A FRAMEWORK FOR BLOCKCHAIN DEPLOYMENT TOWARDS AN ACCOUNTABLE AND SUSTAINABLE GLOBAL FOOD VALUE CHAIN

Abstract

This study provided a thorough and comprehensive framework for using blockchain technology to international food "supply" chains and outlined the process for transforming them into ethical and sustainable international "value" chains. Although earlier academic studies have assessed blockchain implementation at different points in the chain, this study looked at hurdles to blockchain deployment at every level of the value chain. The report began by outlining the linkages among the three Sustainable Development Goals (SDGs) of the UN: food for all (SDG 2), health for all (SDG 3), and sustainable consumption and production (SDG 12). It assessed the underlying trade law legal framework as well as the regulatory needs.

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

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I. INTRODUCTION

Food stands as one of humanity's fundamental needs. Even in a world before the Covid-19 pandemic and the Ukraine conflict, more than 135 million people across the globe experienced acute hunger. Unsustainable human activities, such as widespread deforestation, pollution, and economic downturns, are directly to blame for this severe food crisis (United Nations, 2022). Concerns are mounting that by 2030, more than 840 million people would find it difficult to achieve their daily dietary needs due to the ongoing war and the recent worldwide pandemic (Nature Editorial, 2022). This predicament is further complicated by the extensive and complex nature of global food supply chains, making it exceedingly challenging to track and trace food products reliably from their origins to consumers' plates. Moreover, inefficiencies along the food supply chain result in the wastage of more than one-third of the world's food production annually (Yadav et al., 2021).

In 2015, global leaders took a significant step towards global cooperation and multilateralism by committing to the 2030 Agenda for Sustainable Development Goals (SDGs) for the betterment of all. Among these goals, SDG 2 strives to ensure access to food for all by 2030. It is crucial not to overlook the interconnection between SDG 2 (food for all) and SDG 3 (health for all). These two goals are not only geographically close but also intricately linked through scientific evidence. A healthy and nutritious diet can serve as a preventive measure against numerous lifestyle diseases. According to scientific studies, obesity is a major contributor to serious illnesses like diabetes, hypertension, and cardiovascular disorders (Ali, 2021).

The world's population is predicted to reach 8 billion people by 2022 as it continues to expand exponentially while our resources remain scarce. The most important question is how, given the obstacles and constraints we confront, we can quickly accomplish SDGs 2 and 3. Given that over 3 billion people globally lack access to or cannot afford a regular, healthy food, this subject becomes increasingly important (World Bank, 2020). Stated differently, while over 840 million people worldwide suffer from a lack of daily and consistent access to food (SDG 2), this figure rises to affect over 3 billion people when the focus is shifted from 'access to food' to 'access to nutritious food' (which includes both SDGs linked together).

It's interesting to note that SDG 2 and 3 can be significantly aided by reaching SDG 12, which focuses on "sustainable consumption and production patterns" with an emphasis on the supply chain. This is due to the fact that, even while the resources allocated to boosting food production are limited, we can improve chain-wide efficiencies to raise total output (Coelli et al., 2005). Higher productivity is a result of both dynamic and static efficiency improvements. Greater output can be obtained from the same limited factors of production by superior allocation and more efficient use of resources, through increases in production and allocative efficiency, respectively. In industrial strategy, increased innovation—also referred to as dynamic innovation—can improve output quantity and quality. The production possibility frontier (PPF) therefore shifts upward as a result (Kokkinou, 2013).

In order to improve trust in international trade and achieve health and food for all (SDGs 2 and 3), this article explores the potential applications of blockchain technology

(SDG 12), one of the most talked-about technological innovations in recent times. This article examines the problem from the standpoint of agro-food global value chains (GVCs) in order to make this easier. Agro-food GVCs are lengthy, intricate, and frequently cover multiple nations. Food industrialization has led to a greater global distribution of food GVC than in the past. Food traceability and tracking along the global value chain is a difficult and costly undertaking. This article aims to address the following research question: Can blockchain technology be implemented sustainably throughout the entire global value chain for agro-food products, and if so, will it be possible to track and trace food products from farm to fork and thereby increase consumer trust in international trade? The paper is structured in the following way to methodically address this research question. Section "Introduction" examines how SDGs 2, 3, and 12 are related to one another. The "Literature review" section provides an overview of the existing research and highlights the gap that needs to be filled for this study. It also highlights the methodology employed in the research. The section "Global Food supply chain: From supply chain to a value chain-driven approach" discusses the need to move from a "supply chain" to a "value chain"-based approach. The section "Blockchain technology and its relevance for the Agro-food value chain" covers the basics of the technology. The literature assesses the application of blockchain at various value chain phases. This section offers insights into how incorporating this fragmented approach to blockchain deployment may help create a truly global farm-to-fork blockchain-based value chain. The discussion is brought to a close in Section "Discussions and Conclusion," which also provides a roadmap for future study and recognizes the managerial and policy implications of the findings.

