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Research on Blockchain for Sustainable E-Agriculture

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***Abstract*—In recent years, information technologies have attained remarkable advantages in promoting the development of sustainability in agriculture. However, challenges still exist in technology implementation, which mainly involves biased points of view, initially higher costs, uncertainty, lack of transparency, and trust. To tackle these challenges, recent research attempts to introduce blockchain technology, combined with ICT, to promote sustainable e-agriculture. Blockchain technology, due to its distributed network system, is believed to enable a more transparent supply chain and rebuild trust between members. Therefore, blockchain-enabled e-agriculture is widely considered as the next step towards sustainable agriculture. Realistically, implementing blockchain technology still offers some key issues, and a new perspective about sustainable data management systems is needed. In this paper, data demands from all related parties who care about sustainability achievements in the agricultural sector are taken into consideration. The paper proposes an overall system approach to insert blockchain technology into the current agri-food supply chain. It provides interesting insights about how to achieve sustainability, by creating a new value mechanism among blockchain network members.**

Keywords—Blockchain technology, e-agriculture, sustainability, data management approach

I. Introduction

Sustainability is one of the problems that challenge the current e-agriculture supply chain. The unsustainability characteristics are reflected in several aspects. Socially, agri-food safety and information integrity, as well as fair trade among partners, have all become global issues that draw the attention of local governments, international organizations, and other related parties, such as consumers and scholars. Economically, values and returns that come with the upgrade of old systems are sometimes not worth such huge set-up investment and incoming costs for its maintenance afterward. Environmentally, the amount of energy consumption for e-agriculture is significant and the energy supply should be carefully considered when promoting e-agriculture to rural areas and to developing or less-developed economies. Reasons that cause these anti-sustainable features within the supply chain are complex but are apparently related to the collection and use of data, more specifically, whether the value of data is mined and used effectively. One solution addressing this issue is building an inter-organizational mechanism of data sharing and value creation. Regarding inter-organizational cooperation, blockchain technology is believed to be appropriate to fix these communication issues, compared to many other information and communication technologies (ICT).

The rest of the paper is organized as follows. The second section introduces related works in blockchain's potential for sustainable development, followed by a summary of blockchain characteristics and practical challenges, as well as sustainability measurements used by related parties(section 3). The next section develops a three-layer system approach based on the top-down analysis. Each level emphasizes different considerations for sustainability and critical decisions related to data management are highlighted as well. The paper finalizes with the main findings and propositions.

II. Literature Review of

The majority of the state of art research has focused on exploring potentials of blockchain technology in the supply chain, as well as adoption barriers that organizations have to overcome. Specifically, some have explored critical success factors (CSF) in implementing blockchain technology in SSCM scenarios and the linkage between these factors. In [1], the antecedents of using blockchain in sustainable supply chain management(SSCM) have been identified and classified into three clusters: Independent Elements (Financial Constraints, Top Management, Competition, Culture, Infrastructure, and Planning & Execution) drive dependent elements strongly (Government Support, Supplier Acceptance, Customer Acceptance, External Stakeholders and People). Moreover, ICT, with high dependence and driving power, is the most crucial factor in applying blockchain technology in SSCM [1]. In [2], six major causes for implementing blockchain technology in SSCM are data safety and decentralization, accessibility, laws and policy, documentation, data management, and quality. Some contribute to developing performance measures systems

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for blockchain technologies[3], which include factors for sustainable supply chain transparency and technical characteristics. Attributes for sustainability are decomposed into participation degree, tracking product components, tracking product sustainable information, participant operations and situations information and participant sustainability conditions are identified as cost, adaptability, scalability, security and complexity. In [4], adoption barriers are categorized into inter-organizational, intra-organizational, technical, and external barriers. Moreover, the linkages between blockchain technology and sustainability are discussed involving social, economic and environmental aspects. To summarize, a universal agreement has been achieved that blockchain technology has strong fitness in promoting inter-organizational operation, and a certain understanding of the obstacles to be overcome. The next step is to solve the problem of practice: how to absorb the current findings and existing practice experiences to provide more useful insights and perspectives for sustainable e-agricultural supply chain management.

As for how to fulfill and promote sustainability of e-agriculture, some efforts have been made on discussing technical features and sustainability proposals. [5]identifies information exchange as one of the leading constraints that influence the effectiveness of circular economy (CE). In[6], blockchain technology is demonstrated as a double-edged sword, helping to enhance social welfare while reducing SC profitability. The evidence is provided in the aspect of social sustainability, but the counterexample is provided in the aspect of economic sustainability. In [4], different businesses can benefit from the use of blockchain technology in terms of reduced transaction costs and time[7], human error, reduced supply chain risk[8] brought by improved data security, authenticity and business reliability, as well as increased financial income result from increased consumer confidence.

