A Framework of Blockchain Smart Contract for Sustainable Agri-Food Supply Chain

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***Abstract*—Along with the advancement of a decentralized distributing system like Blockchain, the smart contract has become a crucial ally in redefining the future of our society. One such excellent application of Blockchain is in the Agri-Food Supply Chain (AFSC), where despite the rise of technological modernization, is still plagued with unfair trading practices, unsustainable conducts, and abuses of power. This paper aims to discover and conceptualize a blockchain smart contract platform to support a fair and sustainable agri-food supply chain. Firstly, the paper presents an insight into present-day AFSC and the lack of focus on fairness for food producers. Next, a novel workflow based on blockchain smart contract is presented, along with a focus on food producer, distributor, and end customer. Smart contracts are formed using smart contract functions and messaging capabilities that are used to automate most business processes using if-this-then-that logic. In essence, this platform has the potential to revolutionize the whole food supply chain by increasing efficiency, decreasing cost, strengthening collaboration, saving time, and much more.**

***Index Terms*—Agri-Food Supply Chain, Blockchain, Fairness, Smart Contract.**

I. Introduction

The Agri-food industry, despite its vitality of feeding hundreds of millions of people on the planet, is still one of the least digitized industries. Most of the agricultural products are mostly treated as traditionally as possible, from the way crop is planted and farmed, down to the way it is distributed and sold along the supply chain.

Agri-Food Supply Chain (AFSC) is also facing many uncertainties in its existence, ranging from consumer preference to environmental impact. One factor not given enough attention is its dedication to fairness to all stakeholders, especially food producers. Agricultural product pricing is such a vital factor that even if the farmers produce for domestic consumption, the global price will still profoundly affect their incomes [1]. This means their earnings are not equivalent to minimum wages since most farmers earn only somewhere between 2-6 dollars per day. The repercussion of this situation is that hundreds of millions of people worldwide end up in substandard living conditions, lacking many of the basic necessities. The volatility of price emanates in part from the scarcity of transparency in the supply chain regarding both the information and physical flow of products. Coupled with the shift in consumer preference to more sustainable and organic purchases [2], it is a clear telltale sign that there have to be changed to the way agricultural products are made and sold.

Blockchain, on the other hand, has been gaining a lot of traction as a new technological revolution in the decentralized distributing system by allowing transparency and security to coexist together. It has the potential to shape the world in almost every discipline, ranging from economics to politics [3], [4]. This study seeks to answer the following questions:

- How can this study help resolve the transparency issue of the Agri-food industry with the help of blockchain and smart contract?
- How can we help restore fairness and equal wealth distribution among stakeholders, especially food producers?

Farmers are typically ill-treated when it comes to strategic business decisions, as they are known to be discriminated against and treated poorly by their business partners and employers [5]; whereby the rule of law also does not necessarily favor their wellbeing and competitiveness in the industry [6]. Additionally, a study made [7] encapsulates the imbalance of opportunities received by farmers around the world, especially those living in the Least Developed Countries (LDCs). Approximately 2% of the world's farmers have access to modern motorization of farming tools and equipment, meaning they could utilize fertilizers, special seeds, and plants, as well as other forms of support. Moreover, only two-thirds

of the world's farmers were supported by the green revolution which allows them to obtain specially bred seeds and plants, fertilizers, as well as livestock; however, this occurs at the expense of modern motorization and mechanization. This results in about one-third of the farmers not receiving any support in the form of animal utilization, special crops, and fertilizers at all which forces them to resort to using manual labor for farm management. This revelation, along with global trade, shows that an increase in productivity for some farmers still carries on to overshadow the hard work and lack of support for farmers in LDCs. Furthermore, the same increase in productivity generates an adverse effect on the prices of agricultural products on a worldwide scale, hurting the profitability and well-being of poor, rural farmers. On the other hand, the lack of traceability presented in today's agri-food industry constitutes serious concerns regarding transparency and sustainability. The outbreak of Bovine Spongiform Encephalopathy (Mad Cow Disease) and *E. Coli* in the USA drew significant discussion about the safety of such consumables. There is an estimation that food-related illnesses amount to millions of recorded sicknesses and 9,000 deaths yearly in the USA alone [8]. Moreover, the lack of transparency across the supply chain may also lead to abuses of power by large corporations and intermediaries, which in turn, dramatically reduce farmers' share in the value chain year by year [9]. This study aims to discover the potential usage of blockchain technology in improving fairness and transparency in the agri-food supply chain.

II. Literature Review

The Agri-food industry, since its inception during the industrial revolution, has been providing food to people since the 20th century, while staying fairly non-progressive in terms of modernization in some areas of the world [10]. Most of the agri-food products are often made by uneducated, small-scale farmers in rural parts of the world, and they are usually taken advantage of by middlemen and distributors. As reported [11], unfair trading practices acted upon food producers could lead to unsustainable livelihood, child labor, and even environmental degradation. This literature review aims to point out the overlooked unfairness of trade practices and studies made to promote sustainability in the food industry. The reports and studies are reviewed, filtered, and compiled based on relevance and the impacts they made for fairness and transparency.

The Agri-food supply chain relies heavily on informal contracts and immediate buy-outs from major middlemen and distributors who exert immense market power and pressure. The farmers' market share had been declining over a 16 years period, from 1995 to 2011, while the remaining shares went to the food industry and retail food services. Concurrently, farmers' profit margins are also being gradually overtaken by newer sustainable farming methods and regulations imposed by their clients and governments [12]. The crops once planted to feed the locals have now been discouraged in favor of popular and in-demand seeds meant for export [13]. Instead of helping small, vulnerable farmers thrive, globalized trade only serves to worsen the situation to use lands for export crops.