II. LITERATURE REVIEW

Many academic works have evaluated how well blockchain technology may meet the various goals of the UN Sustainable Development Goals. Parmentola et al. carried out a thorough analysis of more than 184 peer-reviewed publications about blockchain technology that were published in prestigious journals. According to their results, its potential has not been equally explored across the several SDGs (Parmentola et al., 2021). Although the benefits of this technology have been thoroughly studied for several SDGs, others have not gotten enough attention in this area. Notably, a number of academic disciplines have thoroughly investigated the possibilities of blockchain technology, including engineering (17%), computer science (15%), social science (13%), and environmental science (11%) (Parmentola et al., 2021).

The synergistic potential of two new technologies—the Internet of Things and blockchain technology—was investigated in a different study by Villiers et al. with an emphasis on delivering trustworthy data and information and thereby supporting the UN SDGs (de Villiers et al., 2021). The study made clear that increased accountability can lead to increased productivity and better management at every stage of the value chain, which would ultimately help to realize the SDGs.

To evaluate how blockchain technology might improve tracking and tracing within fish supply chains, Tsolakis et al. analyzed numerous case studies, mainly from the standpoint of operations management (Tsolakis et al., 2021). This study covered the use of blockchain technology to medium- to large-scale operations, such as commercial fishing operations and the production of canned tuna in Thailand, as well as small-scale scenarios, such as village fishing operations. The "Principal-Agent Theory" and "Transaction Cost Analysis" are employed to assess the importance of digital supply chains in achieving the Sustainable Development Goals. The main barriers that prevent blockchain technology from being used by the Indian Agricultural Supply Chain are identified by Yadav et al. (Yadav et al., 2020). 'ISM-DEMATEL-Fuzzy MICMAC' methodology, an integrated approach, is used to identify adoption hurdles. This methodology illustrates the linked affects of the 10 identified elements that impact technology adoption, in addition to explaining how they affect it. The authors also do a thorough sensitivity analysis to evaluate the robustness of the model. For example, they find that the adoption of blockchain in the Indian agriculture context is limited not only by factors such as "interoperability and standardization" (factor 4), "scalability and system speed" (factor 7), and "security and privacy concerns" (factor 3), but also by factors that reinforce and magnify each other's impact.

In a later study, Yadav et al. (2021) expand on the model created by Yadav et al. (2020) and group these previously identified obstacles to produce a thorough framework for evaluating the adoption and smooth integration of blockchain technology into the food value chain (Yadav et al., 2021). Throughout the value chain, the writers interact with a wide range of stakeholders, including academicians, farmers, top-level (C-level) executives, and blockchain technologists. This thorough involvement helps to successfully identify the main obstacles to technology adoption. The writers offer shrewd advice to legislators as well as professionals in the agro-food sector. They explain how blockchain technology can support strong monitoring and increase confidence in the Indian food security system by providing real-time information. In turn, this increased trust can help with the investment difficulties in the agri-food industry. Even with small and medium-sized farmers, investors and crowdfunding entities may find it more practical to undertake cost-benefit evaluations and opt to spend their resources if they have access to reliable information about the agro-food supply chain (Yadav et al., 2021).

The aforementioned contributions and the research reviewed in this study are helpful in illuminating the possibilities and limitations of blockchain technology in achieving one or more SDGs. These conversations have either restricted themselves to certain geographic areas or concentrated on particular fields. By adding three notable pieces to the body of current literature, this work makes a substantial contribution to this rigorous discourse.

The paper first examines the entire global Agro-food value chain (GVC) and assesses how blockchain technology may help remove bottlenecks at each stage of the value chain, from financing to documentation, from the farm to the fork, in order to provide a blueprint for a truly global blockchain-driven farm-to-fork GVC. Second, the article uses a case study-based methodology to do this. The results are then displayed in the form of a flowchart, which shows exactly which link in the food value chain each case study may be able to recommend. Third, the study was a commendable endeavor to develop a helpful framework for managers and policy makers alike by employing an interdisciplinary approach and drawing on research findings from operations management, trade and customs law, scientific literature, and management literature. Because of this, the paper carefully analyzes the shortcomings in the current disjointed blockchain implementation, provides an overview of the study, and employs a flow chart to improve the case studies that are discussed. To accomplish this, the study evaluated peer-reviewed literature from numerous fields and conducted desktop-based qualitative secondary research.

