A Framework for Blockchain deployment towards an accountable and sustainable global food value chain

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Abstract

This study presented a holistic and integrated framework for blockchain deployment in global Agro-food 'supply' chains and how to transition them to accountable and sustainable global 'value' chains. Though many a scholarly contribution had assessed blockchain implementation at various levels in the chain, this research holistically looked at impediments to blockchain implementation at each level in the value chain. The study first established interlinkages between the three United Nations Sustainable Development Goals (SDGs), namely food for all (SDG 2), health for all (SDG 3), and sustainable consumption and production (SDG 12). It assessed the legal framework (namely trade law) and regulatory requirements therein.

Keywords-Sustainable Development Goal(SDG), Global Value Chains(GVC)**,** One Up, One Down(OUOD), (Information, Communication and Technology(ICT), Distributed Ledger Technology(DLT)

I. Introduction

Food is one of the most basic human necessities. Despite all the progress made by mankind, even in a pre-Covid pandemic and the pre-Ukraine war world, over 135 million people worldwide suffered from acute hunger. This food shortage could be directly attributed to unsustainable human activities, such as excessive deforestation, pollution and the economic downturn (United Nations, 2022). With the recent global pandemic and the ongoing war, it is feared, that by 2030, over 840 million people will not be able to meet their basic food requirements on a daily basis (Nature Editorial, 2022). The problem gets compounded by the fact that food value chains are often very long, and span across countries and therefore, it is very difficult to track and trace the food products in a reliable manner from the 'farm-to-the-fork'. In addition, over one-third of the food produced worldwide is wasted each year due to inefficiencies along the food supply chain (Yadav et al., 2021). In 2015, global leaders took an important stride towards global cooperation and multilateralism as they joined hands to achieve, for the benefit of all, the 2030 Agenda for Sustainable Development Goals (SDGs). Amongst them, SDG 2 aims to ensure 'food for all' by 2030. Healthy and nutritious food can also positively contribute to better health. Thus, the interlinkage between SDG 2 (food for all) and SDG 3 (health for all) must not be overlooked. The two goals are not only spatially closely situated, but they interestingly, also enjoy a very close evidence-based linkage. A healthy and nutritious diet can prevent many lifestyle diseases. Scientific evidence establishes that obesity is the root cause of many life-threatening diseases, such as hypertension, diabetes and heart-related diseases (Ali, 2021). As our resources remain limited; the world population continues to grow at a geometric rate, and is expected to cross the 8 billion mark in 2022, the big question is how can we, despite all the limitations and challenges, ensure the timely attainment of SDGs 2 and 3? The question is pertinent as over 3 billion people worldwide are unable to enjoy and afford a regular and healthy diet (World Bank, 2020). In other words, while over 840 million are unable to have daily and regular access to food (namely, SDG 2); the number gets still bigger and impacts a population of over 3 billion people globally, as the discussion transitions from 'access to food' towards 'access to "healthy" food' (namely, SDGs 2 and 3 collectively). Interestingly, SDG 12, namely 'sustainable consumption and production patterns' with its focus on the supply chain can be a key enabler to achieve SDGs 2 and 3. This can be explained by the fact that even though we cannot infinitely increase the resources deployed to augment the food produced, we can certainly enhance efficiencies along the food chain to augment the total output produced (Coelli et al., 2005). Increased efficiency, both dynamic as well as static, contributes to higher productivity. More efficient resource utilization and better allocation of resources, through improved production and allocative efficiency, respectively, can help get more output from the same limited factors of production. Greater innovation, also referred to as dynamic innovation in industrial policy, can enhance both the quality as well as the quantity of the output produced. This, in turn, leads to an upward shift in the production possibility frontier (PPF) (Kokkinou, 2013).

This article, accordingly, delves deeper into an emerging and one of the most discussed recent technological innovations, namely blockchain technology (SDG 12), and looks at its potential deployment in global value chains to enhance trust in global trade and achieve health and food for all (SDGs 2 and 3). To facilitate this, this article looks at the issue from the perspective of Agro-food global value chains (GVCs). Agro-food GVCs are long and complex, and may oftentimes span across many a country. Industrialization of food means that the food GVC is more globally dispersed than ever. Tracing and tracking food along the global value chain is a challenging and expensive task. The research question that this article seeks to answer is thus: How can blockchain technology be sustainably deployed across the entire Agro-food global value chain, and whether this can help track and effectively trace the food product from farm-to-fork, and thereby enhance consumer trust in global trade? To systematically address this research question, the article is organized as follows. Section “Introduction” looks at the interlinkages between SDGs 2, 3 and 12. Section “Literature review” offers a literature review and identifies the gap in the current literature, that this study seeks to address. It also highlights the methodology pursued in this research. Section “Global Food supply chain: From supply chain to a value chain-driven approach” discusses the need for a movement from a ‘supply chain’ to a ‘value chain’-based approach. The section “Blockchain technology and its relevance for the Agro-food value chain” discusses the key principles of blockchain technology. Literature evaluates how blockchain has been deployed at certain levels in the value chain. This section offers insights into how this piecemeal approach of blockchain deployment may be integrated to facilitate a truly global farm-to-fork blockchain-based value chain. Section “Discussions and Conclusion” concludes the discussion, identifies the management and policy implications of this research and offers a road map for further research.

