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A Systematic Review on the Role of Distributed Ledger Technology for Agricultural Traceability

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Abstract

Several industries, among them agriculture, have shown interest in distributed ledger technology (DLT). The researchers explore how DLT can be used in agriculture, with a focus on its potential to disrupt supply chain management and enhance transparency. Furthermore, DLT has the possibility of greatly improving agriculture through addressing issues such as traceability, origin, and information sharing. The implementation of DLT will allow every player along the entire agricultural supply chain, such as farmers, producers, distributors, retailers, and consumers, to possess clear, immutable records about each transaction while promoting accountability and confidence in the market. The study used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method. The results of the systematic review shown in this paper suggest that DLT has the potential to revolutionize the agricultural sector by providing a secure and transparent system of data storage and sharing. However, the current literature is limited, and further research is needed in order to fully understand the implications of DLT in agriculture. Overall, the blockchain appears to be a very useful DLT in cacao traceability, and it is a means of reducing fraud and errors in the supply chain in the near future, thereby increasing quality and safety.

Keywords

Agriculture, Blockchain, Distributed ledger technology, Supply chain, Technology, Traceability

Introduction

Agriculture holds a significant role within a nation's economy, primarily because it provides sustenance to the entire population and serves as a critical link to interconnected industries. A robust agricultural foundation is often viewed as a symbol of societal and political stability. Many contemporary farms now incorporate advanced technology and embrace scientific and technological advancements [1]. In today's society, there is a growing consumer interest in the source of their food. People want to eat healthily, and because many areas use technology, farming businesses are looking for software to manage their supply chains. This talks about solutions that improve food safety, food quality, and tracking from farm to table [2].

The farming industry gains from new tech like smart farming, detailed land maps, connected gadgets, high-rise farms, smart location tools, plant care programs, and better ways to move goods. These advancements help farms do better in growing food and managing the process from farm to table. Problems and unclear practices in farming hurt both farmers and people who buy food [2]. Blockchain farming and DLT can improve supply chain efficiency, transparency, and trust [3].

There are different forms of distributed ledgers, but blockchain stands out as the most famous. In Crosby, et al.'s [4] estimation, blockchain is one such DLT that makes it possible for trustworthy records to be kept as well as transactions that are visible. Another kind of DLT is what Bashir [5] states as directed acyclic graphs (DAGs); they are graphs in which nodes are connected through directed branches that always move

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in a single direction without ever forming loops. Yet another variety of distributed ledger technology is hashgraph, which, as stated by Baird [6], is reputable for its speed, security, and fair data structure in addition to its consensus algorithm. In the words of Pariyani, et al. [7], this kind of system promises greater transparency and security in agricultural supply chains. Decentralized, peer-to-peer app creation is enabled by Holochain, another type of DLT. Holochain exhibits great potential for constructing decentralized applications in a wide range of industries, with agriculture being one of them [8]. Finally, Tempo (formerly Radix) is a distributed ledger technology that requires a network of computers connected in a peer-to-peer fashion to communicate with each other [9].

This research aims to contribute to the growing body of knowledge on distributed ledger technology's role in agriculture by investigating its potential benefits, challenges, and opportunities for implementation.

Methods

Inclusion, and exclusion criteria of DLT for agriculture traceability

A systematic review methodology was employed to comprehensively examine the application of Distributed Ledger Technology (DLT) in agricultural traceability. Adhering to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, this consisted of a process encompassing the identification, screening, and eligibility assessment of relevant research. Google Scholar served as the primary database for sourcing diverse scholarly literature from platforms such as Science Direct, IEEE Xplore, and MDPI. To ensure consistency and focus, inclusion and exclusion criteria were established (Table 1), guiding the selection of studies that directly addressed the use of DLT for traceability within the agricultural domain.

To maintain consistency and uniformity and establish the boundaries of this systematic review, a set of inclusion and exclusion criteria was defined, as presented in Table 1. These criteria were set up to act as rules for choosing relevant studies that will help select precise information on the use of DLT for traceability purposes within the agriculture sector.

