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A Systematic Literature Review of Blockchain Technology in Agriculture

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Abstract

Blockchain has got numerous applications in various fields and one of the promising one is agriculture. The blockchain application in agriculture includes food safety through traceability of provenance, information system, agro-trade, finance, crop certification and insurance etc. Thus this paper aims to review the applications of blockchain in agriculture field from all major databases ranging from Web of Science to Scopus. The study shows that though there exist many blockchain based application in agriculture but only few countries are able to grasp it where China is leader followed by USA, Italy, India and Spain. This paper also reviews the recent trends about blockchain research in agriculture and subsequently provides future research directions.

Keywords

Agriculture, Blockchain, Future Research Directions, Literature Review, Traceability

1. Introduction

Blockchain is the most buzz world in today's world and often considered as most destructive technologies till now. Blockchain is shared, cryptographically unaltered distributed ledger for recording the history of a digital transaction (IBM, Hyperledger). Each member (stakeholder) on blockchain system stores copy of all previous transaction ever executed through the given system. But no single party/node is owner which shows that it is not a centralized system. Since each activity in the system is visible and auditable by all members, thus this type of decentralized system creates the foundation of trust. For any transaction to happen, a consensus algorithm is followed means consensus of nodes that agree upon the issue is required which ensure its validation and authorization. Also blockchain based system doesn't require a mediator or third party for transaction leading to lowering transactional cost. These transaction are also irreversible and need of any public and private institution mediator is avoided which makes the system more efficient. The member involved need not to trust each other than system and code which are full proof. Three definitions are blockchain are very predominant as follows:

- *Technically,* it is a back-end database which maintains a distributed ledger and has the facility of being inspected openly.
- *Business-wise,* it is an exchange network for moving value, assets, transactions between peers, without any need of intermediaries.
- *Legally speaking,* it validates transactions history, replacing previously trusted entities.

In simple terms, consider a village having finite number of people where transaction is to be done between two people or parties. For this transaction to happen everybody in the village comes to a common platform and transaction happens in front of everyone. For record purpose, everyone take a note of this transaction in their notebook. Now in future or anytime, if any of two concerned parties between whom this transaction has taken place can't claim any wrong information or deny the transaction because everyone in the village has the original note about the transaction. Also to forge the information, the fraudulent has to change the note of everyone's copy in the village which is not possible in practical circumstance. In similar fashion, suppose these transactions happen through computers and all the villagers are different computers where the record is stored. Also these transactions are cryptographically secured, authenticated and verified by anonymous approvers (also called as miners). This is what happens in actual blockchain environment where each information/records are stored in blocks and everybody connected to the network has this copy. Any further transactions is added in the new block and linked with previous blocks. Since it is cryptographically secured and thus can't be mutable by any fraudulent. The detail working of blockchain based system is shown in figure 1 and could be explained in six easy steps. In step one, transaction is requested and it get broadcasted to the all connected networks in step two. When consensus about this requested

transaction is reached, it gets verified in step three. A new block is created in step four which is cryptographically secured. This new block is added to the existing blocks resulting in completion of transaction in step five and six respectively.