II. Literature review

Many scholarly contributions have assessed the potential of the blockchain technology to meet the various targets of the UN SDG goals. Parmentola et al review over 184 peer-reviewed articles published in top-tier journals, that deal with blockchain technology, and find that its potential has not been evenly explored across the SDGs (Parmentola et al., 2021). While the benefits of the technology are over-explored in some of the SDGs, they remain under-explored in the context of the other SDGs. Most notably, Engineering (17%), Computer Science (15%), Social Science (13%), and Environmental Science (11%) literature have intensively explored the potential of the blockchain technology (Parmentola et al., 2021). Villiers et al study how the two emerging technologies, namely, the internet of things and the blockchain technology, can be successfully married to offer reliable data and information and thereby, contribute to the UN SDGs (de Villiers et al., 2021). The authors found that enhanced accountability can contribute to greater efficiency and more effective management along the value chain and thereby, facilitate the attainment of the SDGs. Using a multiple case study approach, Tsolakis et al. assess the potential of the blockchain technology to augment tracking and tracing in fish supply chains from the lens of Operations Management (Tsolakis et al., 2021). The authors looked at the blockchain implementation in both - the small scale, such as local fishing operations and medium- to large-scale operations, such as commercial fishing operations and canned tuna manufacturing in Thailand. They apply the ‘Principal-Agent Theory’ and ‘Transaction Cost Analysis’ to assess the value of digital supply chains to achieve the SDGs. Yadav et al identify the key barriers that limit the uptake of blockchain technology in the Indian Agricultural Supply Chain (Yadav et al., 2020). To identify the barriers to adoption, Yadav et al use an integrated ‘ISM-DEMATEL-Fuzzy MICMAC’ methodology. This methodology was used to explain how the ten identified factors impact the level of adoption of the technology, as well as how these different factors re-enforce one other. The authors further undertaken a rigorous sensitivity analysis to evaluate the robustness of their model. To illustrate with an example, they identify that ‘interoperability and standardization’ (factor 4), ‘scalability and system speed’ (factor 7) and ‘security and privacy concerns’ (factor 3) not only limit the blockchain adoption in the context of the Indian agriculture, they in fact, also mutually re-enforce and amplify the impact of one other. Yadav et al. (2021) further advance the model developed by (Yadav et al., 2020) and integrate these foregoing barriers into clusters to develop an effective framework to assess how blockchain may be adopted and integrated smoothly into the food value chain (Yadav et al., 2021). The authors selected a very diverse set of stakeholders from across the value chain—ranging from blockchain developers to top (C-level) executives and from farmers to professors. This helps them effectively identify the key factors that limit the adoption of the technology. The authors offered insightful recommendations for the Agro-food industry practitioners as well as for the policymakers. They identified how blockchain technology by offering real-time information can facilitate effective monitoring and augment trust in the Indian food security system. This enhanced trust, in turn, can solve the issue of investments in the Agri-food sector. Finding trusted and reliable information about the Agro-food supply chain at their disposal, investors and crowd-funders may find it easier to undertake a cost-benefit analysis and agree to invest their money even with small and medium-sized producers (Yadav et al., 2021). The literature referred to above, and also as discussed in this paper, made a valuable contribution to highlight the potential and the limitations of blockchain technology in achieving one or more SDGs. These discussions were either field-specific or limited to a particular geography. The present paper contributed to this rigorous debate by making the following three notable contributions to the literature.

First, the paper looks at the entire global Agro-food GVC, and assesses how blockchain technology may help clear the bottleneck at each step in the value chain—from documentation to financing, from the farm to the fork—and thereby, offers a blueprint for a truly global blockchain-driven farm-to-fork Agro-food value chain. Second, to achieve this, the paper pursues a case study-based methodology and summarizes its findings in the form of a flowchart, that clearly maps which case study may have suggestions for which level of the food value chain. Third, employing an inter-disciplinary methodology, with research insights from the scientific literature, operations management, trade and customs law, and management literature, the study was a constructive endeavour to develop a workable framework for management, and policy makers alike. The paper, accordingly, systematically studies the gaps in the current piecemeal blockchain deployment, synthesizes the findings, and complements the case studies discussed, in the form of a flow chart. To do so, the paper employed qualitative desktop-based secondary research and analyses the peer-reviewed literature from different disciplines.