The first criterion concerned the type of literature, which concentrates exclusively on research papers, review papers, and conference proceedings, while other publication formats were not considered in this systematic review. The review also restricted its attention to English-language studies published between 2014 and 2024 that relate to distributed ledger technology (DLT), agriculture, traceability, and supply chains with a traceability model and specific variables.

PRISMA of DLT for agriculture traceability

Following the inclusion and exclusion criteria, a total of 1,280 pieces of literature about distributed ledger technology (DLT) were screened from Google Scholar, published between 2014 and 2024, and written in English. Of those 1,280 articles, 760 are specific to agriculture, and of those, 751 were related to blockchain: 3 were hashgraphs, 5 were directed acyclic graphs (DAG), and limited were specific to holochains or tempo. Out of the 760 papers gathered, the researchers only chose those that simultaneously met the requirements: Articles with a traceability model that included specific variables; articles with the occurrence of one or more keywords related to DLT for agriculture traceability, such as "distributed ledger technology," "traceability," or "supply chain;" and articles that are not published in other formats (aside from research and review papers and conference proceedings).

Eventually, after a careful selection process and assessment of methodological quality, nine relevant studies were included in the review, all of which are centered on the use of blockchain technology in agriculture (Figure 1).

Results and Discussion

Summary of DLT for agriculture traceability review

The table below lists the relevant studies that were included in the review, along with the names of the author, year of publication, type of DLT employed, title of the research, and agricultural product studied (Table 2).

The agriculture sector has shown great potential for change through the use of distributed ledger technologies (DLT). Despite this, the application in agriculture is still in the initial stages. Although research rarely covers some types of DLT that could be used in agriculture, blockchain technology usually takes center stage on this matter. Alamsyah, et al. [10] came up with a system of tracing goods from the manufacturer through the blockchain network that functions properly. Distributed ledger technology has shown significant potential for transforming the agriculture sector. By using blockchain technology, Alamsyah, et al. [10] created a model that can trace back a product's source, such as coffee

Table 1: Inclusion, and exclusion criteria of DLT for agriculture traceability.

Criteria	Inclusion	Exclusion
Types of literature	Research paper, review paper, conference proceeding	Opinion pieces and other publication formats
Published Year	2014-2024	< 2014
Language	English	Non-English
Keywords	Agriculture, Blockchain, Distributed Ledger Technology, Supply Chain, Technology, Traceability	Non-Agriculture; other than stated
Outcome	w/ traceability model and specific variables	w/o traceability model and no specific variables