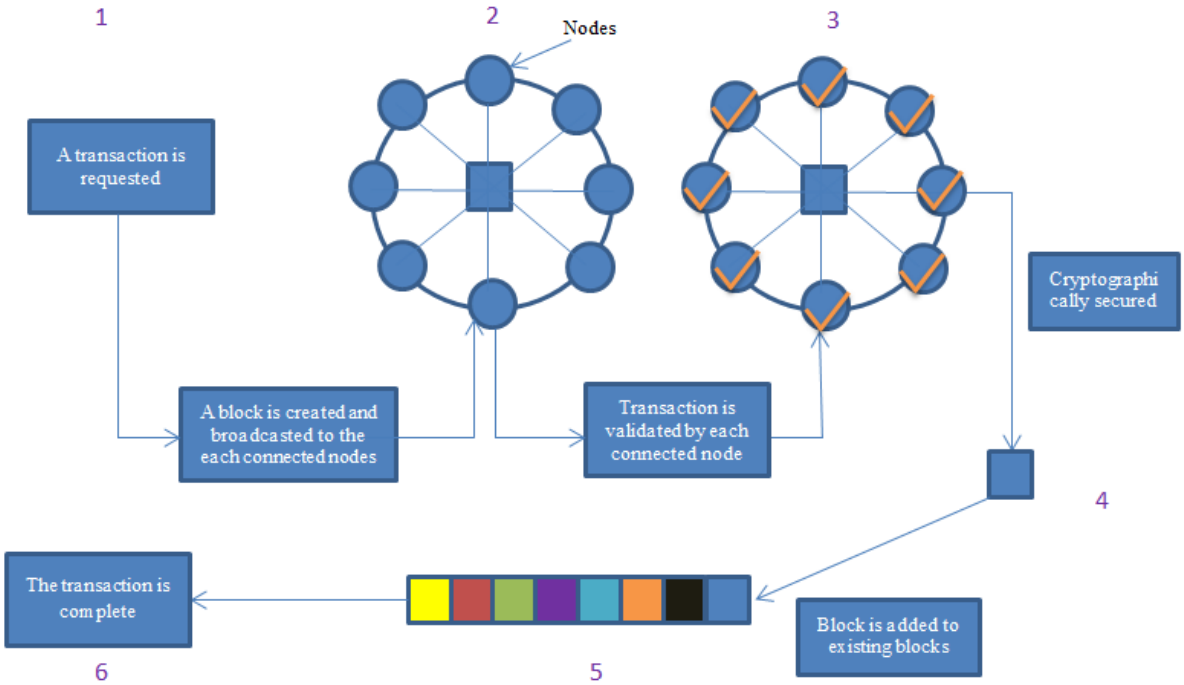

Figure 1. Working of Blockchain

Blockchain has got application in many areas ranging from healthcare (Angraal et al., 2017), finance and banking (Trelevan et al., 2017; Guo et al., 2016), crowdfunding (Cai, 2018), business models (Momo, 2018), governance (Carter and Ubacht, 2018), supply chain (Perboli et al, 2018; Wamba, 2019) to energy (Goranovic et al., 2018; Andoni et al., 2019) etc. Few blockchain based review work in different area exist like IoT (Conoscenti, 2016), service systems (Seebacher, 2017), energy (Chitchyan and Murkin, 2018; Andoni et al., 2019) etc. The blockchain has got applications in agriculture field too which includes food safety through traceability of provenance, information system, agro-trade, finance, crop certification and insurance etc. Blockchain based system could be saviour for different agricultural stakeholder like farmers which are mainly deprived due to various reasons (Yadav and Singh, 2019). Thus, agriculture has been a very promising area for blockchain but no review exists in this area except Bermeo-Almeida (2018) which focuses on only ten studies lacking the detail module. Thus there is need to comprehensively review blockchain based agricultural application. This paper bridges this gap by comprehensively reviewing all blockchain based applications in agriculture till January, 2019. The research methodology of the review is explained in the next section. Section three gives the descriptive analysis about blockchain research in agriculture while section four deals with different dimensions of blockchain research in agriculture. Section five talks about future research opportunities in the concerned area and finally section six gives the concluding remarks of the paper.

2. Research Methodology

The literature review followed here is adopted from Marying (2003) which is a four step methodology. The first step is collection of material followed by descriptive analysis in second step. Third step deals with classification of material into different categories while step four deals with evaluation of the material. Each step is explained in detail as follows:

1. *Material Collection:* The material was collected from various digital libraries and databases. The various digital library included IEEE Explore, Taylor and Francis, ScienceDirect (Elsevier), Springer and emerald insights. In addition to this, three major databases were considered i.e. Web of Science, google scholar and Scopus (World largest database for peer-reviewed literature).

The keyword used of search was “blockchain in agriculture”, “blockchain in food supply chain” “blockchain in agro-food supply chain” etc. A total of thirty six articles were found. However, few refining strategy were applied to

get more related literature leading to elimination of few article resulting in final review of twenty nine articles. These elimination strategies were as follows:

a. Article written in language other than English were eliminated.
b. All types of dissertations i.e. graduates, post-graduates and Ph.D. were eliminated.
c. Conference paper whose extension could be found in form of journal article was eliminated since journal article covered all aspect of conference paper and considering both may result in duplicity.