III. Sustainable development goals

An important mark that weaves all the countries, irrespective of their level of development, whether developed, developing, or under-developed, is the desire to have a peaceful, prosperous, and sustainable future for generations to come. In the 2030 Agenda for Sustainable Development Goals (SDGs), this mutual desire is reflected in the 5Ps of the SDGs—namely, ‘People, Planet, Prosperity, Peace and Partnership’ (United Nations Sustainable Development Goals, 2023). There are 17 SDGs as identified in ‘Transforming our world: the 2030 Agenda for Sustainable Development’. SDG 2 refers to the need to ‘end hunger, achieve food security and improved nutrition and promote sustainable agriculture’. Notable ways recognized in the Charter to achieve SDG2 are to ensure access to food (goals 2.1 and 2.2), doubling agricultural productivity, develop sustainable food production systems and the implementation of resilient agricultural practices and promoting flora- and fauna-bio diversity (goals 2.3, 2.4 and 2.5, respectively) through enhanced investment in scientific, logistics and financial services as well as greater international co-operation for a more egalitarian global development (goals 2.a, 2.b, and 2.c). Before zooming in on SDG 2, and establishing its relationship with trade, and emerging technologies, it is vital to establish its link with the other two SDGs, namely SDG 3 which seeks to ‘ensure healthy lives and promote well-being for all at all ages’ and SDG 12 that seeks to ‘ensure sustainable consumption and production patterns’. SDG 3 calls for healthy lives for all. Global health and well-being are the key goals of this agenda. Access to healthcare and medicines is but one aspect of health for all. Perhaps even more desirable is a healthier life, which means a longer and healthier life with minimalistic dependence on the healthcare infrastructure. As healthcare and pharmaceuticals go digital, there is a momentum towards precision-based medication and personalized healthcare to ensure a healthier lifestyle (Cahan et al., 2019).

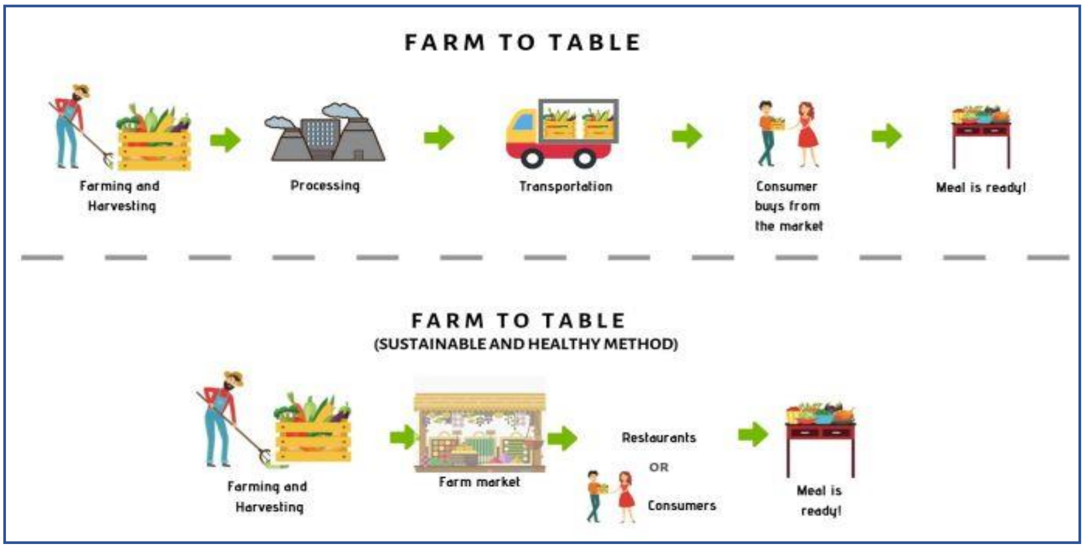

Figure 1. Sustainable Agro food chain

Consider for example, if one’s app indicates early on the need to keep sugar under control, and prevent obesity, then this early detection and recommendation of a low-calorie exercise and a healthy diet can go a long way to prevent many a life-threatening lifestyle disease. Food has a critical role to play in enabling this healthy lifestyle. Empirical evidence establishes that whereas cheap, ready-to-eat, and fast food may have enhanced the quantity of food at affordable rates, it has also significantly pushed the healthcare budgets of Governments worldwide (Lang, 2004). In the US alone, food-borne pathogens, such as salmonella and E-coli, affect one in six Americans each year and cost the US taxpayer an average of US $55.5 billion per annum (McDaniel and Norberg, 2019). Sedentary lifestyle coupled with high carbohydrate and fat-rich diets and processed foods has made millions fall prey to various lifestyle diseases (Lang, 2004). Thus, in order to ensure health and food for all, the inter-linkage between SDGs 2 and 3 must not be overlooked. The two goals are not only spatially closely situated, but they interestingly, also enjoy a very close evidence-based linkage. Interestingly, SDG 12, namely 'sustainable consumption and production patterns' with its focus on supply chains, can be a key enabler for SDGs 2 and 3. SDG 12 calls for a march towards 'sustainable consumption and production' (12.1) by 'sustainable management and efficient use of natural resources' and environment-friendly practices (12.2) such as through reduced use of pesticides and chemicals in the food chain and by encouraging a more circular economy (12.5). To ensure this, the SDG calls for the following notable measures—first, the adoption of and the reporting of sustainable measures by large corporations (12.6); second, creating awareness amongst people (12.8) and third, striving towards the larger vision of sustainability, by considering, varying levels of development in different countries (12.1). To achieve this, the SDGs call for developing monitoring and implementation tools (12.b) and encouraging scientific, technology and knowledge transfer amongst countries (12.a). These SDGs also enjoy cross-linkages with the other SDGs (for instance, the cross-linkage between SDG 1 and 2, cross-linkage between goals 12 and goals 13–15). However, in light of the scope of the present research article, only SDGs 2, 3 and 12 remain central to the discussion. Looking at SDG 12, the focus is to ensure 'sustainable and accountable global value chains. When viewed from the lens of SDGs 2 and 3, the focus can be further narrowed down to 'sustainable Agro-food supply chains. The following section, accordingly, discussed the need for a movement from a 'supply chain' to a 'value chain'-driven approach to enable 'sustainable Agro-food value chains'.