III. SUSTAINABLE DEVELOPMENT GOALS

Regardless of their level of development—developed, developing, or underdeveloped—all countries share the desire to secure a successful, peaceful, and sustainable future for coming generations. The SDGs, or "People, Planet, Prosperity, Peace, and Partnership," are a representation of this common objective in the 2030 Agenda for Sustainable Development Goals (SDGs) (United Nations Sustainable Development Goals, 2023). In line with "Transforming our world: the 2030 Agenda for Sustainable Development," there are seventeen Sustainable Development Goals. SDG 2 aims to "end hunger, achieve food security and improved nutrition, and promote sustainable agriculture". Among the noteworthy initiatives recognized in the Charter to accomplish SDG2 are the adoption of resilient agricultural techniques, doubling agricultural productivity, creating sustainable food production systems, and guaranteeing food access. Furthermore, for more equitable global development (objective 2.a, 2.b, and 2.c), goals 2.3, 2.4, and 2.5, respectively, concentrate on enhancing flora and fauna-bio diversity through increased investment in scientific, logistical, and financial services. Before concentrating on SDG 2 and analyzing its relationship with trade and emerging technologies, it is imperative to establish the relationship between SDG 2 and the other two SDGs, namely SDG 3 (which aims to "ensure healthy lives and promote well-being for all at all ages" and SDG 12 (which seeks to "ensure sustainable consumption and production patterns"). SDG 3 demands that everyone lead healthy lives. Global health and well-being represent this agenda's main objectives. Having access to medical services and medications is just one component of universal health. A healthier life—that is, a longer, healthier life with less reliance on the healthcare system—might even be more desired. Precision-based medicine and individualized healthcare are becoming more popular as healthcare and medicines move digital, with the goal of promoting healthier lifestyles (Cahan et al., 2019).

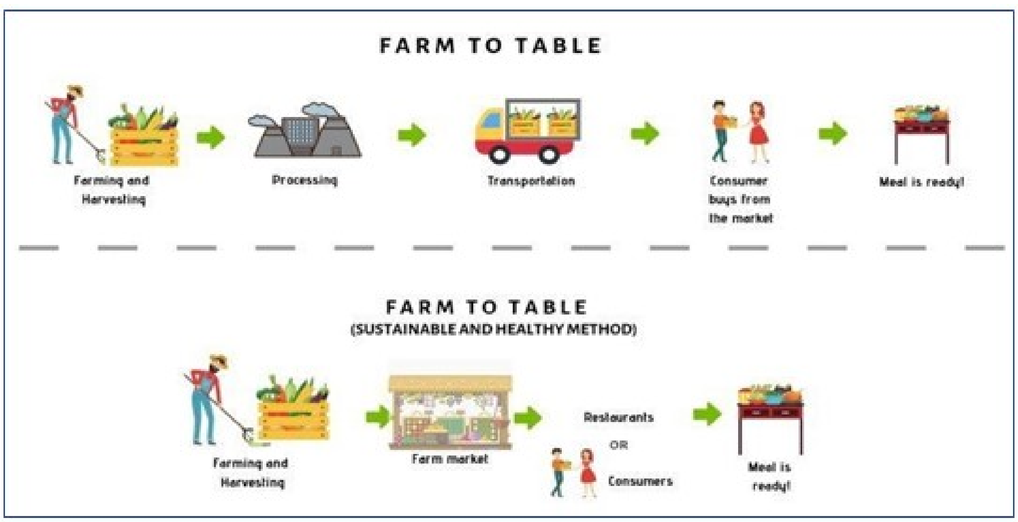

Figure 1: Sustainable Agro food chain

For example, if an application is made early on and it is determined that sugar control and obesity prevention are important, this early identification, in conjunction with dietary and exercise recommendations that are low in calories, can greatly reduce the risk of many serious lifestyle diseases. A key component of encouraging this healthy lifestyle is food. Research confirms that although fast food, which is cheap and easily accessible, has made food more accessible at lower costs, it has also significantly increased the cost of healthcare for governments around the world (Lang, 2004). Food-related infections, such as salmonella and E. coli, affect one in six Americans each year in the United States alone, costing taxpayers over US $55.5 billion yearly (McDaniel and Norberg, 2019). Millions of people are now at risk for a variety of lifestyle diseases due to sedentary lifestyles, high-carb and high-fat diets, and the use of processed foods (Lang, 2004). It is crucial to acknowledge the interdependence of SDGs 2 and 3 in order to ensure the welfare of all. Not only are these two objectives close in terms of location, but empirical data also shows a complex relationship between them. Remarkably, SDG 12,'sustainable consumption and production patterns,' with its focus on supply chains, can play a crucial role in supporting SDGs 2 and 3. 'Sustainable management and efficient utilization of natural resources' and environmentally friendly practices—such as cutting back on the use of chemicals and pesticides in the food chain and fostering a more circular economy—are key components of SDG 12's call for a shift toward'sustainable consumption and production' (12.1). In order to do this, the SDG promotes a number of noteworthy initiatives, such as big businesses adopting and disclosing sustainable practices (12.6), public awareness campaigns (12.8), and pursuing sustainability while taking into account different countries' varying levels of development (12.1). The SDGs ask for the creation of monitoring and implementation instruments (12.b) and the promotion of international scientific, technological, and knowledge transfer (12.a) in order to help with these efforts. Although there are linkages between these SDGs and other SDGs, SDGs 2, 3, and 12 are still the main emphasis of this study paper. When analyzing SDG 12, the focus is on making sure that "global value chains are sustainable and accountable." Under the aegis of Sustainable Development Goals 2 and 3, the focus shifts to "sustainable Agro-food supply chains." In order to facilitate "sustainable Agro-food value chains," the need to shift from a "supply chain" to a "value chain"-oriented strategy is examined in the part that follows.