2. *Descriptive Analysis:* The literatures were organized on the basis of number of publications per year, type of publications, country of research etc.
3. *Category classification:* The literature was classified under four head namely traceability, architecture and security, information systems and others applications of blockchain in agriculture field.
4. *Material Evaluation:* The literature was analysed on specific structural attribute to identify relevant issues and current trend about blockchain research in agriculture field.

3. Descriptive Analysis

The papers were arranged year wise which showed that there is increasing trend in terms of publication on this topic (refer Figure 2). The first paper appeared in 2016 and there is substantial increase in number of publication over the years. This shows the growing interest in this area among researchers, academia and industries. However it was seen that most papers occurs in international conferences rather than in journals and book chapters (refer Figure 3).

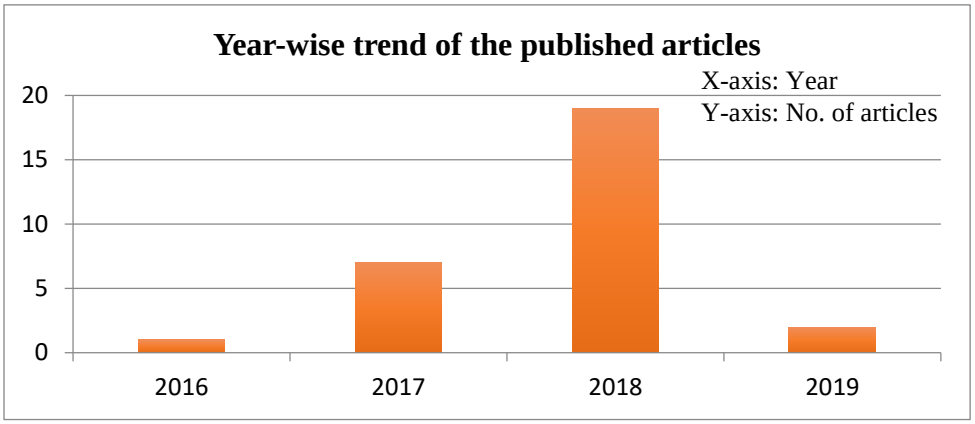

Figure 2. Summary of year-wise blockchain research in agriculture

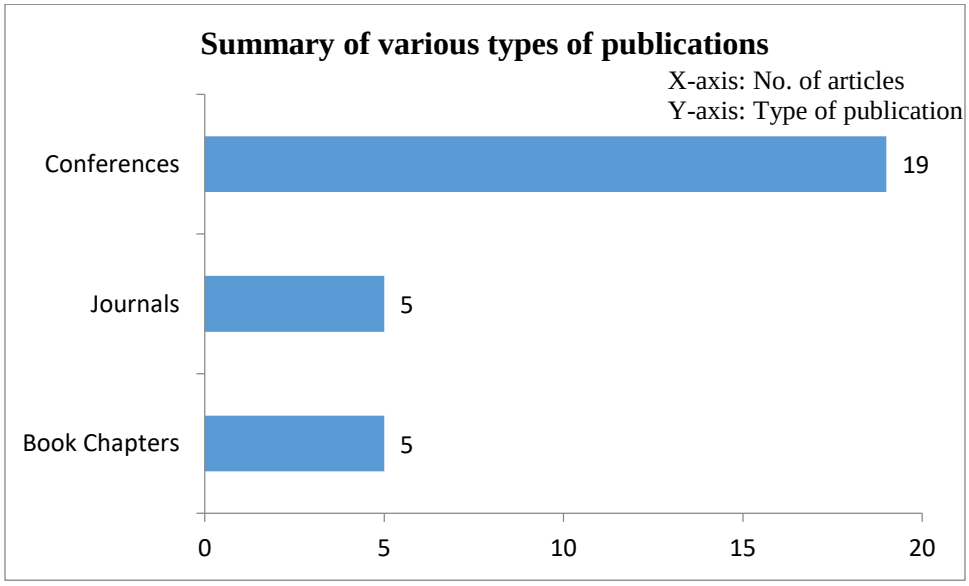

Figure 3. Summary of the various types of publications

Further the publications were arranged country wise which showed that China is leader followed by USA, Italy, India and Spain. Other countries in this list include Australia, Canada, Colombia, Ecuador, Luxemburg, Russia, and South Korea (refer Figure 4). The country-wise classification was based on geographical location of the study conducted. Although there were few paper which doesn't mention any territory, in such case affiliation location of first author was used as criteria for country classification.