IV. Global food supply chain: From supply chain to a value chain-driven approach

The two expressions, namely, supply chain and value chain are used interchangeably in the literature. To offer clarity to the discussion, this section first elucidates the difference between the two, and then explains why an Agro-food value chain approach may be better suited to appreciate the contributions of the blockchain technology.

The first important question is why does one view this debate from the perspective of value chains, and more particularly in this case, as Agro-food global value chains? This may be attributed to the fact that today competition does not take place between firms. Competition, today is 'between competing supply chains' (Grainger et al., 2018). For a competitive advantage to be sustainable, a given supply chain must be able to offer better value and more competitive costs to its customers. Value-driven Agro-food chains must be trackable and traceable. This can be a key contributor to the sustainable dimension of a value chain. To ensure the sustainability of supply chains, they must consider the triple bottom line concept. The 'triple bottom line' (TBL) refers to the 'environmental, social and business dimensions' of the value chain. This TBL approach in management literature also aligns with the focus of this article on the SDGs, most notably SDG 12, from a policy perspective. An important strategic and competitive dimension of this TBL-driven approach is to ensure 'confirmation and verification [of] sustainability criteria and certifications' (Saberi et al., 2018). A supply chain, that is operated like a value chain, promises better value to the consumers and also presents greater opportunities for cross-border trade. In this respect, the interlinkage between a robust value chain and trade cannot be underestimated.

An agricultural supply chain refers to the different steps—starting from farming, production, distribution to processing to sale to end consumer—namely the steps that complete the journey of an agricultural product from the 'field to table' (Mirabelli and Solina, 2020). The concept of value chain, on the other hand, is more nuanced as it maps the value-added at each stage in this production process (Handfield and Nichols, 2002). In other words, a value chain-based approach to logistics management helps identify the key promise areas and pain points as well as key value points along the supply chain. This also helps identify levels in the value chain, whereby leveraging new technologies will maximize return on investment and in turn, optimize the productivity of the entire supply chain. When viewed from this perspective, the supply chain transitions to a value chain. To illustrate this approach and its significance with an example, scholarly contributions have mapped the value chain of personal computers (PCs) and tablet PCs. Three notable findings emerge from that study.

First, based on a value chain-based approach, a firm may choose to outsource and focus on its core competencies to maximize profits. This is typically observed in the information communications and technology (ICT) sector where innovation and marketing are key sources of value addition and product differentiation. Firms, in such an industry, may, therefore, prefer to sharpen their competitive edge and focus on their core competencies. Second, value addition at different stages across the value chain may vary substantially. In the case of the Nokia 95 smartphone, for instance, the country of 'final assembling' captured only 2% (circa Euro 11) of the total value of Euro 546 plus taxes, as distinct from the countries of research, innovation and marketing, that captured over 51% (circa Euro 275) of the total value. Third, and very important from a trade policy perspective, was the issue of inter-linkages and 'dispersed geographic effects of [a change in conditions of] trade even within the same country [or within the same economic area, such as the European Union]' (Tyagi, 2020). These observations call for a well-designed optimal trade policy. The discussion, henceforth, accordingly, looked at the debate from the lens of global Agro-food value chains.

The next important, and related question was what determines the position of a country on the global Agro-food Value Chain? Empirical analysis indicated that successful participation in the value chain calls for a measured and an optimal policy design. Such measures may include easing regulatory restrictions, enhancing pro-innovation climate and simplifying 'tariff, time, speed and administrative procedures' (van der Marel, 2015). For a movement along the value chain—whether relative upstream or relative downstream—countries must scale up their services, offer labour market flexibility and intensify investment in ICT and knowledge management (van der Marel, 2015). As production and manufacturing become more complex, services spontaneously become an integral part of the value chain. Even for products, such as Agro-foods, revealing as it may appear, services account for a major part of the value chain. The food value chain has experienced continuous 'industrialization', 'servicification' and technological interventions over time. To illustrate with an example, the introduction of the 'Chorleywood process' in the baking industry led to a quantum leap in the bakery sector. This turned the baking industry into an automobile-like industry, wherein the newly introduced 'Chorleywood process' could now make 'whipped bread to rise in a few minutes'—a process that until then took up to 48 h (Lang, 2004). These and other technological innovations over time led to 'flexible specialization' and the emergence of a 'new human geography of food' (Lang, 2004). Therefore, 'servicification of the production process'—meaning services become an increasingly significant and integral part of the GVC—too needs to be taken into account to ensure 'an optimal allocation of information, [which in turn also implies] cross-border data flows' (van der Marel, 2015). As the value chain in general, and the Agro-food industry in particular becomes more service-based, data has an increasingly essential role to play. Interestingly, in the case of Agro-food GVCs, this is truer than ever, whereby taking account of, and optimization of the use of ICT services, such as the blockchain technology, can also substantially enhance efficiencies and minimize food waste (Saberi et al., 2018).