IV.GLOBAL FOOD SUPPLY CHAIN: FROM SUPPLY CHAIN TO A VALUE CHAIN-DRIVEN APPROACH

In the literature, the terms "value chain" and "supply chain" are used interchangeably. In order to provide some clarity, this section first describes the distinctions between the two and then goes on to explain why an approach based on the agro-food value chain may be more appropriate for understanding the benefits of blockchain technology.

The first crucial query is: Why is this discussion being seen via the lens of value chains, namely global value chains related to agro-food in this instance? This could be explained by the absence of firm-to-firm competition in modern times. According to Grainger et al. (2018), competition nowadays occurs "between competing supply chains." A certain supply chain needs to be able to provide its clients with higher value and more affordable prices in order for a competitive advantage to continue. Value-driven agro-food chains need to be able to be traced and tracked. This may have a significant role in a value chain's sustainable aspect. They need to take the triple bottom line idea into account in order to guarantee the sustainability of supply networks. The value chain's "environmental, social, and business dimensions" are referred to as the "triple bottom line" (TBL). The TBL method used in management literature and this article's emphasis on the SDGs—most especially

SDG 12—from a policy standpoint are complementary. Assuring "confirmation and verification [of] sustainability criteria and certifications" is a crucial strategic and competitive component of this TBL-driven approach (Saberi et al., 2018). When a supply chain is managed similarly to a value chain, consumers are promised better value, and there are also more chances for international trade. In this regard, it is important to recognize how closely trade and a strong value chain are related.

An agricultural supply chain is made up of the several stages that take an agricultural product from the "field to table" (Mirabelli and Solina, 2020). These stages include farming, production, distribution, processing, sale, and end-user purchase. In contrast, the idea of a value chain is more complex since it charts the value added at every phase of the production process (Handfield and Nichols, 2002). To put it another way, a value chain-based approach to logistics management aids in locating important supply chain value points as well as pain and promise regions. This aids in identifying the stages of the value chain at which utilizing new technology will optimize productivity throughout the supply chain by maximizing return on investment. According to this viewpoint, the supply chain becomes a value chain. Scholarly contributions have mapped the PC and tablet PC value chains to provide an illustration of this approach and its significance. That investigation yields three noteworthy conclusions

In order to maximize earnings, a company may first decide to outsource and concentrate on its core skills using a value chain-based approach. This is commonly seen in the information, communications, and technology (ICT) industry, where marketing and innovation are important sources of added value and distinctive product attributes.

Because of this, businesses in this sector could choose to hone their competitive advantage and concentrate on their core

Competencies. Secondly, there could be notable variations in value addition at different stages of the value chain. The countries of research, innovation, and marketing, for instance, got over 51% (or roughly Euro 275) of the total value in the Nokia 95 smartphone case, while the country of "final assembling" only received 2% (or roughly Euro 11) of the total value of Euro 546, including taxes. Third on the list of important topics for trade policy were the interconnections and the "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). The best trade policy needs to be developed in light of these facts. Consequently, the argument was now investigated from the standpoint of the world's agro-food value chains.

The next important and related question was about what elements determine a nation's place in the global Agro-food value chain. A deliberate and well-calibrated policy framework is necessary for effective participation in this value chain, as empirical evidence has shown. These could include the easing of regulatory restrictions, fostering an atmosphere that encourages innovation, and optimizing elements such as "tariffs, time, speed, and administrative procedures" (van der Marel, 2015). Countries must strengthen their service sector, encourage labor market flexibility, and increase investments in information and communication technology (ICT) and knowledge management in order to move up the value chain and into more upstream or downstream positions (van der Marel, 2015).

In a fascinating twist, services have naturally evolved into essential elements of the value chain as manufacturing and production become more complicated. In the entire value chain, services are important, even in the case of products like agro-foods. Technological developments, "servicification," and "industrialization" have all been ongoing processes in the food value chain. For example, the baking sector underwent a transformation when the 'Chorleywood method' was introduced, transforming it into something more like the automotive industry. Before this invention, "whipped bread could rise in as little as a few minutes," but it could take up to 48 hours (Lang, 2004). A 'new human geography of food' and 'flexible specialization' have resulted from these and other technical developments (Lang, 2004).

Consequently, the best use of information, including cross-border data flows, must be taken into account in the growing "servicification of the production process," where services play an ever-more-important and integrated role in the Global Value Chain (GVC) (van der Marel, 2015). Data becomes even more important as the value chain gets more and more service-oriented, especially in the agro-food sector. It's interesting to note that this is especially true for agro-food GVCs, where optimizing the usage of ICT services, such blockchain technology, can greatly increase efficiency and decrease food wastage (Saberi et al., 2018).