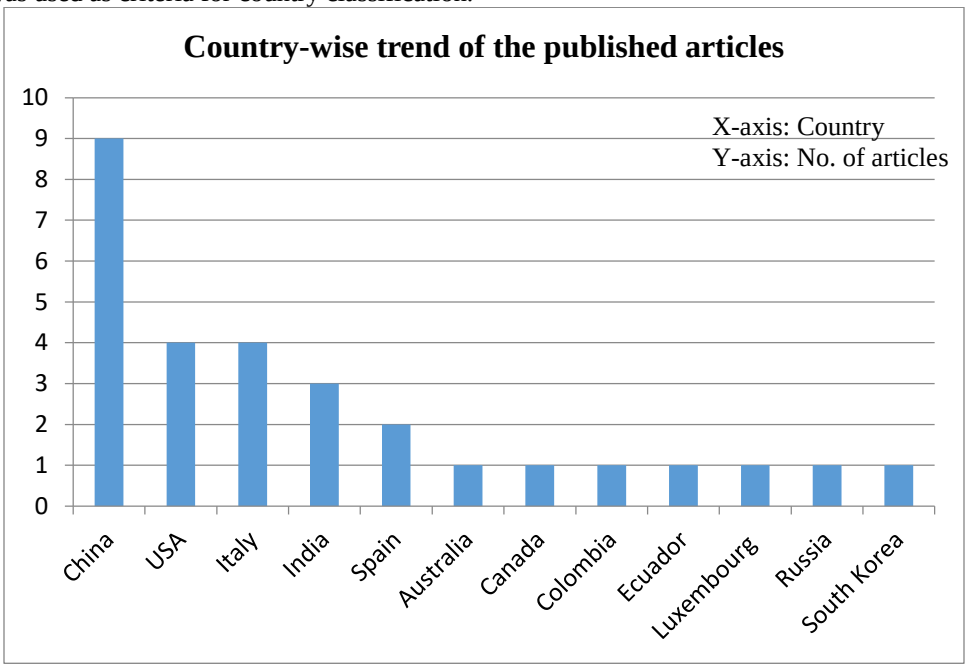

Figure 4. Summary of country-wise blockchain research in agriculture

4. Classification of Blockchain Research in Agriculture

The literature was classified under four head namely traceability, architecture and security, information systems and other applications of blockchain in agriculture field.

Traceability: Traceability is considered as suitable mechanism to monitor food safety in food supply chain. For this purpose, researchers and supply chain manager have tried various mechanisms like digitization, RFID tagging etc. for traceability. But none of them has been full-proof solutions. However blockchain could be real saviour in such cases. This has been verified through some real world case studies by various reputed organization like IBM, Walmart, Tsinghua University etc. IBM along with Walmart conducted a case study where they traced the journey of mango from farm to fork in 2.3 seconds using blockchain which was used to take longer than a week in earlier Walmart system. Further, Provenance is UK based company which conducted a Pilot Study using blockchain along with smart tags and mobile phones in early 2016 to track tuna journey from its catching to feeding consumers. The study made it possible for an Indonesian firm to convert their business of tuna fish into great asset by providing digital identification which could be easily verified through open registry. Similar provenance technology was utilized by Everledger for tracking wine in case of any fraudulent sales.

Tian (2016) studied the development and utilization of blockchain technology and RFID in agriculture sector and gave its advantages and disadvantages. A framework was also proposed for the same. Further, Tian (2017) developed a real time traceability mechanism for agro-food supply chain using HACCP (Hazard Analysis and Critical Control Points), Internet of things and blockchain. The system was built on BigchainDB to provide openness, transparency, security, neutrality and reliability to all parties of agro-food supply chain. Malik et al. (2018) proposed a permissioned blockchain framework "ProductChain" for tracing food provenance. The simulation result showed that the trade flows were kept confidential among stakeholder of food chain and query were answered in milliseconds.

