient farming practices. The main functionality of WACS is to integrate data inputs from sources such as remote sensors to create a transparent and immutable record of the VRCs generated by farm plots via adaptation efforts, which is possible thanks to the immutable characteristics of DLT. The result is guaranteed sustainability and reduced vulnerability of the whole food supply chain through leading climate adaptation practices.

The SCALA programme (scaling up climate ambition on land use and agriculture) is a joint project by the United Nations Development Programme, Food and Agriculture Organisation of the UN and the International Climate Initiative. The programme responds to the urgent need for increased action to cope with climate change impacts in the agriculture and land use sectors, focusing on twelve countries in Africa, Asia and Latin America, to support them in identifying and implementing priority climate actions under the agriculture and land use sector to achieve their national development contribution (NDC) goals and targets to build resilience to the changing climate conditions. The project focuses on designing key data elements that represent climate-resilient practices and it aims to help policy makers, food producers and audit agencies stimulate the uptake of climate-resilient practices registered in blockchain. Some of the possible actions include crop management, water resource management, soil and land management, livestock management, fishery management, warning system development, research and technology development, food availability enhancement and capacity development.

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