TABLE I
Fair Trading Practices Review

No.	Authors (Year)	Title	Findings	Challenges
1	Hingley, (2005) [15]	Power Imbalance in the UK Agri-Food Supply Channels: Learning to Live with the Supermarkets?	- Power is noticeably imbalanced in the Agri-food industry by favoring the distributors. - Inequality among stakeholders, especially for food producers is often overlooked.	- Legislative actions are historically ineffective against essentially oligopsony powers in developing countries. - Horizontal and vertical integrations require immense effort and coordination.
2	Chen et al., (2005) [14]	Changes in Food Retailing in Asia. Implications of Supermarket Procurement Practices for Farmers and Traditional Marketing Systems	- Agribusiness firms have a tendency to avoid using wholesalers and directly contact individual farmers for supplies. - Limited access to production tech, limited dispersion of information, limited intelligence on buyers and prices, low negotiating power, and financing heavily prohibit farmers to take advantage of the modern supply chain. - Food retailing in Asia is delineated by the heavy involvement of supermarket chains.	- Capitalist economic system poorly leverages the livelihood of farmers by leaving the market forces free to act. - New legislations targeted Supermarket chains that could hurt the livelihood of consumers who benefit from fierce competition. - The need to modernize and enforce public regulations in rural remains substantial in developing countries.

TABLE I
FAIR TRADING PRACTICES REVIEW (CON.)

No.	Authors (Year)	Title	Findings	Challenges
3	Padel & Zander, (2010) [26]	Regional Production and "Fairness" in Organic Farming: Evidence from a CORE Organic Project	- Fair and equitable financial returns for farmers are expressed by both the producers and consumers. - Organic and transparent food system is demanded by vital stakeholders to be implemented based on local supply chain structure. - Local and regional supply chain structures could reinvigorate the well-being and fairness of local food producers.	- The term "Fairness" can be misleading without specifying criteria and framework upon which an agreement is made. - Misguided usage of the term can result in loss of trust from consumers. - The use of Information-Display-Matrix (IDM) has some limitations in terms of variables used.
4	Hellberg-Bahr & Spiller, (2012) [16]	How to Treat Farmers Fairly? Results of a Farmer Survey	- Around 40% of farmers taken part in the survey argued they didn't feel treated fairly. - Key success factors influencing fairness in supply chain are: price satisfaction, reliability, and relationship quality. - Reliability and relationship quality are more important than price to achieve fairness from farmers' perspective.	- The study was conducted in Germany, which is not a representation of most food producers, especially those in developing countries. - The study focuses on only one production sector and did not cover the entire supply chain. - Further studies needed in price volatility and its definition of fairness.
5	Schutter, (2014) [11]	Who's Got the Power? Tackling Imbalances in Agricultural Supply Chains	- The concentration of power among some stakeholders affects food producers badly. - The abuses of power create unfair trade practices. - Agri-food liberalization creates price volatility.	- Need close government support. - Need huge investment over a long period of time. - Require collaborative effort from all related entities.
6	Fałkowski et al., (2017) [27]	Unfair Trading Practices in the Food Supply Chain: A Literature Review on Methodologies, Impacts and Regulatory Aspects	- 96% of food suppliers in the EU food chain experienced at least one form of Unfair Trade Practices (UTPs). - Available data to analyze UTPs is imperfect as firms involved aren't willing to disclose sensitive information. - There is no consensus on the definition of being "unfair" any effort to leverage farmers' market power is not guaranteed to be efficient.	- A vital increase in agri-food supply chain transparency. - There is arguably little corroboration regarding the validity of the effect of UTPs and whether the anti-UTP regulation works as intended. - Lack of systematic evidence stems from the issue of measurement and lack of systematic evidence regarding UTPs' impact.
7	Blizkovsky & Berendes, (2017) [17]	Economics of Fairness Within the Food Supply Chain in Context of the EU	- Imbalance in market power means more powerful actors get to benefit more at the expense of farmers and small retailers. - The stronger and bigger the firm is, the more market power and tendency to take advantage of the market. - Consequently, food producers' share of the revenue has steadily been declining for decades, sparking inequalities in profit sharing among actors in the food supply chain.	- Although in the same region, producers in some countries do receive fair profit distribution. - In-depth studies investigating correlations between price set by producers and legislative measurement. - An investigative study incorporating non-EU regions would further validate the issues of UTPs.
8	Yoo & Won, (2018) [28]	A Study on the Transparent Price Tracing in Supply Chain Management Based on Blockchain	- Give stakeholder easy access to retail price information. - Each transaction is valid and transparent. - Stakeholders can reduce operational costs.	- Unproven Concept - Expensive to implement - Requires extensive collaboration

TABLE I
FAIR TRADING PRACTICES REVIEW (CON.)

No.	Authors (Year)	Title	Findings	Challenges
9	Fair World Project, (2018) [18]	Fairness for Farmers: A Report Assessing the Fair-Trade Movement and the Role of Certification	- Most food producers face marginalization. Fair-trade helps them improve terms of trade with other actors in value chains. - Enforcing strong auditability and traceability help improve profitability and trust for food producers. - Setting up minimum prices and guaranteed equal treatment from other players improve farmers' livelihood.	- Long term sustainability is still questionable. - Abuse of power is still present. - Needs government intervention
10	Segal & Le Nguyet, (2019) [1]	Unfair Harvest: The State of Rice in Asia	- Inequality in food value chains are worsening as some farmers only receive 4% of total price. - Food producers lack the power to fairly negotiate with traders and other actors. - Climate change, unsustainable production, and increasing input costs pressure farmers to accept low incomes.	- Developing new, better regulated value chains - Government support and subsidies - Guaranteed fair treatment of food producers by other actors

In Table I significant studies regarding fair trading practices toward food producers and substantial sustainability projects and researches are examined and reviewed to project the state of livelihood food producers are facing. The issues of unfair trading practices in AFSC have always been prevalent since before fair-trade association was formed. The growth of multinational food corporations came from the cut-throat competition and their abilities to extract extra profits from food producers [14]. Also found that firms that source products from producers tend to do so from an individual, small farmers rather than community-based ones, particularly because those producers lack production information, intelligence, negotiating power, and general competitiveness to negotiate any contractual terms at all. Making the matters worse, the food supply chain in Asia is also delineated by almost total involvement from big supermarket chains that possess enormous market power over small suppliers. In the UK, noticed that power in the agri-food industry is significantly imbalanced and overlooked [15]. The research regarding fairness and power gap is undermined and mostly overlooked in academic researches. In a study conducted [16] in Germany, they concluded that around 40% of farmers who had participated in the survey expressed they didn't feel they were treated fairly by their supply chain partners. Furthermore, they found there are positive correlations between higher payments and the acknowledgment of being treated fairly as seen by farmers. Additionally, reliability and relationship quality proves to be even more important from farmers' perspective on the issue, mainly because they believe they can rely on their partners in the long run.