Currently, issues that need to be solved in the agricultural supply chain includes: 1) Information sharing, which can benefit all partners; 2) Data security: the original quality of data can be improved by implementing Internet of Things (IoT)technologies, but data security and privacy among stakeholders need to be further studied; 3) Data demands of Life Cycle Assessment (LCA) and other sustainable analysis tools, which can help the industry to obtain more accurate forecasts, further achieving the goal of energy conservation and emission reduction, as well as sustainable agricultural strategy; 4) Expectation of stakeholders for sustainable supply chain; 5) Integration mechanism for implementing sustainable model; 6) Indicators to measure sustainable benefits brought by the application of blockchain technology; 7) Validation and verification, which is that business processes and product processing should achieve certain sustainability goals[9]; 8) Unsustainability characteristic of the technology itself: blockchain-enabled services such as the mining of Bitcoin consumes significant amounts of energy and its consumption is comparable to that of countries[10]. Hence, the question to be considered in this paper is how to use blockchain technology to strengthen environmental and social sustainability and reduce its impacts on economic sustainability in the agricultural supply chain. In other words, how to make blockchain technology more economically sustainable?

III. Blockchain Technology and Sustainable E-Agriculture

A. *Characteristics and Practical Challenges of the Blockchain Technology*

Several characteristics of blockchain technology relevant to SCM have been identified and its potential uses include enhancing product safety and security, quality management, as well as reducing counterfeiting and the need for trustful long-term supply chain relationships[11]. In [12], methodology consisting of actor definition and solution canvas is created to guide the adoption of the blockchain-based solution for non-financial uses, such as in logistics and supply chain.

As for blockchain technology in practice, many studies have identified potential challenges. Storage capacity and scalability is a deeply questioned issue which affects the size of the data block, the processing rate of transactions and the latency of transmission negatively[13]. Some believe advanced storage management and cloud computing[4] can tackle this issue, but their anti-sustainable characteristics such as power consumption[14] are neglected. As for privacy, how to control the negative influences of increased transparency is still an unsolved problem, since neither enterprises nor individuals would agree to publish their private information on public databases[14]. Standardization of blockchain-based networks also limits the realization pace and expected benefits. Data interoperability is another non-neglectable issue and involved companies need to agree on data structure, format, as well as what data to share[15].

Blockchain-based solutions in agriculture also face several social challenges. Firstly, Heterogeneity of the sector. Actor variety in the agri-food system makes it impossible to provide a single solution to fulfill diverse demands. More complexity comes from agri-food diversity, ranging from crops and horticulture to livestock and fishery, along with different planting and breeding environments. The second issue is related to scale and costs. Since blockchain-enabled systems usually require comparatively large set-up investment and consistent maintenance costs, it is not hard to find that larger and technical-intensive farms are more likely to uptake the blockchain technology. Pilot projects worldwide are mainly led by large companies in developed economies, such as Walmart and Bumble Bee Foods[16]. Therefore, the current challenge is to attract small-scale farmers to invest affordable capital for new technologies by making available technical-offerings and dispelling fears of data misuse significantly. Furthermore, the lack of appropriate business models and confidentiality standards also hinders the sustainability of blockchain-enabled agri-food, such as fair trade and value share along with supply chain participants[17].

B. *E-agriculture and Sustainability Measurement*

E-agriculture is defined as using ICT and digital solutions in innovative ways to boost the agricultural sector[18]. Inspired by [19], the fulfillment of sustainable e-agriculture refers to the integration of the traditional perspectives of efficiency and environmental impacts from agriculture management, with a simultaneous awareness of the environmental impacts of technology. [20] integrated two increasingly popular but distinct topics of Industry 4.0 and circular economy to understand how different technologies in Industry 4.0 could support CE strategies. Furthermore, in [16], characteristics of blockchain technology are linked with the ReSOLVE model of the circular economy through several case studies. In particular, smart execution is applicable in some loop activities as well as emission targets supervision. Another increasingly popular tool for measuring environmental impacts is LCA and study about blockchain technology and LCA, just as circular economy, is very limited. Blockchain technology is believed to be able to address the quality issue of data collection in LCA scenarios with a conceptual blockchain-based LCA framework and system being built under this belief[21]. However, the validation of the proposed framework was confirmed only by experts in blockchain technology deployment and the undetailed implementation of this framework still needs to be further discussed and improved. In conclusion, as emerging topics, research gaps exist in unvalidated sustainable e-agriculture implementation and non-informalized sustainable analysis. In this paper, data demands for both e-agriculture supply chain operation and its sustainability measurement are combined together during the development of blockchain-based solutions.