Data Abstraction and Analysis

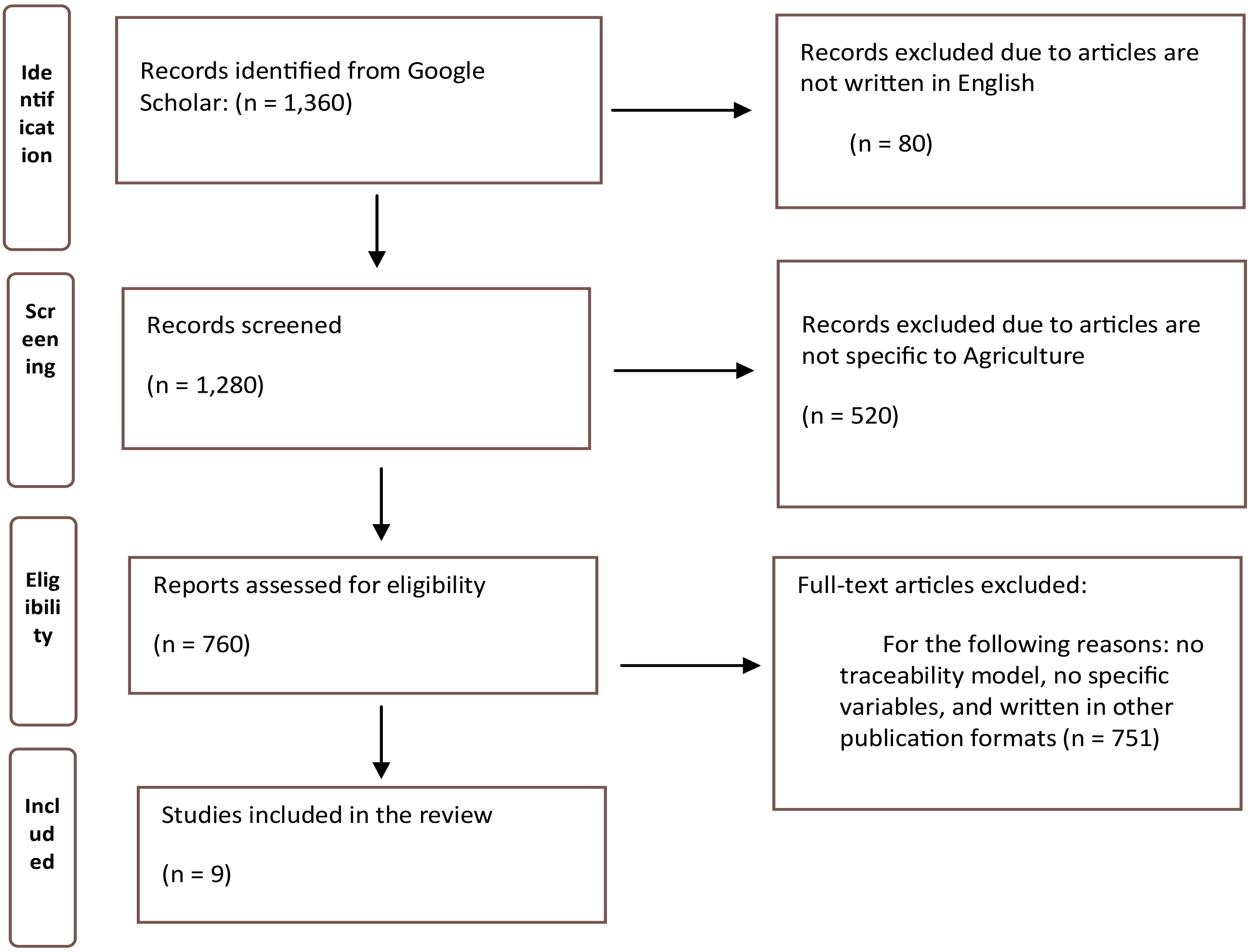

Figure 1: PRISMA of DLT for agriculture traceability.

Table 2: Summary of DLT for agriculture traceability review.

Author	DLT	Title	Agricultural Product
Alamsyah, et al. [10]	Blockchain	Blockchain traceability model in coffee industry	Cocoa/Cacao
Salah, et al. [11]	Blockchain	Blockchain-Based Soybean Traceability in Agricultural Supply Chain	Soybean
Vikaliana, et al. [12]	Blockchain	Traceability System on Mangosteen Supply Chain Management Using Blockchain Technology: A Model Design	Mangosteen
Marfuah, et al. [13]	Blockchain	Design Traceability for Indonesia Agricultural Supply Chain Based on Blockchain (Case Study in Chilli Commodities)	Chilli
Xu, et al. [14]	Blockchain	A Reliable Traceability Model for Grain and Oil Quality Safety Based on Blockchain and Industrial Internet	Grain and Oil
Ehsan, et al. [15]	Blockchain	A Conceptual Model for Blockchain-Based Agriculture Food Supply Chain	General (Seeds)
Trang and Tan [16]	Blockchain	Framework for Blockchain Implementation to Trace the Vietnam Dairy Supply Chain	Dairy
Mishra, et al. [17]	Blockchain	Food Traceability System Using Blockchain and QR Code	Crops
Purwandoko, et al. [18]	Blockchain	Design Framework of a Traceability System for the Rice Agroindustry Supply Chain in West Java	Rice

production, in a verifiable manner. The proposed item tracing framework includes a vast number of actors, such as farmers, processors, manufacturers, national government agencies, market/retailers, and end consumers. This presentation breaks down every stakeholder's role in terms of particular data and operational aspects. The farmers are responsible for harvesting within the essential details, such as the name of the farm, street address, latitudes and longitudes, types of coffee plants cultivated within the estate, and payment documents, among others. This study harnessed blockchain to enable every stakeholder within the supply chain to contribute to data collection and actively monitor the status of each coffee batch.