The Agri-food sector, as intriguing as it may be, has a long history of technological integration. Scientific innovations have continuously played a pivotal role in this sector. As early as the 1980s, laser barcodes and Electronic Point of Sale (EPOS) systems found applications in the retail sector (Lang, 2004). This technological journey progressed to include the Japanese-style 'just-in-time' (JIT) distribution system, robotic warehousing, and satellite-based crop and retail management. Notably, the potential of big data and customer profiling was initially realized in the retail arena when Target, a US retail giant, accurately predicted a teenage girl's pregnancy before her family was aware of it (Hill, 2012).

An essential aspect of Agro-food Global Value Chains (GVCs), as discussed earlier, is their extensive and intricate nature, often spanning multiple countries. The industrialization of food has led to Agro-food GVCs becoming more globally dispersed than ever before.

Agro-food markets have witnessed a different pattern from the ICT sector, which is trending towards global value chains and horizontal specialization with globalization. 'Cross-border concentration' has emerged inside global agro-food value chains as a result of the swift regionalization and globalization trend (Lang, 2004). Numerous reasons can be related to this phenomena. One important contributing reason is the absence of record-keeping standards, which leads to different forms for data and information at different points in the value chain. Agro-food value chain players generally use the 'one up, one down' (OUOD) technique to save record-keeping expenses (Kamath, 2018). Because of this strategy, each link in the value chain only keeps track of their direct upstream and downstream suppliers, which raises issues with transparency and accountability.

Businesses in the industry frequently turn to vertical integration to solve these problems of knowledge asymmetry and internalize externalities. In the agro-food value chain, externalities are one of the reasons that push businesses toward non-horizontal concentration, which includes vertical and conglomerate integration. These elements include the drive for greater economies of scale and scope, the chance to take advantage of cutting-edge technologies, and the development of a more powerful negotiating position following a merger, all of which raise the profitability of vertically integrated businesses. Global competition authorities are keeping a careful eye on the trend of increased concentration in the agro-food-seed industry.

Exist any other strategies to counteract this trend of increased global concentration in the agro-food industry? More specifically, may some of these issues be resolved by a technological advancement like blockchain technology? If that's the case, this invention could not only solve problems with competition but also boost trade confidence by making these GVCs more traceable and accountable. Thus, the next part explores the essential features of blockchain technology and then talks about how it might help with decentralization and improve Agro-food GVCs.

V. BLOCKCHAIN TECHNOLOGY AND ITS RELEVANCE FOR THE AGRO-FOOD VALUE CHAIN

In actuality, blockchain is a conglomeration of numerous technologies that have evolved over time rather than a single technology. To put it simply, a blockchain is a distributed digital log of almost unchangeable, time-stamped transactions. "Nodes" are responsible for storing and appending transactions to the chain. Any internet-connected, converged telecommunications device, including smartphones, laptops, PCs, and other interconnected handheld devices, can be considered a node. As the section "Limitations of the blockchain technology" infra demonstrates, the ability of smartphones to function as nodes can be a compelling feature to guarantee the technology's widespread adoption in the undeveloped and underdeveloped countries. A new transaction is "broadcast to the network for verification and auditing" each time it is added to the blockchain (Saberi et al., 2018). A transaction needs the approval of the majority of nodes in order to be approved. Decentralization is the absence of a single central server controlling the entirety of the data within a blockchain. Decentralized storage of the data takes place among the nodes. This guarantees faith in the system, as opposed to depending on a single central authority or middleman.

Permissioned or permissionless blockchains are both possible. Participants in a permissionless blockchain are strangers to one another, and anyone can join the public permissionless blockchain. A well-known example of a public permissionless blockchain is Bitcoin, created by Satoshi Nakamoto (Nakamoto, 2008). A private blockchain is distinct from public blockchains in that access is restricted to approved users and known participants only. Put differently, everyone involved in a private blockchain is acquainted with one another, and access to the network is granted only with permission. Permissioned blockchains of this type are generally appropriate for tracking, tracing, and certification reasons, wherein the participants might gain insight into the specifics of the service provider(s) and the caliber of inputs contributed across the value chain.

The OUPD rule, which stipulates that each service provider only knows the identities of those who are immediately above or below them in the supply chain, is typically followed by vertical supply chains. The above section "Global Food supply chain: From supply chain to a value chain-driven approach" provides examples of this.. This value chain becomes more circular when using a blockchain-based solution because every new digital transaction that is entered on the platform is shared with every member of the network. The data is added to the ledger only when this transaction has been authorized by the majority of nodes. Furthermore, everyone involved in the value chain who is not directly connected to the suppliers upstream—including the customers—can nevertheless view the complete information ledger. This improves the goods' traceability, which raises systemic trust. A consortium blockchain is one that is managed by a number of companies. The consortium members are acquainted with one another, and access is granted exclusively by invitation on this type of semi-private, "partially decentralized" blockchain (Ganne, 2018).