Needless to say, the reality concerning fairness from the market says otherwise. The whole food supply chain is driven by price resulting from unchecked competition. Another study done [17] brilliantly illustrates the power imbalance between farmers and suppliers: "Asymmetric scopes of power to enforce self-centered profit distributions and/or possibilities to actively influence certain actors to conduct economic performances according to one's own concepts and interests form a threat towards a fair functioning of bargaining practices within the food supply chain." Strong actors obtain even more power because therein lies a lack of competition in the industry. The same lack of competition fuels the buyer's bargaining power of suppliers and retailers, forming what is essentially oligopsony, and thus forcing farmers to sell at much lower prices than necessary. This, in turn, further fuels the tendency of other actors to engage in Unfair Trading Practices (UTPs).

Reports similar occurrences for farmers in rural developing countries. 84% of worldwide farmers rely on 2 hectares of land or less to feed their communities and the region. However, the issue of global export of agricultural products threatens their well-being and communities. By allowing for corporations to exploit these vital food producers, the communities face numerous obstacles, ranging from land grabbing due to apparent corruption, unfair trade practices, uneven wealth distribution, low and volatile prices, and most importantly, the corporations' control of the food supply chain itself [18].

TABLE II
SUSTAINABILITY IN AGRI-FOOD SUPPLY CHAIN

No.	Authors (Year)	Title	Findings	Challenges
1	Bunte, (2006) [9]	Pricing and Performance in Agri-food Supply Chains	- There are abuse of power done on food suppliers. - Income risks are shifted to farmers. - There has been little study into sustainable agri-food supply chains.	- Creating a measurement for sustainable supply chains. - Leveraging food producers' roles and income in supply chains. - Fostering vertical and horizontal integration.
2	Thompson et al., (2007) [20]	Agri-Food System Dynamics: Pathways to Sustainability in an Era of Uncertainty	- Majority of farm production does not consider negative ecological impact in mind. - Traditional food producers are suffering from poverty and poor livelihood amidst technologically driven farming system.	- Invoke the use of sustainability production requires government support. - Multinational corporations have to cooperate fairly with food producers.
3	Fritz & Matopoulos, (2008) [21]	Sustainability in the Agri-Food Industry: a Literature Review and Overview of Current Trends	- Consumer trends, and globalization have shaped unsustainable business practices. - Concentration of sector has influenced retailers to enforce unfair practices on food producers to retain profitability. - Most firms focus less on environmental and social impact, while maintaining more interests on economic factor.	- Changing consumption pattern of consumers requires elaborated collaboration from governments and corporations. - Huge investment in training employees and communities about sustainability.
4	Pouliot & Sumner, (2008) [8]	Traceability, Liability, and Incentives for Food Safety and Quality	- Improved food safety encourages consumers to pay more; thereby increasing profitability for food producers. - Traceability allows for potential increase in vertical integration and coordination.	- Traceability does not offer huge incentives to food producers. - Requires extensive information exchange.
5	Seuring & Müller, (2008) [19]	Core Issues in Sustainable Supply Chain Management – a Delphi Study	- The integration of sustainability in supply chain needs to be studied case by case. - There are four dimensions of which a sustainable supply chain discussion can be made: pressures and incentives, measuring impacts, supplier management, and supply chain management. - Pro-active companies are seen as the ones developing sustainable products and supply chains.	- Delphi study relies on open questions, developed into a set of issues. - Contrasting opinions between practitioners and researchers make the study somewhat inconclusive.
6	Albino et al., (2009) [29]	Environmental Strategies and Green Product Development: An Overview on Sustainability-Driven Companies	- The integration of Triple Bottom Line (TBL) and Supply Chain Management boosts the sustainability performance of the firm. - Enhanced communication based on long-term collaboration helps reduce costs and time. - Obtaining standards and certifications can drastically improve the quality and consistency of end products.	- The lack of government support and subsidies across many developed regions affects innovation. - Most companies cannot afford to gamble with innovation and untested market opportunities. - Competitive pricing limits the scope of firm's innovation and responsibility. - TBL model focuses more on economic aspect rather than ecological responsibility.

TABLE II
SUSTAINABILITY IN AGRI-FOOD SUPPLY CHAIN (CON.)