Another study was examined by Salah, et al. [11] on the use of blockchain technology for soybean harvesting in supply chain management. The technology model has seven individual aspects: Seed company, farmer, grain elevator, grain processors, distributor, retailer, and customer. Every single transaction, without exception, is carefully recorded and maintained in such a way that the blockchain's unchangeable ledger interfaces with a decentralized file system called InterPlanetary File System (IPFS). The linking of these two together brings about an absolute level of openness and checkability along the whole supply chain ecosystem, aimed at providing protection, credibility, dependability, and efficiency among all stakeholders.

Vikaliana, et al. [12] conducted a study on the implementation of blockchain technology in traceability systems within mangosteen supply chain management. The study is about the value chain of mangosteen, which consists of several principal actors, such as the supplier at the origin (the farmer), intermediary suppliers like collectors and packaging houses, as well as exporters for both local (domestic) and global markets, including the end customer. Farmers are in charge of keeping the necessary records in line with the agricultural guidelines, for example, plantation certificates and Good Agricultural Practices (GAP) compliance, whether the cultivation is organic or inorganic, type and time of fertilizer application, harvesting tools used, age at maturity of the fruit, details on transport packaging and containers, transport vehicles, and time taken for distribution from the mangosteen plantation to the packing house. The data entered by farmers is accessible to end users through the mangosteen fruit traceability system.

In the study published separately in 2021 by Marfuah, Arkeman, Machfud, and Yuliasih [13] a focus was made on coming up with a system of tracking for the agricultural supply chain of Indonesia, specializing in red chili products, with the help of blockchain technology. For the following purpose, the study deployed blockchain as well as smart contracts that were running on the Ethereum platform to follow up on transactions within the chain that supplied red chili. The plan was to create options that did not require a central power while at the same time setting up a system that would always give accurate information for supply chain management and the safe execution of transactions. The emphasis was on having the best standards of credentials, quality, and reliability. The well-informed farmers kept track of the data about how they were sowing seed and the particularities of growth; farmers saved pictures. In that regard, a decentralized file system was broadly accepted for monitoring the data about how they were sowing seed and the particularities of growth; it is known for being able to store files in a network of many nodes or peers in IPFS. Gapoktan, an association of farmer groups, has a key function in the distribution system by delivering goods, such as red chili products, to different consumers, such as individual households, retailers, or industries. Furthermore, it functions as a processor of the red chili raw materials that are sourced from different companies. The study elaborated on how farmers recorded plant growth specifics in a decentralized file system through IPFS at specified time intervals. As per the findings by Marfuah and their research team, farmers have had problems monitoring their farm land and plant growth. However, the proposed solution is that farmers should frequently upload plant and soil condition images via IPFS. Based on this information, it is possible to generate digital data for checking certain conditions. This procedure produces electronic documents used in verifying pre-set parameters. When traceable indicators are included in every group, it is easy for people, with all of them being able to be traced back successively, to watch every single stakeholder's activity in ensuring that quality standards are met each time. These sensors are able to function continuously during shipping and send messages to share the condition of plants, products, or items while on the move. Due to blockchain technology, such information and announcements become instantly available to anyone in need of them. This is important because this data should be accessible to supply chain partners in a trustworthy and decentralized way throughout all stages of transportation operations. Importantly, maintain a balance between cognitive workload and intrinsic motivation.

A study by Jiping Xu, et al. [14] found the layout of blockchain traceability data and a way to detect and solve problems in the industrial internet framework in detail about grain and oil quality and safety supply chains. The aim of this initiative was to create a trustworthy traceability model for the quality and safety of grain and oil products, eventually resolving current issues in the traceability process. Identification and resolution systems for the grain and oil sectors were developed during the research based on the foundational tenets of industrial internet analysis. They formulated a trustworthy traceability system architecture in order to satisfy the varied requirements of corporations, users, and government regulatory bodies at different stages of the grain and oil quality and safety supply chain. This architecture aligned the grain and oil quality and safety credit traceability model with the specific needs of stakeholders. Moreover, an illustrative system interface diagram was presented in the study alongside real-time monitoring and sales information, along with a detailed description of the system's traceability function.