Further few researchers integrated blockchain with IoT for traceability. In such systems, IoT devices were used for recoding data and these data were fed on blockchain to trace the provenance. Caro et al. (2018) developed a

blockchain based traceability mechanism for agro-food supply chain in form of AgriBlockIoT. The authors successfully integrated IoT devices for consuming and producing digital data along the supply chain. They made use of use-cases to test their blockchain based system implementation. The implementation was done through two platforms namely Hyperledger Sawtooth and Ethereum. Lin et al. (2018) also proposed traceability of agro-food supply chain through use of blockchain and IoT technology. All manual verification was eliminated through IoT devices and correspondingly smart-contract were designed for law suit if exists any. Hong et al. (2018) proposed a traceability mechanism for food using IoT and blockchain based system. The authors believed that traceability could be achieved by using IoT devices for recording data and consortium blockchain as basic network. Hua et al. (2018) proposed a blockchain based system for traceability of agro-food supply chain. The focus was to maintain credibility of data and integrating sub-systems of involved companies. Bettin-Diaz et al. (2018) proposed a novel strategy for traceability of organic coffee in Colombian context. Their methodology integrated marketing practices, process engineering, technology and information into unified blockchain based supply chain. Kim et al. (2018) proposed a traceability mechanism for farm to fork in form of "Harvest Nestwork" using Ethereum Platform and IoT devices. The authors also revealed the working mechanism of smart contract and explained the procedure to "tokenized" agricultural products onto a blockchain ledger for tracing its physical custody.

It was observed from literature that traceability was most shouted application of blockchain in agriculture field. Further, various challenges in using blockchain for food tradability were analysed by Galvez et al. (2018). As blockchain based system doesn't have control on sensor through which data are fed to blockchain system, if such sensors are manipulated it will difficult to catch such fraudulent.

Information System: Few authors used blockchain for providing information in correct form at right place in right time. Lin et al. (2017) proposed a blockchain based ICT for e-agriculture applications. The authors also developed an evaluation tool for such ICT system. Tse et al. (2017) proposed use of blockchain based information systems for the food chain in China. The authors considered blockchain technology as worthy in tracking, auditing and monitoring food supply chain. They stated blockchain as beneficial to manufacturers, customers and supervision departments (government agencies) and found it useful in enhancing the efficiency of supply chain. Davcev et al. (2018) proposed a blockchain based cloud ICT platform to build trust and awareness in food supply chain. A case study of grape in city of Skopje was considered and sensors were installed to monitor the data for traceability. Further, the author also conducted a questionnaire for assessing Quality of Experience from stakeholders to verify the utility of the concept. Petec and Zajec (2018) established principle for blockchain based information exchange in form of Luxembourg Slovenian Business Club to enable creation of communication tools between decentralized food/nutrition parties. They named their platform as "CONFIDENCE." Andreevich et al. (2018) emphasized on blockchain based information system for leveraging its implementation.

Architecture and Security: Researchers have come up with better architecture and security features to mitigate risk existing in present blockchain based system. Xie et al. (2017) proposed blockchain based double-chain storage system and designed secured data storage scheme for tracing agri-food products. Double chain system was introduced to overcome the problem in automating the agri-practices. A practical implementation of the proposed system was also shown. Leng et al. (2018) proposed blockchain based double-chain architecture comprising of storage module and dual chain structure to solve few issues of Chinese public platform for agro-products. Patil et al. (2018) proposed a security mechanism of IoT based Greenhouse Farming through blockchain technology. For this purpose, a suitable framework was prepared through integration of blockchain and IoT devices to provide secure communication for Greenhouse Farming.

Other applications: Though tractability seems to be highly cited area for blockchain in agriculture but it possesses other notable applications too. Kim and Laskowski (2017) explored the application of blockchain in agriculture. The authors classified three category of agricultural application namely food safety, sustainable agro-practices and agro-finance. Papa et al. (2017) investigated the possibilities to use blockchain in agri-business and found that such system could bring transparency through effective monitoring of agricultural trade. Yadav et al. (2018) developed a blockchain based app for payment in online food court ordering on Ethereum Platform.

Kumar and Iyengar (2017) proposed a blockchain based framework to address key problem in rice supply chain for Indian context. The authors also demonstrated example scenario to show the utility of the proposed blockchain based framework for food safety. Yadav and Singh (2019) proposed a blockchain based system for addressing farmer's issues in Indian context. The authors did exhaustive literature search and used Delphi method to finalize

issues of Indian farmers, and proposed their solution through blockchain based information system. Pinna and Ibba (2019) developed a blockchain based decentralised system to address the key issues of contract employees. The authors used their application to test through a case study in agriculture sector.