No.	Authors (Year)	Title	Findings	Challenges
7	Dangelico & Pujari, (2010) [30]	Mainstreaming Green Product Innovation: Why and How Companies Integrate Environmental Sustainability	- Companies go green to comply with regulations, but it also allows for risk minimization, revenue, and image protection. - Green product design is influenced by: market growth, increasing profit, brand image, and ecological responsibility.	- Integrate environmental and conventional product attributes. - High development and manufacturing costs lead to highly competitive price. - Limited customers' awareness of the benefits and price sensitivity.
8	Lai & Wong, (2012) [25]	Green Logistics Management and Performance: Some Empirical Evidence from Chinese Manufacturing Exporters	- Green Logistics Management (GLM) is characterized into four attributes: procedure-based, evaluation-based, partner-based, and general environment management practices. - Study supports environmental management or GLM does in fact facilitates environmental and operational performance in recycling, reducing carbon footprints, product quality, and shorter lead time. - Pressure from customers and governments compel producers to comply to environmentally-friendly regulations.	- To verify the effectiveness of attributes, a long-term study should be made using consistent data over a period of time. - More credible insight and data could be extracted from specific fields of manufacturing, including telecommunication equipment and consumer electronics. - More research could be done focusing on how the ratio of both import and export sales volume could relate to environmental pressure and manufacturers' effort in implementing GLM.
9	Tseng et al., (2013) [31]	Sustainable Consumption and Production for Asia: Sustainability through Green Design and Practice	- Utilizing new policies to enable for a greener Public Private Partnerships (PPP). - Combining Green and Lean Supply Chain to help achieve true Triple Bottom Line (TBL) in accordance to the emergence of Green Consumerism. - Investment in technology for optimization and innovation of green supply chain design helps boost its deployment across various segments of industries.	- The shift to renewable energy and green supply chain is extremely challenging, especially in developing countries. - Call for collaboration from various stakeholders in every industry, including government bodies.
10	Hendrickson et al., (2017) [24]	Power, Food and Agriculture: Implications for Farmers, Consumers and Communities	- Constrained choices force farmers into choosing predetermined selections of input - Industrialized farming increase income inequality among stakeholders. - The environment has been severely affected by large-scale farming with no sustainable practices put into place.	- Establishing food sustainability policy worldwide. - Subsidize food producers using agro-ecological means.

Table II details the studies made in supply chain sustainability. In the long run, through acquiring market power, price changes and their risks are shifted to food producers through various means (absence of price transmission, asymmetrical price changes, and the lag of time between price changes), while leaving some room for suppliers to still make a profit. Meanwhile, identifies the economic aspect among the three aspects of sustainability as the most important one, arguing that without long-term profit a business will not survive the competition. Also, the study reveals that lack of customer demand and government regulation threatens the producers' businesses [19].

On the other hand, traceability is seen as a key solution to the supply chain's adaptiveness to modern-day fast-moving markets. Improving food safety and traceability does encourage customers to pay more, and therefore, has the potential to open up a new class of market to increase both the safety and profitability of food producers. On top of this, [20] provides excellent narratives as to how profoundly factual it is that farmers cannot negotiate their way out of unfair trading. The study unearthed vital issues, from the ineffective and irresponsive agricultural system to changes in the modern supply chain and

customer preferences. It also proposes some key aspects to solving sustainability issues such as ecological care, modernized agricultural technology, government regulation, and making good use of the dynamics of modern supply chain production.

In hindsight, what is missing the most from today's cluttered food supply chain is the dynamics of a creative, technologically-driven supply chain that is both fair and transparent for all stakeholders. In a similar fashion, [21] argues that corporations basically fail to look after the economic aspect of sustainability of their own suppliers and instead focus more on social and environmental aspects, which only helps them sell more products. It is further asserted that food producers face immense risks and pressure from its own buyers who can do whatever it wants and command the farmers to adopt any sustainable production methods at their own expenses. The system simply lacks the modernized, fair, and sustainable model in which all stakeholders could participate as it leaves government regulation and implementation of sustainability be influenced by transnational supermarket chains. This only exacerbates the circumstances up to the point where unfair trading practices are prevalent and the imminency of poor rural farmers' economic collapse is not far ahead.

In 2050, there will be more than 9 billion people on earth to be fed [22]; while natural resources are getting disturbingly closer to being depleted. One key solution to the issue is to increase productivity and efficiency with utmost focus on sustainability. As proposed [23] and [24], the modern-day agri-food industry is capitalistic in nature. Take international trade as an example, we see price dumping happening a lot on an alarming scale that risks the livelihood of all farmers in developing nations. The flawed assumption about the existence of perfect competition has been proven to be a huge mistake as negative externalities and a lack of sustainable production threaten the long-term wellbeing and prosperity of millions of people around the globe. The studies recommend sustainable food sovereignty as a potential solution to the global food supply chain in this century. Finally, not only sustainability has proven to save costs and the environment in the long run, but it also is shown to deeply correlate to the performance of the circular supply chain as well [25].

III. Design Architecture

A. Actors

In this study, there are three important actors/ participants along the supply chain:

- Producer: This refers to food producers and farmers.
- Distributor: The one who handles the system infrastructure of the whole supply chain.
- Customer: The buyers as well as end users who consume the end products.

B. System Architecture

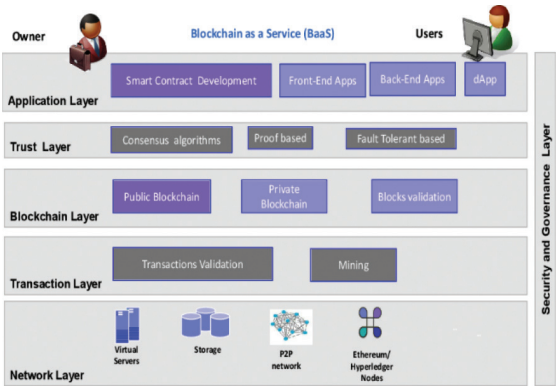

Fig. 1. Blockchain system as layers [32]

This paper adopts a blockchain system as layers to increase efficiency and transparency. As shown in Fig. 1, we have layers of blockchain system in which various components reside and function. For instance, in application layer, it uses both front-end and back-end applications to support the traffic and connection to and from D Apps (Decentralized Applications) which operate almost identical to traditional server-based system. Smart Contract development is based on predetermined terms negotiated between distributor and producer trust layer incorporates consensus protocol that are concerned around proof-based and fault tolerant-based mechanisms. What this essentially means is that the system will utilize proof-of-authority consensus, of which can withstand up to 50% of compromised nodes, as in hacking for instance. This blockchain model, however, does not fall into public blockchain platform. It, in fact, will rely on a form of consortium blockchain [33], a type of blockchain that only accepts known candidates who obtained permissions from other members in the system. Furthermore, everyone in the system will be able to apply to be a validator and has to go through aforementioned conditions to gain some sort of certificate of authority. The blockchain layer will also exercise its usual strength in areas like encryption, peer-to-peer (P2P) connection, and immutable dataset.