Interesting as it may sound, the Agri-food sector is no stranger to technology. In fact, it has been the subject of constant scientific innovation. Laser bar codes and Electronic Point of Sale (EPOS) systems were employed way back in the 1980s in the retail sector (Lang, 2004). This was soon accompanied by the Japanese style 'just-in-time' (JIT) distribution system, robotic warehouses and crop and retail management through satellites. As a matter of fact, the so-called revelations and advantages of big data and customer profiling were first experienced in the retail sector, when Target, a US retail outlet accurately predicted the pregnancy of a teenage girl, even before her family came to know about it (Hill, 2012). Another important subtility with the Agro-food GVCs is that they are, as discussed above, long and complex and may oftentimes span across many countries. Industrialization of food means that the Agro-food GVCs are more globally dispersed than ever. Following globalization, the ICT sector experienced the rise of global value chains and horizontal specialization; the Agro-food markets, on the other hand, experienced an opposite trend. The 'rapid regionalization and the move towards globalization' led to the rise of 'cross-border concentration' in global Agro-food value chains (Lang, 2004). This can be explained on account of a number of factors. Lack of standardization in terms of record-keeping may mean that participants across the value chain may record data and other related information in varying formats. To minimize the cost of maintaining records, producers in the Agro-food value chain normally follow the 'one up, one down' approach (OUOD) (Kamath, 2018). This means that suppliers along the value chain carry information only about the immediate supplier upstream and the one downstream to them. This creates issues of accountability and transparency. To iron out these information asymmetries and internalize externalities, firms in the sector engage in vertical integration. Externalities may be one key reason why firms engage in non-horizontal concentration (meaning vertical and conglomerate) in the Agro-food value chain. Other factors include increased economies of scale and scope, the possibility to deploy new emerging technologies and a strengthened post-merger bargaining position, which in turn leads to enhanced profitability for the vertically-integrated firm. Competition authorities worldwide are taking note of this trend towards concentration in the Agro-food-seed sector. Can there be other alternatives that can check this trend toward global concentration in the Agro-food sector? More particularly, can a technological innovation, namely blockchain technology address some of these concerns? If so, then this technological innovation may then not only be a panacea for competition, but it may also contribute to trust in trade, by enhancing the traceability and accountability of these GVCs. The following section, accordingly, first explores the key features of the blockchain technology, followed by a discussion on how it may facilitate decentralization and add value to the Agro-food GVCs.

V. Blockchain technology and its relevance for the agro-food value chain

Blockchain is not one technology, it is, in fact, a combination of many technologies that developed over time. Simply put, a blockchain may be identified as a distributed digital ledger of transactions that are time-stamped and nearly immutable. The transactions are stored and added to the chain by 'nodes. A node may be an internet-connected converged telecommunications device—such as a smartphone, a computer, a laptop, or any other inter-connected handheld device. Possibility for smartphones to act as a node, as section "Limitations of the blockchain technology" *infra* illustrates, can be an attractive attribute to ensure the widespread adoption of the technology in the developing and the under-developed world. Each time a new transaction is entered on the blockchain, it is 'broadcast to the network for verification and auditing' (Saberi et al., 2018). For a transaction to be approved, the majority of the nodes must approve this transaction. Decentralization means that no one central server is in control of all the information in a blockchain. The information is stored across the nodes in a decentralized manner. This ensures trust in the system, as distinct from reliance on one central authority or an intermediary.

A blockchain may be permissioned or permissionless. In a permissionless blockchain, participants do not know each other and anyone can participate in the permissionless public blockchain. Satoshi Nakamoto's Bitcoin is a classic example of a public permissionless blockchain (Nakamoto, 2008). A private blockchain is different in the sense that the network is closed and access is offered only to known participants and those invited to the network. In other words, the participants in a private blockchain know each other and participation is available only upon authorization. These kinds of permissioned blockchains are typically suited for tracing and tracking, and for certification purposes, where the participants may benefit from knowing the details of the service provider(s) and the quality of inputs added across the value chain.

A typical supply chain—as the section "Global Food supply chain: From supply chain to a value chain-driven approach" *supra* illustrates—is vertical, and the suppliers follow the OUPD rule, wherein each service provider knows the identity of only those immediately above or those immediately below them in the supply chain. A blockchain-based solution makes this value chain more circular, as each new transaction digitally entered on the platform is flashed across to all the participants in the network. It is only after the majority of the nodes have approved this transaction, that the information is added to the ledger. Moreover, the entire ledger of information remains visible to all the participants, including the customers, that are distantly located from the suppliers upstream in the value chain. This enhances the traceability of goods, and thereby, augments trust in the system. In a consortium blockchain, a group of firms manages the blockchain. This is a kind of semi-private and 'partially decentralized' blockchain, whereby the consortium partners are known to each other, and access can only be available upon invitation (Ganne, 2018).