Ehsan, et al. [15] research was done on constructing a thoroughly decentralized traceability system by fully employing blockchain technology so as to guarantee the sanctity and clarity of the system. This non-traditional model has, therefore, addressed wholesale various challenges that are always coupled with traditional supply chains, hence meeting the desires of consumers, which are on constant increase. The study featured food product details, such as date of harvest and cost, uploaded by a supplier before embedding a radio frequency identification (RFID) chip in every item. These tags served different functions and significantly improved security measures within the farm system due to the application of blockchain technology. The study model introduced product origin verification, shipment tracking, and secures transaction record storage. Another vital point disclosed in the study was that agents were employed to make sure partners both complied with the terms and conditions of smart contracts. Using the unchangeability of blockchain technology, trust, transparency, and security all through the supply chain were improved by this approach. Significantly, there is a chance of employing it in a variety of supply chains in different fields.

Trang and Tan [16] also conducted research on the traceability of the dairy supply chain using blockchain. At these five stages, they consider having their proposed system traceable based on the blockchain they recommend: on the farm, during transport to processing factories, or even up until final retail outcomes. Notably, the data kept at each stage is markedly different. Dairy farmers document meticulous records of milk accumulated by different types of cows, the date each cow's milk is drawn in the diary, milk drugs given to the animals, and the buyer's identity and contact information. On the other hand, during the collection and transport phases, recorded data include the collection date and time, geographic location, batch number, quantity of milk taken, quality details, vehicle type, and person who collected or inspected quality information.

Mishra, et al. [17] introduced a food traceability system using blockchain technology and QR codes. The system was created to follow the movement of the goods across different levels, maintaining transparency from one end to the other and giving live updates on their current state. The following are some of the most important people involved in food tracing: Farmer, farm inspector, processor, distributor, and retailer. This scope of activities is their responsibility.

Another study, conducted by Pradeka Purwandoko, Kudang Seminar, Sutrisno, and Sugiyanta [18], focuses on the development of a traceability system framework for the rice agroindustry supply chain in West Java. The research took place over two years, beginning in October 2016 and ending in December 2018, with West Java Province being the main area of interest as it is well-known as a leading paddy producer within Indonesia. It involved surveys undertaken in the fields with the following goals: (1) Identifying crucial figures along the rice value chain; (2) Looking at different stages of the production cycle; and (3) Outlining what sort of details should be recorded at every point of the process. The main purpose of this traceability system was to accurately record and document the relevant data about food products and the raw materials used in their production. The term traceability represents a combined system through which different parties perform their specific duties. In addition, for rice supply chains to run successfully, a rice traceability system implementation required internal and chain traceability to be set up. This setup called for smooth collaboration from all stakeholders in the supply chain. Information sharing provided the basis for supply chain stakeholder integration and coordination. This method enhances transparency and good risk management in terms of product quality and safety. Within a supply chain, there was a need to keep clear track of everything that was useful in any way before passing it on to other people. According to research carried out recently, there exists a system of open information flow so that everyone involved can follow what happens from beginning to end in rice production.

As evident from the preceding discussion, there is a growing interest in harnessing blockchain technology to enhance the security, transparency, and legitimacy of various measures within agricultural commodity supply chains. A significant portion of the research focuses on the theoretical application of blockchain within agricultural supply chains that face potential vulnerabilities within specific frameworks or implementation approaches. Blockchain technology presently stands as one of the emerging innovations, causing disruption across various sectors, and harboring the potential to usher in profound advancements in agriculture. Its impact is poised to extend to areas such as fortifying supply chains and preserving the integrity, security, and traceability of data. The technology possesses the capacity to bolster a nation's economy by mitigating corruption and elevating both producer and customer satisfaction. By eliminating intermediaries from the realm of supply chain management, blockchain introduces an efficient and transparent system, as underscored in the study by Ehsan, et al. in 2022 [15].