Transaction layer will be handled by a form of independent digital wallet, separated from real, tangible currency to avoid complexity and market influence. It will be validated by certified validators known by every member based on their reputation. The network layer of the system will rely on either physical, or virtual servers based on Ethereum Virtual Machines (EVM) which provides exceptional cost-saving measures. Using localized servers will also allow for convenient testing and ready-made tools in a closed environment condition.

C. Workflow

This model requires three actors and three smart contracts. The process begins when distributor seeks producer for predetermined contractual clauses to be used in the platform. The contractual terms should include, but not limited to: duration of the clauses, percentages of shared revenues, minimum requirement of purchases, sustainable practices, fair treatment of prices according to market indicators, and rights to renegotiate the contract.

After this, distributor designs, tests, and deploys the production, sale, and account contract, preferably in localized virtual servers. Production contract will deal with producer and distributor regarding the processes during and after production of which automated smart contract will rely on reliable database, a set of specially designed processes of using IoT devices to confirm for successful monitoring of goods along the supply chain, from outbound to inbound, into Distributor's custody. As distributor orders from producer, the production will pick up data tracked from vital checkpoints along the transportation routes, confirmed using IoT (Internet of Things) devices, and saved to be used later on. Everything from the place of originality, to transportation, and product handling will be recorded by sensors and other devices which will automatically feed into the production contract. Upon physical inspection and verification by distributor, goods are then placed inside the warehouse, waiting for customer orders.

Using a form of interactive application on his/her smart device (phone, tablet, computer), the user can conveniently order from distributor, while the sale contract is then triggered to start in the background. Distributor will then receive the order feed from sale contract, and automatically refills the goods with a new unit/batch from producer as per requested. The order will then be processed and transported from distributor to the customer. He/she uses their smart device to confirm delivery, much like existing e-business platform does, by utilizing barcode, signature, or QR code. After verification of successful delivery, sale contract will close the order and send a message to the third contract, account contract, which will release the payment paid by customer account into both the distributor and producer accounts based on negotiated terms, using transfer function. Finally, the transaction is recorded and built into the blockchain.

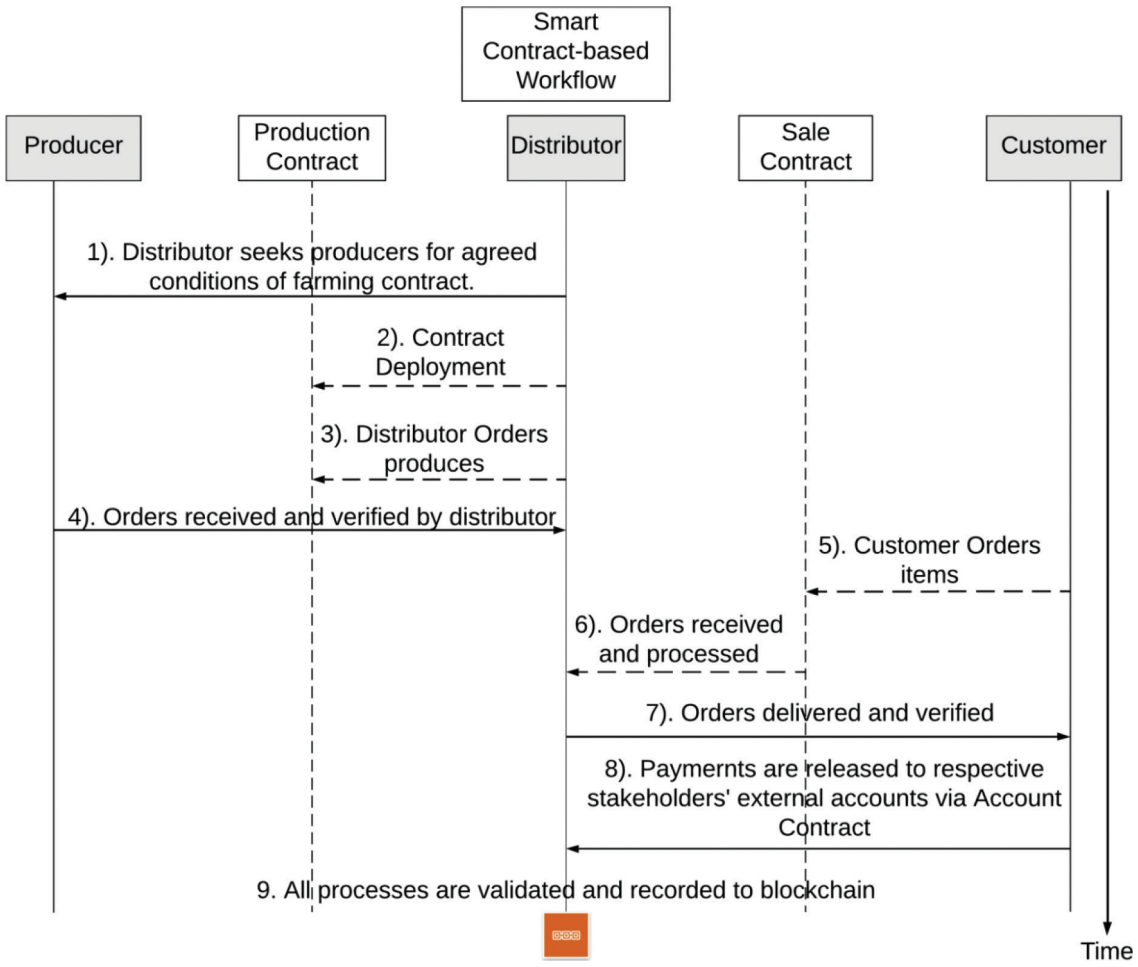

Fig. 2. Smart contract workflow between stakeholders

D. Production Contract

In Fig. 3 exists the workflow process of production contract. It is used to monitor and handle physical and information flow in supply chain between producer and distributor. Firstly, the contract itself is built upon agreed terms and conditions, before being deployed. There, both public and private keys will be automatically generated by the contract. Only private keys will be given to each party respectively. Public keys, however, will remain in the database to account for future verifications

These processes use Create and Construct functions in smart contract. Upon planting the crops, the database (using an open source-based software relying on externally connected device, or oracle) will send a command to the contract, triggering the start and set a deadline for the transaction itself, using Start as a function. External sensors combined with physical inspection will monitor the quality during planting and record the state of each batch of crops in the aforementioned database.