One key feature of blockchain technology is the ability to create "smart contracts," which follow a "if-then-else" logic structure. They are not contracts in the legal sense; rather, they automate the performance of a predetermined act upon the satisfaction of a certain predetermined requirements. These self-executing smart contracts have the ability to receive inputs from many data sources, often known as "oracles." A response is produced by these inputs. For example, in our "sliced mangoes" example (see Walmart case study in the section "Walmart uses blockchain to enhance tracking and traceability" infra), if Walmart feeds a condition stating that all "sliced mangoes" must be recalled immediately by a specific date, the smart contract will automatically flash an instruction to all the relevant nodes in the blockchain at the suggested time. This suggests that smart contracts work in concert with other technologies as well, such as the Internet of Things (IoT), which is a crucial source of data and triggers actions at different stages of the value chain.

1. **Advantages of the Blockchain Technology:** Blockchain technology is a form of distributed ledger technology (DLT). However, what sets it apart from other DLTs is its decentralized nature. In a decentralized network, information is not centralized in a single location but is instead distributed across the network in a decentralized fashion. This means that no single central authority has complete control over the network, and altering its contents would compromise the integrity of the time-stamped ledger of transactions. In simpler terms, any attempt to tamper with the blockchain may result in a "forking" of the chain, essentially breaking it into separate branches. This unique feature contributes to the near-immutability of blockchains.

   To be clear, "near-immutability" does not mean that blockchains are impervious to manipulation in any way. Yaga et al. (2019) state that blockchains are "tamper-evident" and "tamper-resistant," meaning that tampering with them is extremely difficult. But tampering can happen in some circumstances, particularly in permissionless blockchains, as we will see in the next section on the "Limitations of blockchain technology."

   The ability for cellphones to function as network nodes is another noteworthy benefit of blockchain technology. This capacity has the potential to be extremely important in fostering the technology's uptake and success. The success of M-PESA, a mobile money service in Kenya, is one such example. M-PESA emerged in Kenya as a safe and effective way to send money across the nation due to a number of socioeconomic and political issues.

People were forced to keep large sums of cash in their houses due to the country's poor banking infrastructure. People were often forced to carry cash in dangerous and unstable situations in order to send money to their loved ones. Sensing a chance, Safaricom, Kenya's top mobile network operator (MNO) and a Vodafone subsidiary, launched a service in 2007 that let customers make and receive cash transfers to friends and family around the nation. Senders could leave money with a local agent in one part of Kenya, while receivers could safely take it out of the country via another Safaricom agent. Within the first month of its launch, M-PESA registered more than 20,000 users. Ten years after its introduction, M-PESA has grown to be one of Kenya's most widely used mobile-based money transfer services, with over 27.8 million of the country's 45 million residents utilizing it on a daily basis (Miriri and Blair, 2018).

Not only that, but big app shops like Google have started to take payments via the M-PESA service. There are two main reasons for M-PESA's success. It did two things: first, it made it possible to make transactions using mobile phones; and second, it constituted an early public-private cooperation. Without initial support from the public sector, M-PESA offered a solution to a societal problem that might not have attracted the interest of the commercial sector. Similar to this, blockchain provides answers to societal issues that could profit from a public-private partnership, such improving the accountability and traceability of agro-food goods.

The public sector may need to provide some initial seed capital in order to invest in this technology, especially if consortium blockchains are being developed (Ganne, 2018). We will return to this topic in the "Case Studies" section, where two blockchain-based pilot proof of concepts—more specifically, the NAFTA/CAFTA project (case study "NAFTA/CAFTA and Blockchain POC") and the importation of flowers from Kenya to the Netherlands (case study "Flowing Flowers from Kenya to the Netherlands"—showcase the importance of public-private partnerships in the early adoption and later widespread acceptance of the technology.

2. **Limitations of the Blockchain Technology:** Data that has been added on the blockchain cannot be removed since blockchain technology is temper resistant. The data that was first recorded on the blockchain, though, might not be accurate. Put differently, the data placed into the blockchain determines its legitimacy. The technology itself is unable to rectify inaccurate or misleading data that has been recorded onto a blockchain. This implies that despite the technology being used, human intervention will still be necessary in some capacity, such as data entry and manual document verification (Ganne, 2018). When using the technology, this is an important detail that should be taken into consideration. Blockchain can guarantee that data is "temper resistant," meaning that once it is entered, it cannot be changed. Blockchain, however, is unable to guarantee that data entered into it hasn't been tampered with. Therefore, the possibility of entering inaccurate and misleading information on the blockchain is also brought about by human participation.