An important functionality of blockchain technology is 'smart contracts', that work with an 'if-then-else' kind of logic. They are not contracts as understood in law, instead, they automate the self-execution of a prescribed act, once some pre-defined sets of conditions have been fulfilled. These self-executing smart contracts can take information from different data points, technically referred to as 'oracles', as inputs. These inputs trigger action. As an example, in our example of 'sliced mangoes' (see Walmart case study in the section "Walmart uses blockchain to enhance tracking and traceability" *infra*), if Walmart feeds a condition that all the 'sliced mangoes' must be immediately recalled by a certain date, the smart contract will automatically flash this instruction to all the relevant nodes in the blockchain at the suggested point in time. This also means that smart contracts work in alignment with other technologies, such as the Internet of Things (IoT) that act as an important source of data, and trigger actions along the value chain.

A. Advantages of the blockchain technology

Blockchain is a kind of distributed ledger technology (DLT). However, what makes it different from the other DLTs is that it is a decentralized network. This means that the information is not stored in one centralized network. Instead, the information is disbursed across the network in a decentralized manner. No one central authority can completely control the network, or alter its contents without compromising the integrity of the time-stamped ledger of transactions. In other words, tampering may lead to 'forking', or in other words, breaking up the chain. This particular feature makes blockchains near-immutable. 'Near-immutability' does not mean that a blockchain cannot be tempered with. What it means is that blockchains are 'temper evident and temper resistant', which makes it extremely difficult to temper with them (Yaga et al., 2019). There may, however, be situations whereby the blockchain (especially permissionless) can be tempered with, as the section "Limitations of the blockchain technology" *infra* illustrates with an example. Possibility for smartphones to act as a node for blockchain technology is another notable advantage of the technology, as it can be a key enabler for the uptake and success of the technology. An important case in point is the success story of M-PESA, the mobile money, in Kenya. In Kenya, a host of socio-economic and political factors led to a technological innovation called M-PESA. M-PESA emerged as a safe and secure way of transferring money across Kenya.

The country had a poor banking infrastructure, which meant that people were forced to keep large amounts of cash in their homes. To transfer money to their near and dear ones, they are often required to carry cash in unsafe and dangerous conditions. Seeing an opportunity, Safaricom, part of Vodafone and Kenya's leading Mobile Network Operator (MNO), starting 2007 offered mobile users the possibility to deposit and send cash to friends and family situated across the country. Senders could deposit cash with a local agent in one part of Kenya, and the receiver could safely withdraw it from another Safaricom agent located in another part of the country. Within the first month of its operations, M-PESA gained over 20,000 registered users. Following a decade after its launch, today, M-PESA is a leading means of mobile-based money transfer service in Kenya with over 27.8 million out of 45 million Kenyans using the service on a daily basis (Miriri and Blair, 2018). Even leading app stores, such as Google, have started to accept payments from the M-PESA service. The success of M-PESA can be attributed to two important factors—first, the possibility to conduct transactions on a mobile phone, and second, the role of public-private partnership in the initial stages of the project. M-PESA offered a solution to a social problem, which without initial funding from the public sector, may not have attracted the attention of the private sector. Blockchain, likewise, offers solutions to social problems, such as accountability and traceability of Agro-food products, which may benefit from a public–private partnership. Investment in the technology, particularly for the development of consortium blockchains, may call for at least some initial seed funding from the public sector (Ganne, 2018). We return to this issue in the section " Case studies", wherein two blockchain-based pilot proof of concepts—namely importing flowers from Kenya to the Netherlands (case study "Flowing flowers from Kenya to the Netherlands") and the NAFTA/CAFTA project (case study "NAFTA/CAFTA and blockchain POC")—establish the role of the PPP for at least the initial uptake and the follow-on mainstream acceptance of the technology.

B. Limitations of the blockchain technology

Blockchain is temper resistant, meaning that data once entered on the blockchain cannot be tempered with. However, the information first entered on the blockchain may be false. In other words, the credibility of the blockchain depends on the information entered into it. In case of false and incorrect information being entered on a blockchain, this cannot be corrected by the technology itself. This means that despite the implementation of the technology, some form of human intervention—as is for example the case for data entry and manual document verification—will still be required (Ganne, 2018). This is a crucial fact that merits due attention while employing the technology. What blockchain can ensure is that once data is entered on it, it cannot be altered, in other words, it remains 'temper resistant'. However, what blockchain cannot ensure is that the data entered on the blockchain has not been tempered with. Thus, the human intervention also brings with it the possibility of entering incorrect and false information on the blockchain.

Another important limitation of the technology is that even though it is near temper resistant, it nonetheless, remains fallible. This can be attributed to the '51% attack' problem, as per which once a validator or a group of validators control more than 50% of the network's computing power, they can easily hack-in to change and compromise the entire system. In an early example that clearly exhibited the limitations of the technology, US-based Distributed Autonomous Organization (DAO) invited participants to its Ethereum-based public platform to invest in the cryptocurrency 'ethers' on a project of interest. A hacker identified a problem with the blockchain and forked the system to divert over US$ 60 million out of the total US$150 million raised by the DAO seed funding project. To resolve the issue, the Ethereum developers had to personally intervene and hard fork the system, meaning 'break down the whole system, and not just the DAO' (Tyagi, 2018). It emerges that architecture-wise, this problem is more endemic to a public blockchain. However, even for a private blockchain, albeit in a different manner, this attack remains a possibility. In other words, the user interface is the point where one may encounter the most troubles in the blockchain ecosystem. Consider for example, when a majority of validators enter into a collusive agreement and decide to attack the network. Such a collusion-driven alteration may be easily undertaken in a private blockchain where the participants know each other, and may easily connive with one another. Theoretically, though Vitalik Buterin proposes a '99% attack solution' to this problem, but its implementation remains to be seen in practice (Ganne, 2018).