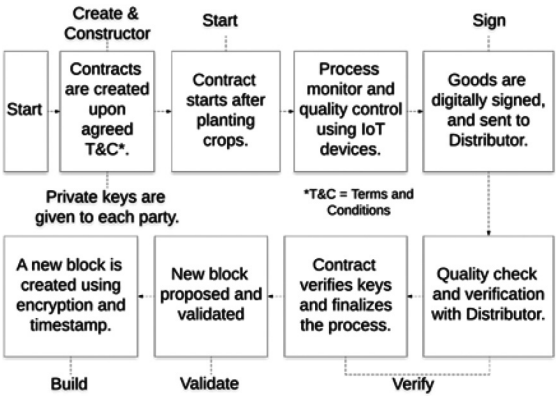

Fig. 3. Production contract

Later, Producers will harvest and package the produce into batches. It will then be sent to distributor, who will inspect and verify the quality with the database to ensure the right batches are received. The produce is digitally signed using Sign function by both producer and distributor before being verified—using Verify function. Next, the contract will finally verify public keys with private ones owned by both producer and distributor in an attempt to finalize the process. After this, a new block will be proposed to local validators to accept, using Validate function. Finally, the system uses Build function to compile a new block, while also timestamping it for security, transparency, and traceability.

E. Sale Contract

The second contract, concerning the purchase between customer and distributor is labeled as sale contract. To trigger the start of the contract, customer has to order products using an online interactive application, which will alert the contract into activate both the public and private keys with start function. Next, the contract gives customer his private key and set a deadline for the purchase. Customer can track his order using a simplified delivery tracking system that is integrated with smart contract, which allows for flexibility and transparency. After receiving the product, customer needs to confirm order delivery using his smart device to trigger contract's next step which is to verify the keys for one final confirmation of order completion, by decrypting private key and compare it to the already-existing public key using Verify function. At the end of the order, a new block is created containing the transaction details and messages, of which is validated and built into the blockchain by authorized valid actors.

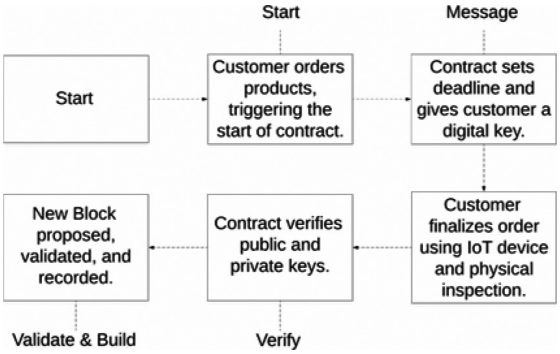

Fig. 4. Sale contract

F. Account Contract

This contract incorporates the management and monitoring of funds in the external accounts owned by producer, distributor, and customer. Account contract is triggered by the confirmation message sent from sale contract about the successful transaction. Upon an instance in which the message is received, the contract will execute transfer function which will redistribute payments out of customer's account, based on predetermined terms, to both producer and distributor's accounts. Some form of reward and loyalty system will be implemented that will award customer's account with a form of e-currency or tokens, or even special privileges to ensure long-term adoption of the platform. Finally, this transaction is proposed and validated by validators, who then compile it into a block that is built into the blockchain.

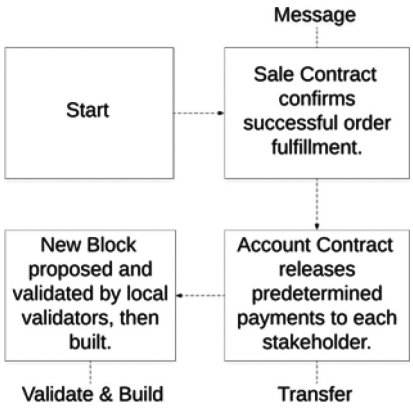

Fig. 5. Account contract

G. Blockchain Consensus

In Blockchain technology, consensus is "The process of keeping the ledger transactions synchronized across the network to ensure that ledgers update only when transactions are approved by authorized validators, and that when ledgers do update, they update with the same transactions in the same order is called consensus" [34]. It is done this way since there is no centralized system or an authoritative figure to monitor and control the transactions and truthfulness of said data and information [35], [36]. This system utilizes a variation of Proof-of-Authority (PoA) consensus as it provides a plethora of benefits over its Byzantine Fault Tolerant's (BFT) variants. The term Proof-of-Authority was proposed by former CTO of Ethereum, Gavin Wood, on his GitHub page in November 2015 [37]. This uses a rather miniscule amount of power compared to Proof-of-Work (PoW) consensus as this mechanism does not rely on competition between validators or miners; instead, it depends on a predetermined and limited number of validators to do the job that is, to focus on the accuracy and truthfulness of the result based on the reputation of the validators themselves. What makes Proof-of-Authority such a compelling consensus in this case is because it is favored by many corporations for use in most consortium blockchain applications, such as JPM Coin and Microsoft Azure Platform [38], [39]. There are, however, some requirements to achieve Proof-of-Authority's speed and effectiveness [40]:

- Trustworthiness and real, verifiable identities for validators.
- Extensive tests, investment, and tough requirements to allow for reputable validators.
- Fair and equal tests for all validators.