DLT Comparison

Additional research on the comparison of DLT in terms of application development is also conducted, as shown in Table 3. The parameters used for comparison are implementation requirements, technical support or demand, resource management and cost.

Implementation requirements: This criterion primarily focuses on the programming languages commonly employed by developers in specific Distributed Ledger Technology (DLT) systems. Prominent programming languages for Blockchain developers encompass C++, Solidity, Java, Python, Vyper, and Golang. Python finds extensive use in developing cryptocurrency exchanges and smart contracts, whereas Solidity and Java are renowned for their adeptness in crafting smart contracts. Golang, with its manifold advantages, enjoys popularity for DApp development. C++ is favored among blockchain developers due to its advanced multi-threading capabilities and precise control over memory allocation [19].

In the context of hashgraph, core components are typically scripted using LISP and Java programming languages, with a predilection for JVM languages such as Java and Scala [20]. DAG developers, conversely, commonly opt for Python [21]. In the realm of holochain technology, the Go programming language is predominantly utilized, while applications can be

Table 3: Distributed ledger technology comparison.

Criteria	Blockchain	Hashgraph	DAG	Holochain	Tempo
1. Implementation Requirements	• C++, Solidity, Java, Phyton, Vyper, and Golang [7]	• Lisp and Java; JVM languages[35]	• Python [22]	• Go programming language (Lisp or JavaScript) [4] • Rust programming language [14]	• Scrypto[33]
2. Technical Support Requirements	• MongoDB Atlas [25]	• Distributed hash table (DHT)	• SQL Database [26]	• Distributed hash ledger and source hash chains [19]	
3. Resource Management	• *Processor*: GPU [2]	• *Processor*: 24-core or better CPU hyperthreaded (48 threads) - Intel Xeon Silver class or higher/AMD EPYC 74xx class or higher Virtual hosts must have 48vCPU (single-threaded) [2]	• *Processor*:	• *Processor*: 4+ cores CPU/ 6+ cores (rec) [28]	• *Processor*: Intel Pentium 4 2.00 GHz
	• *Memory*: 250 GB of blockchain data containing the block headers and transactions [17]	• *Memory*: 256 GB PC4-21300 2666 MHz DDR4 ECC Registered DIMM; 2 x 240 GB SSD with RAID 1 for OS Storage [2]	• *Memory*:	• *Memory*: 8 GB + RAM/16 GB + (rec) [28]	• *Memory*: 512 MB
	• *Network* (bandwidth): 255 Kbytes when network bandwidth of miners varies from 250 kbps to 1200 kbps [17]	• *Network*: Single 1-Gigabit/10-Gigabit Ethernet [2]	• *Network* (bandwidth):	• *Network* (bandwidth):	• *Network* (bandwidth):
	• *Others* (Storage): Mature blockchain networks can take several Gigabytes of storage. Using the most conservative estimate of 1000 transactions per block for the 100 TPS level of blockchain activity, 0.659 TiB of storage per year[36]			• *Others (Disk Space):* 30 GB + available disk space [28]	• *Others (Graphics Card):* NVIDIA GeForce 7100/ nForce 630 • *Operating System*: Windows 7 (SP1+) and Windows 10, 64-bit versions only • *File Size*: 500 MB
4. Cost	• $0.29 USD/VPC-hour or Php16.14/ VPC-hour [13]	• $0.0001/HCS message [15]			

crafted in either Lisp or JavaScript [22]. It's noteworthy that an official member of the Holochain team mentioned that Holochain itself is coded in the Rust programming language. Furthermore, Holochain developers execute WebAssembly code at a lower level but should build applications in a language that compiles to WebAssembly, such as Rust, C, C++, or Go [23]. Finally, in the context of Tempo or Radix, the Scrypto programming language is commonly harnessed for designing smart contract blueprints and components [24].

Technical support requirement: This aspect concerns the diverse database systems linked with specific distributed ledger technologies (DLTs) that necessitate technical support, such as Hyperledger. Notably, blockchain technology relies on MongoDB Atlas, Hashgraph utilizes a distributed hash table (DHT), DAG operates with a SQL database, and Holochain is dependent on distributed hash ledgers and source hash chains. Regrettably, there is a lack of available information regarding the technical support requirements for Tempo.