IV. Overall System Approach

A. Entry point: Demands for Inter-organizational Data Management

Four main actors in a typical e-agriculture supply chain are agri-food producers, processing enterprises, distributors, and retailers. Data created inside each actor can be generally split into three main streams:

1) Information about food or products.
2) Information about various suppliers.
3) Information related to different customers.

It is clear that information related to agri-food is shared inter-organizationally, while the other two are mainly stored intra-organizationally. Moreover, expectations of consumers as direct stakeholders, parties represented by government regulators and expert groups for sustainable development, are also taken into consideration. Before implementing blockchain technology, it is important to identify inter-organizational challenges in the areas of agri-food data. Data setup is the first challenge. Although sharing agri-food data is required for sustainable supply chain management, access to data is still privileged and should be set up by different actors. This time and effort consuming process can be done more easily with the help of blockchain technology. Secondly, agri-food data, as well as data related to suppliers and customers, should be maintained and updated regularly within enterprise systems. The third challenge is data standardization; Lack of standardization is common for different actors along the supply chain since data are collected and stored independently. Out-of-sync and unstructured data can lead to transaction failure, as well as other negative impacts. Finally, multi-system architecture is required to integrate various data sources [22].

The above challenges highlight the need for a decentralized system that can play as a generalized data repository. To maximize the sustainability of the blockchain-based data system, the approach is divided into three steps, namely blockchain-based ecosystem and governance, blockchain-based system and value creation and ICT deployment and data collection.

B. Blockchain-based Ecosystem and Governance

Because of its decentralized nature, each participant will have a stake when achieving sustainable e-agriculture management. It is essential to understand stakeholder's expectations when building a blockchain-based ecosystem (shown in Fig.1). For processing enterprises and retailers, strategic needs for increasing market share and consumer confidence make these enterprises natural leading organizations in blockchain alliances. As coordinators, central companies should form discussion groups to determine a set of rules about how participants interact with each other. Regarding sustainability, related parties in terms of agri-food data interested institutions, are also part of the blockchain-based ecosystem and have the right to access data. For all participants, the expectation for types of roles that each one will take part in, the way to access or exit the blockchain network, data type and ownership should all be clearly defined. For producers and distributors, because of a lack of market power, they are less likely to join a blockchain ecosystem that does not have a clear governance model and value creation mechanism. Incentives to participate in alliances can be tangible, such as reducing costs and time, but they can also be intangible.

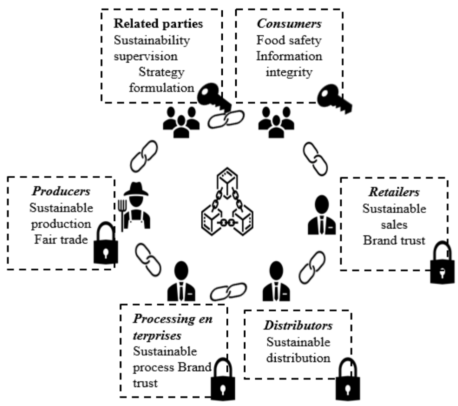

Fig. 1. A Blockchain-based ecosystem of agriculture supply chain

After clarifying all parties' expectations, data planning is the next step which helps to specify data demands and the following tables offer a very useful tool. The first column stands for each operation process or a single data point. After identifying a single point, data specificity should be determined and this will influence data collection methods[23]. Other data dimensions (shown in Table 2) help to further understand details about these data. By filling in this kind of template, participants can fully understand why data are collected in the first place and where to store them will be the best decisions for sustainable management.