Scalability of the blockchain technology presents another area of concern. This may be a bigger area of concern for permissionless blockchains, as distinct from permissioned consortium-based blockchains, where access is available only upon permission. To illustrate with an example, theoretically, Bitcoin may conduct up to 4000 transactions per second; however, in practice, a Bitcoin network, on average, processes only seven transactions per second (Ganne, 2018). Private sector solutions, such as IBM's permissioned Hyperledger fabric have been able to overcome this limitation, which can process up to 3500 transactions per second for certain pre-determined standardized tasks (Ganne, 2018). However, the issue nonetheless requires attention and investment, particularly in the case of government-led blockchains. This is well-illustrated by the post-pilot participant survey in the NAFTA/CAFTA and Blockchain POC, discussed in section "NAFTA/CAFTA and blockchain POC" *infra*.

To ensure widespread adoption, interoperability of the blockchain is a must-have feature. Alternatively, in the medium to long run, on account of the network effects, the market may tip to one or two dominant blockchain architectures. This will then bring its own set of problems as the current multi-sided platforms present to the competition law authorities worldwide. Currently, the blockchain architecture is scattered and different blockchain-based solutions are being developed worldwide. These market participants may be categorized into infrastructure providers (such as IBM, Microsoft, and Bluzelle), application providers (such as Ripple and Factom), and service providers (such as Infosys and Accenture) (Blockchain Vendors, 2019). While some of the solutions may currently allow communication with an external vendor—such as Microsoft's Azure blockchain currently allows access to blockchain platforms such as Hyperledger Fabric, Ethereum, and Cord—this interoperability, however, remains limited and different blockchains continue to evolve independently in 'digital islands' (Blockchain Vendors, 2019). Interoperability and standardization are notable limitations of the current stage of development of the blockchain technology that merits attention of policymakers. For a successful and widespread deployment of the technology, these infrastructure bottlenecks merit timely consideration and intervention.

V. Discussions

For sustainability to be durable and long-lasting, sustainable thinking must permeate through the entire Agro-Food GVC. In the case of food production, and with our focus on Sustainable Development Goal No. 2 which is 'zero hunger', this requires accountability and transparency across the value chain through the implementation of green environmental standards and a resilient digital infrastructure across the Agro-food GVC. As per estimates by the World Economic Forum (WEF), the reduction of supply chain-related barriers can raise the global GDP by 5%, and international trade by over 15% (McDaniel and Norberg, 2019). This positive effect is up to 15 times bigger when compared with the effect of eliminating tariff-related barriers to trade. Trade-related environmental measures and agreements richly borrow from two legal worlds, namely, international environmental law and international trade law (Lockhart et al., 2022). Implementation of these measures though highly desirable, may also lead to higher non-tariff barriers to trade. This article suggests and offers a road map for the introduction of speed and efficiency, and minimization of non-tariff barriers across the Agro-Food GVCs by leveraging the benefits of blockchain technology to facilitate the SDGs, trade, and competition.

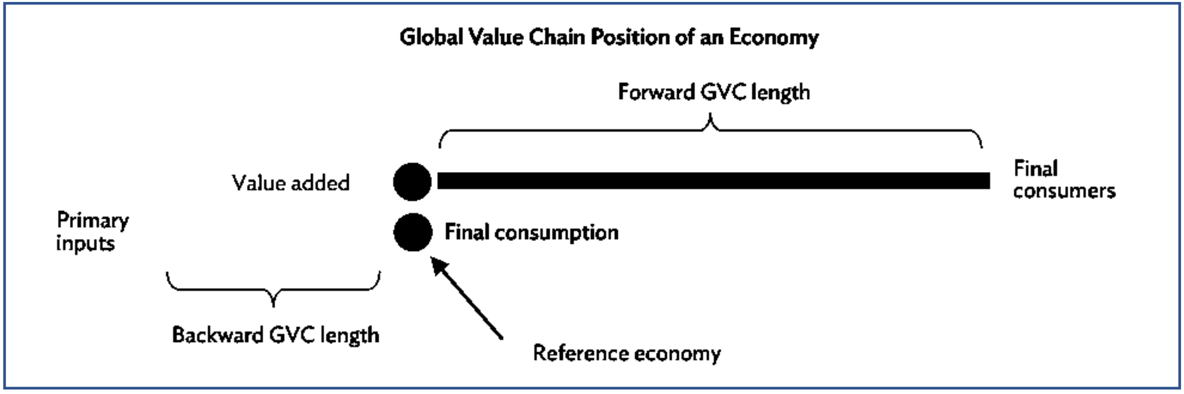

Figure 2. Global Value Chain Position of an Economy
Note. From Alvarez et al., 2021, p. 11. CC BY-NC 3.0 IGO

According to paras 7 and 12 of the Rio Declaration, 'transboundary environmental problems' should be resolved through international cooperation, multilateral approach, and inclusive participation of the different member countries. The vision of SDG 12—notably the sub-sections that encourage scientific, technology, and knowledge transfer amongst countries (SDG 12.a)—has a critical role to play in this regard. In alignment with this approach, this article identifies the potential of blockchain technology to develop agile and sustainable Agro-food GVCs—where finance and customs do not hold up the suppliers, and the possibility to track and trace goods—nourishes consumer trust in the food, that they cherish.