Resource management: This criterion revolves around the allocation of diverse resources like processors, memory, network capacity, and storage. For blockchain technology, specific resource prerequisites encompass a GPU for processing, a memory capacity of 250 GB to accommodate block headers and transactions, and a network bandwidth of 255 Kbytes to support miners' network rates spanning from 250 kbps to 1200 kbps. Additionally, storage is a pivotal resource, with established blockchain networks typically necessitating substantial gigabytes. Based on a conservative estimate of 1000 transactions per block and a blockchain activity level of 100 TPS, an estimated annual storage requirement of 0.659 TiB has been determined.

Conversely, Hashgraph imposes node requirements that entail a processor with a minimum of 24 cores or better, with hyperthreading support for a total of 48 threads. This can be achieved using an Intel Xeon Silver CPU or a higher-level CPU like AMD EPYC 74xx. Furthermore, virtual hosts must feature 48 virtual CPUs capable of single-threaded operations. Memory should be a minimum of 256 GB PC4-21300 2666MHz DDR4 ECC Registered DIMM, ensuring ample memory capacity for efficient Holochain app execution. In terms of storage, it mandates 2 × 240 GB SSD drives configured in RAID 1 for operating system storage, furnishing redundancy and data protection in case of drive failure [25].

Regrettably, there's a paucity of available information regarding DAG's resource requirements. On the other hand, Holochain necessitates a minimum of 8GB RAM (with 16GB recommended), a CPU featuring at least 4 cores (with 6 cores being preferable), a minimum of 30GB accessible disk space, and a high-speed internet connection. In the quest for peak performance, Tempo mandates the following specifications: a minimum of 512 MB of memory, compatibility with an NVIDIA GeForce 7100/nForce 630i graphics card, an Intel Pentium 4 2.00 GHz CPU, a file size of 500 MB, and compatibility with Windows 7 (SP1+) and Windows 10, specifically 64-bit versions.

Cost: This primarily pertains to the specified expenses linked to the integration of a specific DLT, with a preference for highlighting subscription costs, if applicable. In the context of blockchain, IBM Blockchain Platform has introduced a new simplified pricing model based on the allocation of virtual processor cores (VPC). Under this streamlined model, the cost is predicated on the CPU allocation (VPC) that your IBM Blockchain Platform nodes receive on an hourly basis, priced at a flat rate of $0.29 USD per VPC-hour. Notable advantages of this pricing model encompass the absence of membership fees and no stipulated minimum payment requirements.

In contrast, Hashgraph adopts a different cost structure by charging users solely for the messages they submit. Irrespective of whether these messages are used independently or in conjunction with a permissioned blockchain, each individual HCS message incurs a cost of $0.0001 USD [26]. However, it's important to note that there is a dearth of available information concerning subscription fees or other cost-related aspects for DAG, Holochain, and Tempo. This might be attributed to the relatively recent introduction of these technologies into the market.

In conclusion, each of the factors discussed plays a crucial role in the decision-making process. When selecting a programming language, it is important to consider the platform and the proficiency of the development team. Choosing a platform-supported programming language is important to guarantee a seamless implementation and an effective troubleshooting process. Processor, memory, and network requirements should be included in effective resource management to ensure the best performance and scalability. The balance between functionality and affordability can be achieved if one considers how much he or she will pay for subscriptions. By considering these points slavishly, firms, organizations, and agencies will make decisions that are based on facts and go for the best DLT platform that is specific to them.

After examining the data more closely, it is clear that blockchain technology has become the most common type of DLT, whereas all other kinds have been implemented to a lesser extent.

Conclusion and Recommendation

To fully harness the benefits of blockchain in agriculture, future research should delve deeper into its potential applications within the industry. Investigating emerging distributed ledger technologies is also crucial for developing innovative traceability systems.

Although this systematic review highlights the transformative power of blockchain in agriculture, it also underscores the need for further research to comprehensively understand its implications. Nevertheless, the findings strongly suggest that blockchain is a valuable tool for enhancing traceability, reducing fraud, and improving product quality.

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