   The fact that the technology is still imperfect even if it is almost completely impervious to heat is another significant drawback. This relates to the "51% attack" problem, which says that once a validator or group of validators gains more than 50% of the network's processing power, they can easily compromise the entire system by hacking. In an early example that clearly illustrated the limitations of the technology, the US-based Distributed Autonomous Organization (DAO) allowed users to invest in the cryptocurrency "ethers" on a project of interest on its Ethereum-based public platform. A hacker split the system after finding a weakness in the blockchain, with the goal of stealing roughly US$ 60 million of the $150 million that the DAO seed fundraising project had raised. To "break down the whole system, and not just the DAO," the Ethereum developers had to manually intervene and execute a hard fork in order to resolve the issue (Tyagi, 2018). It turns out that this issue is more intrinsic to a public blockchain from an architectural standpoint. But this attack is still possible, albeit in a different way, for private blockchains as well. Stated differently, the blockchain ecosystem's user interface represents the most likely point of troubleshooting. Think about the scenario when the majority of validators decide to assault the network by coming to a collusive agreement. In a private blockchain where players are acquainted, it could be simple to carry out a collusion-driven modification whereby they can easily manipulate one another. Although Vitalik Buterin offers a theoretical "99% attack solution" for this issue, its practical application is still up in the air (Ganne, 2018).

Another area of worry with blockchain technology is its scalability. Compared to permissioned consortium-based blockchains, which only allow access with permission, this might be a greater cause for concern for permissionless blockchains. As an illustration, a Bitcoin network can theoretically process up to 4000 transactions per second, but in practice, it typically only processes seven transactions per second (Ganne, 2018). Private sector solutions, such IBM's permissioned Hyperledger fabric, which can process up to 3500 transactions per second for particular, pre-defined workloads, have eliminated this restriction (Ganne, 2018). However, the issue still needs to be resolved, particularly with blockchains that are managed by governments. The NAFTA/CAFTA and Blockchain POC post-pilot participant survey, which is discussed in the infra section "NAFTA/CAFTA and blockchain POC," is a prime illustration of this.

The blockchain's interoperability is a crucial component for ensuring broad adoption. On the other hand, due to network effects, one or two dominant blockchain systems may win out in the medium to long term. The current multi-sided platforms will then raise their own set of issues to international competition law authorities. The blockchain architecture is now dispersed, and several blockchain-based solutions are being created globally. These industry players can be divided into three categories: service providers (like Infosys and Accenture), application suppliers (like Ripple and Factom), and infrastructure providers (like IBM, Microsoft, and Bluzelle) (Blockchain Vendors, 2019). Even though some of the solutions can currently communicate with an outside vendor—for example, Hyperledger Fabric, Ethereum, and Cord can be accessed through Microsoft's Azure blockchain—the interoperability of these solutions is still limited, and various blockchains are still evolving independently in "digital islands" (Blockchain Vendors, 2019). Policymakers should pay attention to the two significant limitations of the blockchain technology at this point of development: interoperability and standardization. In order to ensure the technology is successfully and widely implemented, it is important to address these infrastructure obstacles as soon as possible.

VI.DISCUSSIONS

The entire Agro-Food GVC needs to be permeated with sustainable thinking if sustainability is to be strong and long-lasting. In the case of food production, and with our focus on Sustainable Development Goal No. 2: "zero hunger," this means that in order to ensure accountability and transparency throughout the value chain, the Agro-food GVC needs to implement resilient digital infrastructure and green environmental standards.. The World Economic Forum (WEF) believes that removing obstacles connected to supply chains can increase international trade by more than 15% and the global GDP by 5% (McDaniel and Norberg, 2019). When comparing this beneficial impact to the removal of trade barriers caused by tariffs, the difference can be as much as fifteen times greater. International environmental law and international trade law are the two legal domains that trade-related environmental accords and policies heavily draw from (Lockhart et al., 2022). Although very desired, the implementation of these measures may result in increased trade obstacles that are not tariff-based. This article makes recommendations and provides a roadmap for utilizing blockchain technology's advantages to promote trade, competition, and the SDGs while introducing speed and efficiency and minimizing non-tariff barriers across the Agro-Food GVCs.

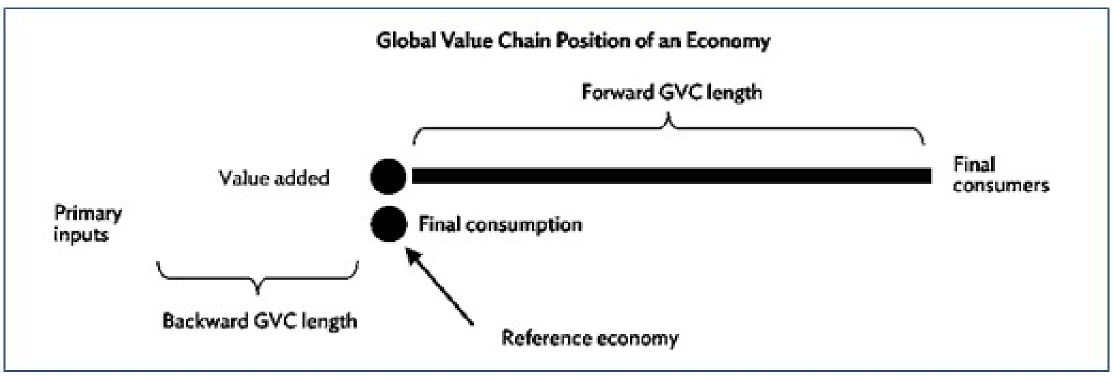

Figure 2: Global Value Chain Position of an Economy Note. From Alvarez et al., 2021, p. 11. CC BY-NC 3.0 IGO

As stated in Rio Declaration paragraphs 7 and 12, 'transboundary environmental challenges' require international cooperation, a multilateral approach, and inclusive participation of various member countries. A key component of accomplishing this goal is the vision presented in SDG 12, especially the subsections that encourage the transfer of scientific, technological, and knowledge resources among states (SDG 12.a). This essay acknowledges the potential of blockchain technology in the creation of flexible and long-lasting agro-food GVCs in line with this strategy. These GVCs are distinguished by efficient financial and customs procedures that do not impede suppliers. Additionally, they provide the capability of tracking and tracing items, which in turn promotes customer confidence in the food products they value.