TABLE I. TEMPLATE FOR PLANNING AGRI-FOOD DATA（1）

Data point	Specificity				
	Very high	*High*	*Medium*	*Low*	*Very low*
A	X				
B		X			
C			X		

TABLE II. TEMPLATE FOR PLANNING AGRI-FOOD DATA（2）

Data point	Type	Source	Access	Storage	Usage
A	Concentration	Producers	Intra-	Local	Operation
B	Kg/year	Processing enterprises	Inter	On chain	Prediction
C	Unit process		Public	Cloud	Right to know

C. Blockchain-based System and Value Creation

A blockchain-based supply chain can be regarded as a value-creation platform[24], on which network members create value together through a series of specific practices and dynamic allocation of tangible and intangible resources(shown in Fig.2). At the strategic level, its key elements include a value proposition, value creation and value distribution within the blockchain network. A value proposition is important to bring sustainability goals into income and cost model as well as core business process identification. For example, participants need to decide whether or not anti-sustainable behaviors should be punished, as well as how to encourage sustainable behaviors. Consideration should also be given to whether smart contracts should be encoded into the blockchain and whether digital tokens should be used to facilitate sustainable behaviors. The awareness of all participants on fair value distribution is essential to maintain and cultivate the flexibility of the blockchain value platform[25]. For data management, how to integrate different enterprise systems under the guideline of data planning is the main challenge. Moreover, in order to achieve a better sustainable performance, the algorithm adoption for distributed consensus is another critical issue and usually depends on different cases.

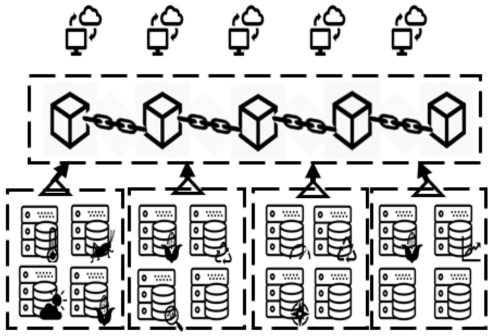

Fig. 2. System design of Blockchain-based agricluture spply chain

D. ICT Deployment and Data Collection

In Fig.3, a conceptual framework for data planning and collection is illustrated. An agriculture supply chain is the first layer and it presents traditional material and information flows. The layer above represents e-agricultural data demands among different business processes for sustainability. In detail, during the production of raw Agri-materials, all data including temperature, weather, health condition of lands and livestock should be collected by IoT technologies, decreasing human error and material waste. By collecting this data, better operation decisions can be made in order to achieve sustainable production. However, in rural areas, investment in the development of ICT is the initial step before launching any blockchain-based projects. Logistics services linking four supply chain partners together should also be monitored for sustainable indicators including CO_2 emissions and fuel consumption. Processing companies are in charge of food safety and, usually running modern production lines, the extra data demands related to this stage are more sustainability-focused, such as for the usage of recycled material.

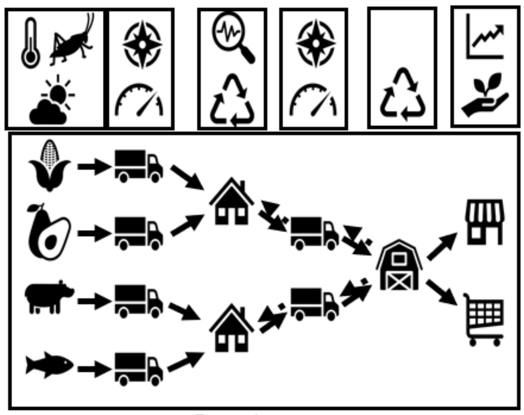

Fig. 3. A conceptual framework for data collection

Finally, retailers prefer to sell products with better market performance, which means they need products with better information integrity and safety. Moreover, after-sale data can be collected at this stage and analyzed for more accurate predictions in the future.

V. Conclusion

Blockchain technology has become a disruptive technology that creates opportunities to improve traditional industries from multiple aspects. Agriculture or agri-food supply chain, at the central concerns of national strategy, is combining this technology with other ICTs for better sustainable performance. Under such circumstances, the paper proposes a top-down approach to promote IT implementation in agricultural supply chains. Several critical issues are highlighted and discussed in detail. Firstly, the paper discusses energy consumption related to blockchain adoption, especially in rural areas, which should be analyzed from both supply and demand perspectives. For instance, how to produce sustainable energy for the use of blockchain and its related technologies? Secondly, data planning is the key to excellent sustainability performance. It is undeniable that data quality determines the reliability of sustainable analysis as well as the efficiency of supply chain operation. Detailed planning in data management helps to make wise decisions on data collection and storage, thus saving physical resources. Thirdly, initial incentives from government or leading companies are important. By thinking from the perspective of different participants, a consensus for economic benefits is achieved in the first instance, followed by social and environmental benefits.

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