Additionally, there are aspects of usefulness that enable PoA to achieve unprecedented superiority over other consensuses [41], [42]:

- Increased efficiency and high transaction speed within network.
- Easily scalable for consortium platforms.
- High tolerance to attacks, provided not more than 50% of nodes are not compromised.
- Less requirement on hardware to achieve better performance.
- Predictable interval time between each block creation.

H. Smart Contract Functions

The framework used in this study will incorporate the following functions:

- Create: Create contract
- Constructor: Deploy contract into blockchain
- Start: Utilizing system to trigger the start of contract
- Sign: Sign transactions using digital signature
- Message: Send message(s) from one user to user, user to contract, and contract to user
- Transfer: transfer digital asset or currency
- Validate: used by validators to mine the transactions
- Build: Build new blocks into blockchain
- Stop: For emergency situations
- Restart: Resuming operation after emergency situations

```
1  pragma solidity ^0.4.24;
2
3  contract SampleTokenContract {
4    address owner;
5    mapping (address => uint256) public accounts;
6
7    constructor(uint256 initialSupply) public {
8      owner = msg.sender;
9      accounts[owner] = initialSupply;
10   }
11
12   function transfer(address to, uint256 value) public {
13     require(accounts[msg.sender] >= value);
14     require(accounts[to] + value >= accounts[to]);
15     accounts[msg.sender] -= value;
16     accounts[to] += value;
17   }
18 }
```

Fig. 6. Smart contract code

In Fig. 6, we have a screenshot of a sample token contract made to transfer tokens between two accounts. This code is written in remix IDE using solidity, the official smart contract language used in Ethereum. On line 1, pragma is used to enable compiler features for local file, followed by solidity version number. On line 3, we have our contract name as Sample Token Contract, whereas line 4 and 5 exemplify that owner owns the contract and that the contract uses uint 256 as its word size as well as being a public contract where anyone in the network may utilize its functions. From line 7 to 9, constructor refers to the deployment of contract into the blockchain environment. It is a public function that participants

can utilize, where the owner of the contract can send messages out. He is also the sole provider of token into the account as well.

Finally, Line 12 indicates transfer function and the address in which one can type in order to send the tokens. Again, this function is public which means it is not restricted to just the contract owner to use it. However, line 13 clarifies that the message sender (or in this case, the owner) must have enough token in his account to avoid errors. Line 14, on the other hand, is done to avoid overflow error where numbers are misrepresented. Line 15 and 16 explain the subtract and add operations done on both sender and receiver accounts.

I. Comparison of Models

Below is a list showing the concept's capability in solving main concerns surrounding the agri-food industry:

Core Concerns	This Model	Traditional Models*
Fairness	☑	☒
Consensus	☑	☒
Transparency	☑	☒
Sustainability	☑	☒

*Based on literature review done in this study

Fig. 7. Comparison of models

This model focuses on achieving fairness by utilizing blockchain technology, which boasts an in-built data encryption/decryption and immutability across all nodes in the network. This particular type of blockchain called consortium blockchain is known for its extra precautions tailored towards security such as membership system, modular consensus, and flexibility in operation. Additionally, in term of operation, this model can be freely customized to suit certain needs such as using channels for coordinated communication and information sharing between stakeholders. Consensus can be swapped out freely due to the fact that the system is modular and built with customization in mind to accommodate for an evolving environment. Transparency is a key component making this blockchain system ground-breaking and beneficial for all stakeholders. In addition to being highly secured, it also allows for transparent information flow needed to optimize costs in the whole supply chain which is a feature current supply chain cannot emulate. Using channels and encrypted communication, we can specify which information to whom we want to share making it feasible to enhance information sharing across the whole network. All of the factors mentioned above act jointly to meaningfully promote sustainability of both material and communication flow as resources such as raw materials, documents, labor force, and time can be substantially reduced due to a more collaborative supply chain.

IV. Discussion

The aforementioned framework and its components can be applied on existing AFSC with moderate changes to both the technological and operational aspects. Food producers, distributors, customers (wholesalers, supermarkets, retail customers), and other stakeholders can feasibly adopt a blockchain platform where transactions and messages are communicated seamlessly without the need for additional security or expensive maintenance; not to mention maximum transparency, accurate traceability, and enhanced scalability. As seen in Fig. 2, the transactions are enhanced using blockchain, by allowing for smart contracts integration, of which can automate both vital and menial tasks. The orders and stock replenishment between food producers and distributors are automated; while human interactions are only needed to confirm the activities/transactions. The contracts, which are agreed upon by stakeholders even before the food production starts, will work efficiently alongside minimal human support while increasing efficiency and reliability across the whole network by cutting down on human errors. This results in a more effective and cost-saving supply chain as orders and messages are communicated efficiently and accurately without adding unnecessary costs.

If we take a look at existing AFSCs from the literature review of this study, there are major issues regarding transparency, sustainability, and fairness in supply chains themselves. One way this proposed framework can help with transparency is to establish AFSCs where communication and information sharing is mandatory. The blockchain network can be customized based on the number of organizations involved, as well as the minimum requirements from each of the stakeholders. The network administrators can create channels in order to share sensitive information without the security concerns because of blockchain's built-in encryption feature; while each stakeholder is required to participate in sharing supply chain information such as product sale performance, logistics, and general operational parameters. This creates a new type of supply chain environment that promotes transparency as each stakeholder can maximize his own organization's efficiency within the network, ultimately improving on the overall average performance of the network. On the other hand, there is also a serious issue regarding sustainability in AFSCs as most supply chain is operating traditionally. The organizations involved would prioritize their own economic aspect of sustainability over social and environmental aspects. In the end, this is just a typical characteristic

of a capitalistic market; however, as humanity is facing many threats to its existence such as global climate change, deforestation, and population increase, the global supply chain has to move on to a much more sustainable and efficient form. The blockchain-based value chain is the solution to a smoother, more reliable transition toward green supply chain.