As explained in this article, an Agro-food GVC powered by blockchain has the potential to improve trade trust by allowing for better tracking and traceability of food products throughout the entire value chain. It also unintentionally addresses a major issue that competition authorities around the world have long been concerned about: the persistent issue of growing concentration within Agro-food GVCs. This paper also identifies three key areas that policymakers should address right away and that offer promising opportunities for greater multidisciplinary study.

As was said in the section "Limitations of the blockchain technology," the public and private sectors need to pay attention to blockchain technology's interoperability, standardization, and scalability. There is fear that blockchain technology may remain restricted to proofs of concept and pilot projects in the absence of an appropriate legal and technological framework for these three components (Ganne, 2018). Taking a cue from the M-PESA narrative, which began in the early 2000s when Vodafone executives answered a request for ideas to accelerate the accomplishment of the Millennium Development Goals (MDGs), which were the precursors to the SDGs. In order to promote entrepreneurship, wealth development, economic activity, job creation, and trade, they came up with a creative way to improve financial access (Hughes and Lonie, 2007). The Department for International Development (DFID) of the UK government and Vodafone invested about £2 million together to launch a prototype M-PESA project in Kenya in early 2003, following the World Summit for Sustainable Development 2003 in Geneva (Hughes and Lonie, 2007). It is commonly known that M-PESA has been successful in advancing the MDGs or SDGs. Similar to M-PESA, blockchain technology has the potential to solve a societal issue: the tracking and tracing of goods from farm to fork. In a similar vein, the previously discussed obstacles to blockchain technology can be successfully addressed by carefully thought-out public-private collaborations. Further investigation into the technical aspects of "interoperability, standardization, and scalability" as well as how policymakers, especially those in charge of trade and innovation, can establish a framework that will facilitate the improvement of interoperability, the advancement of standardization, and the expansion of ongoing pilot blockchain projects would be extremely beneficial.

Second, the case study on NAFTA/CAFTA and the subsequent post-POC survey (under the section "NAFTA/CAFTA and Blockchain POC") highlight the importance of raising awareness and educating people about the technology. This implies that implementing an agile blockchain and automating the process alone won't be sufficient. Programs for start-ups and SMEs, such as brief training sessions led by experienced university academic staff in partnership with governmental and non-governmental organizations, may greatly aid in fostering an open mindset and promoting rapid technology adoption. From a more pragmatic standpoint, more research and development of these kinds of programs would be instructive.
Third, expanding on the qualitative results of this study and applying them to a real-world "farm-to-fork" operation could be beneficial. This expanded initiative shouldn't be restricted to just funding the transaction or particular facets of the value chain, including tracking and tracing. It should make an effort to evaluate the viability of implementing blockchain technology throughout the whole agro-food value chain in a pilot or simulated environment.

VII. CONCLUSION

Lessig popularized the idea of "code as an efficient means of regulation" back in the 1990s (Lessig, 1996). The possibility to convert laws and regulations "into code and store them on the blockchain" is provided by a blockchain-based smart code (Shope, 2022). This study simplifies the intricacies of agro-food GVCs in order to demonstrate how blockchain technology might speed up commerce. Improving blockchain-based smart contracts with data inputs from several Internet of Things (IoT) devices is a crucial next step. This is important because, as this article explains, data integrity can only be guaranteed by blockchain after it is on the blockchain. It is unable to confirm that the data that was first input into the blocks was accurate. At the moment, declarants who enter data on the blocks are humans (Shope, 2022). This is where IoT data points and artificial intelligence (AI) are useful. In order to increase agricultural output and better control inputs, especially fertilizers, Escorcia et al. used the "weighted voting ensemble deep learning (ISNpHC-WVE) technique" (Escorcia-Gutierrez et al., 2022). Although the primary emphasis of their research was precision farming, their findings have important ramifications for blockchain integration of AI-driven and Internet of Things data inputs. As was covered in the section above on "International Trade, Food Value Chains, and Blockchain Technology," this in turn may help with eco-labeling concerns. But since the study of AI raises a number of intricate technical, managerial, and legal issues (such as ownership, privacy, and data protection), more research in this area is needed to clarify how an ecosystem powered by AI, IoT, and Blockchain can revolutionize the agro-food sector and bring it into line with Industry 4.0's technological marvels.

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