Lucena et al. (2018) analysed the implementation of blockchain for assuring grain quality through tracking in real time. Based on preliminary analysis, the authors claimed that blockchain based quality certification can enhance grain export value by 15% in Brazilian context. Perboli et al. (2018) showed critical aspects for blockchain implementation through a case study in fresh food delivery in Italian context. The authors used GUEST methodology which focuses on controlling process from scratch till actual implementation. Johng et al. (2018) developed a framework in form of "Fides" to utilize blockchain capabilities in creating trust in food supply chain business. The other contribution of "Fides" was carrying out business process re-engineering through diagnosing AS-IS business processes to TO-BE business processes. Casada-Varo et al. (2018) proposed a smart-contract based blockchain model for agro-supply chain to promote circular economy. The authors used multi-agent system to coordinate all the transaction occurring in the proposed agro-supply chain. The summary of blockchain based research for various agricultural applications is shown in Table 1.

Table 1. Summary of blockchain based research for various agricultural applications

Sl. No.	Area	Authors
1.	Traceability	Tian (2016); Tian (2017); Malik et al. (2018); Caro et al. (2018); Lin et al. (2018); Hong et al. (2018); Hua et al. (2018); Kim et al. (2018); Davcev et al. (2018); Galvez et al. (2018)
2.	Architecture & Security	Xie et al. (2017); Hua et al. (2018); Patil et al. (2018); Leng et al. (2018)
3.	Information System	Lin et al. (2018); Tse et al. (2017); Davcev et al. (2018); Petec and Zajec (2018); Andreevich et al. (2018)
3.	Others	Kim and Laskowski (2017); Papa et al. (2017); Kumar and Iyengar (2017); Almeida et al. (2018); Casada-Varo et al. (2018); Yadav et al. (2018); Lucena et al. (2018); Perboli et al. (2018); Johng et al. (2018); Yadav and Singh (2019); Pinna and Ibba (2019)

5. Future Research Directions

The research on adoption of blockchain is still in naive stage but there is growing interest in this area which can be observed from the increase in number of publications. In this context, this study reviews the relevant literature on application of blockchain in agricultural field. Further reviews shows that blockchain has got good future in agriculture field. However few important issues related to blockchain implementation exists like scalability, interoperability, proof of verification mechanism etc. Also few challenges lies in designing better architecture to enhance security features in blockchain based system against 51% attacks (someone attains the majority in a network and abuses it), DNS attacks (sending peers wrong information), DDos attacks (achieving denial of service), mempool attacks (flooding new blocks with transactions), consensus delay (preventing peers from reaching consensus), double spending attacks (creating two transactions from the same unspent transaction) and selfish mining (miners trying to increase their rewards by keeping blocks private) etc. Also a major concern is about increasing the speed of blockchain based transaction. At present, seven transactions are stored per seconds (Croman et al., 2016) while there is also uprising concern about power consumption and storage for blockchain based system. Few ground research for blockchain technology could be as follows:

- How precision agricultural activities could be integrated with blockchain for leveraging blockchain technology?
- Various stakeholder of the agro-supply chain like farmers are generally not very high-tech and hence it will matter a lot with how ease the blockchain based solution could be provided to various stakeholders?
- One area could be providing suitable solution for integrating blockchain with existing food supply chain network.
- The compliance of blockchain based system with regulatory issues must be explored.

6. Conclusion

This study was focused on understanding the current trends about blockchain research and applications in agriculture field. For this purpose, the study accounted articles from all major databases and publishing partners. It

was found that China is leading this area of research with maximum number of publications followed by USA, Italy, India and Spain. It was also observed that the research on blockchain is limited to only few countries and most the publications occurred as proposal in conference rather than journal and book chapters. There were only few articles which actually focus on implementation aspect of the blockchain based system. The literature was also analysed under four heads of research dimensions namely traceability, architecture and security, information systems and other applications in agriculture field. It was observed that blockchain based research in agriculture is mainly focused on traceability and specific research whereas notable research also exist for blockchain architecture and security design and blockchain as information system. However few important issues related to blockchain implementation exists like scalability, interoperability, application of blockchain for precision agriculture and food supply chain network design etc. which are emerging areas for further studies. We hope this review inspire researchers to take this call to solve some of the socio-economic issues comprising blockchain for benefitting society.

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