The ultimate objective of this framework, however, is to achieve fairness for all stakeholders. What literature review has shown us is that bigger, stronger players in the supply chain usually exert their power to pressure other actors which, in most cases, are food producers to adapt to their pricing, production plan, and even information sharing scheme. This severely handicaps the latter's abilities to negotiate, compete, and retain their own profitability. The blockchain framework presented here has the potential to change the game and bring equity to all players, while at the same time giving all of them new opportunities to increase their own profitability. The Blockchain framework would act as a middle ground where information and transaction are passed around whilst ensuring that each player can fully trust each other. The proposed framework also utilizes smart contract functions to help ensure that transactions are processed accurately and on time. The possibility to configure the parameters in the framework to accommodate for the needs of each supply chain is numerous. For instance, the consortium of each supply chain may discuss with its players and declare a set of conditions or rules that each of its players deem to be "fair" for the whole operations. The result for food producers is a whole new supply chain that prioritizes their well-being and value their contributions to the value chain, while also making sure that they're paid what they deserve.

Additionally, to dive deeper into the consensus model and benefit-sharing, we may take a look into smart contract itself. The framework functions as a "high-risk, high-reward" due to its experimental nature. The framework allows for each player to receive benefits based on the risks it had accepted to take. For example, one player may invest more into the infrastructure of the whole consortium to receive more long-term benefits, or that a food producer wants to invest his extra stock into the consortium and in turn he will secure higher profit-sharing percentages in the future. What makes all of this possible is the consensus and smart contract aspect of the blockchain network. The framework will utilize Proof-of-Authority (PoA) as its consensus as it takes less time to process transactions as compared to other consensuses and it helps forming trust within the whole supply chain as users who are selected to be validators underwent strict and arduous tests. Smart contract of the framework will make sure that agreements are fulfilled and that benefits are distributed as had been discussed. This eliminates most human errors and increase trust in the whole supply chain not to mention that operational performance will be increased compared to traditional system.

The smart contract aspect also acknowledges and supports the flexibility of business operation, and thus, is configurable as a version-based file. Blockchain developers can work closely with stakeholders to develop dynamic rules and benefit-sharing plans for their intended scenarios. What players can do is to essentially devise a set of rules and agreed-upon benefit sharing options to account for every possible situation therein, of which will be automatically carried out without the need for human interaction. When one or more set of rules are no longer working (which means one or more party's demand for changes), the stakeholders can call out meetings to make amends and update the smart contract itself. What makes both smart contract and consensus even more appealing is their scalability to support essentially all sizes of supply chain. Small, medium, and large consortiums can still benefit from every feature of the framework, providing that they utilize Proof-of-Authority as a consensus. Developers can seamlessly update the consortium members' information, including their desired peer nodes, channels, smart contracts, and more without rebooting the network in some instances.

The proposed framework aims to apply Hyperledger Fabric as it is favorable by corporations for its support of consortium mode. Hyperledger Fabric is most suited for this framework because it is a permissioned membership network, meaning members are approved before joining. It also focuses on performance and system scalability, making it appropriate for consortiums of all sizes to experiment on. Furthermore, it helps build trust as data can be promoted to share or be strictly on a need-to-know basis depending on the configuration of the network and channel. Moreover, Hyperledger Fabric protects sensitive data and digital keys using enhanced encryption which enables for a secured environment for low-cost consortiums. Perhaps the most important of all is that Hyperledger Fabric is currently the only one supporting modular architecture with plug-in components, capable of hot-swapping consensus and smart contract components without restarting the network. This culminates in a network that encourages experiments and trials without sacrificing performance, security, and transparency.

As with all frameworks, this study also comes with limitations. First of all, this framework is still in its infancy as researchers are still building a prototype for a rapid testing. The blockchain layers and its components are, without a doubt, might be changed according to future tests where it will be utilized

based on test-bed implementations on real-world scenarios, with experts in the field of food supply chain. Various system parameters will be put to tests as the concept might not readily reflect real-life situations. Moreover, the consensus will be subject to numerous scenario analysis in order to test its flexibility and resilience during real-time data sharing. Lastly, the researchers recommend rapid prototyping and various changes to consensus, as well as organization setups to optimize for an optimal performance and reliability.

V. Conclusion

Agri-food Supply Chain (AFSC) is seen as one of the least modernized of all industries. A majority of food producers are from developing countries, and thus, are exploited by their so-called "allies" along the supply chain. One key factor often misunderstood or overlooked entirely is the aspect of fair business practices. Traditional form of AFSC relies heavily on wholesale/bulk purchases or buyouts from middlemen or retail sellers who often undermine the real value of products, and twist the markets to their wills. This doesn't get better as the whole value chain is often found to be in a state of oligopsony.

Upon reviewing the studies, we've found an astonishingly low interest in further exploration of unfair trading practices, as well as potential solutions. From Europe to Asia, the supply chain is plagued with issues, ultimately impacting the lives of hundreds of millions of food producers, a majority of whom is living in developing countries with limited assistance from government bodies.

Arisen from this premise, we determined to seek out a framework based on blockchain, primarily due to its data immutability and transparency that provide outstanding rewards to willing participants of this experimental system coupled with smart contract in order to save costs and increase efficiency. With the framework, we are hoping to re-empower the rights and competitiveness of food producers, as well as leveling the playing field, so to speak, in the agri-food supply chain. This would not just benefit all the stakeholders of the industry; it would also be exceedingly favorable to the end consumers and sustainability as a whole.

The framework relies on three main smart contracts to function: production contract, sale contract, and account contract. These contracts would receive information from the reliable database, or external real-time data streams, in order to trigger or confirm specific pieces of data needed for contracts to function. The system would also make use of an already existing form of e-commerce and logistics to simplify the ease of use for stakeholders. Finally, the framework offers a number of benefits, when combined, to offer a brand-new platform from which food producers could benefit.

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