As this article elucidates, a blockchain-based Agro-food GVC promises to not only enhance trust in trade by augmenting the tracking and traceability of food products across the entire value chain, but it will serendipitously also address a key concern of competition authorities worldwide, namely the issue of ever-rising concentration in Agro-food GVCs. This article, in addition, also identifies the following three areas that merit urgent attention of the policymakers and that can be a fertile ground for further inter-disciplinary research.

First, as the discussion on the limitations of the blockchain technology in section "Limitations of the blockchain technology" *supra* indicate, interoperability, standardization and scalability of the blockchain technology require deliberation by both the public as well as the private sector. Absent a proper legal and technical framework for these three issues, it is apprehended that blockchain may be 'confined to proofs of concept and pilot projects' (Ganne, 2018). Connecting this to the story of M-PESA, which dates back to early 2000, when following a call to the multinationals to develop solutions for quick attainment of the Millennium Development Goals (MDGs), the predecessor to the SDGs, executives at Vodafone came up with an innovative idea to enhance access to finance. The underlying idea was that enhanced access to finance would boost entrepreneurship and wealth generation through economic activity, job creation, and trade (Hughes and Lonie, 2007). In early 2003, following the World Summit for Sustainable Development 2003 in Geneva, the UK Government's Department for International Development's (DFID) newly established Financial Deepening Challenge Fund (FDFC) and Vodafone together invested about £2 million to run a pilot M-PESA project in Kenya (Hughes and Lonie, 2007). The success of M-PESA to achieve the MDGs (or the SDGs) is well-known to all. Like M-PESA, blockchain holds a promise to a social problem, that is the possibility to track and trace from the farm to the fork. Likewise, above-referred problems confronting blockchain technology can be suitably addressed through well-planned public–private partnership. It may be very insightful to further study the issue of 'interoperability, standardization and scalability' both from a technical perspective, as well as how policymakers (notably innovation and trade policy) can create an enabling framework to augment interoperability, promote standardization as well as scale up the current pilot blockchain projects.

Second, the NAFTA/CAFTA case study and the follow-on post-POC survey there in (section "NAFTA/CAFTA and Blockchain POC") indicate the need for creating awareness of and knowledge about the technology. This means that only the automation of the process and the adoption of an agile blockchain will not suffice. Programmes, such as short training courses by trained academic staff at universities, in collaboration with the public authorities and non-governmental groups, for start-ups and SMEs may go a long way in creating an open mind-set and encourage quick adoption of the technology. From a more practical perspective, it may be insightful to further study and develop such programmes.

Third, it may be useful to further develop the qualitative findings of the present study, and use them in a real-world 'farm-to-fork' project. This scaled-up project should not be limited to certain aspects of the value chain, such as tracking and tracing, or mere financing of the transaction. It should attempt to assess in a simulated, pilot set-up, the feasibility of blockchain implementation across the entire Agro-food value chain.

VI. Conclusion

Way back in the 1990s, Lessing presented a vision of 'code as an efficient means of regulation' (Lessig, 1996). A blockchain-based smart code presents the possibility to present law and regulations 'into code and housed on the blockchain' (Shope, 2022). This paper offers the potential of the blockchain technology to expedite trade by smoothening the rough edges of the Agro-food GVCs. An important next step is to make blockchain-based smart contracts smarter with data inputs from different Internet of things (IoT) points. This is important, as the discussion in this article illustrates that blockchain can only ensure that the data on the blockchain is not tempered with. The reader may recall from the above discussion that the solution in itself cannot promise is whether the data first entered on the blocks is correct or not. Currently, data on the blocks are entered by human declarant(s) (Shope, 2022). This is where the Artificial Intelligence (AI) and IoT data points becomes important. Escorcia et al. deploy the 'weighted voting ensemble deep learning (ISNpHC-WVE) technique' to enhance farm productivity and more effective input, namely fertilizer, management (Escorcia-Gutierrez et al., 2022). Even though their research offered insights for precision-based farming, it has related significant implications for developing AI-driven and IoT data point inputs on the blockchain. This, in turn, can also, potentially address the eco-labelling-related issues as referred to in the section, "International Trade, food value chains, and the blockchain technology" *supra*. However, as the discussion of AI leads to another set of complex technical, managerial, and related legal rules (such as privacy, data protection, and ownership), further research in this field can take this discussion a block further and articulate how an AI, IoT and Blockchain-driven ecosystem can transition our Agro-food landscape, that is befitting to leverage on the technological marvels of Industry 4.0.

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