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Review

Blockchain Applications in Forestry: A Systematic Literature Review

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Abstract: Blockchain applications have received a lot of attention in recent years. They provide enormous benefits and advantages to many different sectors. To date, there have not been any systematic studies comprehensively reviewing current blockchain-based applications in the forestry sector. This paper examines published work on blockchain-based applications in the forestry sector. A systematic review was conducted to identify, analyze, and discuss current literature on current blockchain applications deployed (and/or proposed) in the forestry sector, grouping results into three domains of forest management, traceability of forest-based products, and forest fire detection based on content analysis. The analyses highlight reported benefits, opportunities, and challenges of blockchain applications in the forestry sector. The study results show that blockchain has great potential in sustainable forestry, minimizing illegal logging, conserving biodiversity, and many other areas in forestry. It also shows that blockchain in forestry is still immature and complex, since it requires specialists to adopt. This paper contributes towards filling the existing research gap through this systematic review on blockchain applications in forestry. This review offers insights into a deep understanding of blockchain applications for managers, practitioners, and consultants interested in forestry. The paper identifies existing research gaps on related topics of blockchain applications in forestry and makes recommendations on potential future directions for research into blockchain in forestry.

Keywords: blockchain; blockchain applications; sustainable forestry; systematic review; forest fire detection; traceability; forest management; wood products; illegal logging

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1. Introduction

The use of blockchain technology has been rapidly growing, the most well-known example being the cryptocurrency Bitcoin [1]. Indeed, until recently, the interest in blockchain technology was primarily due to the rapidly increasing value of cryptocurrencies and large investments being made in financial services blockchain startups [2]. However, as the technology has matured, there has been increased attention to how this 'distributed ledger' technology can be used in a range of applications across multiple industrial sectors. To date, the blockchain applications in forestry has not been comprehensively reviewed.

Forestry involves the science and practice of creating, using, planting, managing, conserving, and caring for forests. Forestry covers a broad range of forest management and conservation activities, including urban forestry, industrial forestry, and non-industrial forestry [3]. Forestry, broadly, is involved in managing forestry assets, conserving ecosystems and biodiversity, preventing forests/bush fires, and engaging in climate change adaptation. In this systematic review, forestry includes all of these areas. Globally, the forestry sector is facing several common problems, including, as examples, deforestation and illegal logging. Deforestation is a major contributor to the loss of animal habitats, including many endangered species [4]. Similarly, illegal logging/timber trading is occurring worldwide. Illegal timber trading has been reported in Mexico, China, and Russia to process and manufacture wood products [5,6]. Our previous work [7] identified that illegal logging gains much attention and its technical solutions need to be assessed. In this context, it is perhaps not surprising that many industrial customers and end-consumers of wood products have become increasingly interested in knowing whether their timber or wood products are sourced and manufactured in an eco-friendly and sustainable manner [8]. This, in turn, has highlighted the increased need for supply chain traceability and transaction transparency, both potentially suitable for blockchain applications. However, the potential utility, benefits, and challenges of blockchain applications in forestry have not previously been comprehensively reviewed, which has provided the justification for the focus of this research paper.

Numerous previous studies of blockchain technology have been completed across a wide range of other industries. These existing studies have included a focus on blockchain technology in healthcare [2]; education [9]; the agri-food sector [10]; the energy sector [11]; logistics and supply chains [12]; travel and tourism industry [13]; insurance [14]; and many other industries. Antonucci et al. [10] investigated blockchain applications in the agri-food sector, specifically all types of blockchain commercial applications in agri-food (coffee, beef, fish, etc.) supply chains. Antonucci et al. indicated that blockchain technologies are promising in agri-food supply chains. Blockchain applications have been studied in the education sector [9]. Blockchain applications have been mainly used in certificates management, learning outcomes management, and evaluating students' professional abilities [9]. Tijan et al. [12] studied blockchain applications in supply chains and logistics with benefits and challenges. The study identified the potential use of blockchain applications in logistics: identifying counterfeit products, easing paperwork processing, facilitating origin tracking, and operating the internet of things [12]. Blockchain applications have been investigated in the energy sector as well [11]. Andoni et al. [11] studied activities, blockchain platforms and consensus protocols of blockchain application in electric vehicle charging, e-mobility and emerging peer-to-peer energy trading. In healthcare, Hölbl et al. [2] found that blockchain applications are mainly used in data sharing, managing health records and access control. To the best of our knowledge, there is no study comprehensively investigating the blockchain-based applications in the forestry sector.

The objectives of this paper are to investigate current blockchain-based applications in forestry; to understand how blockchain technology is applied in the forestry sector; and to assess the benefits, opportunities, and challenges of blockchain applications implemented (and/or proposed) in forestry. The contribution of this work is providing guidance for decision-makers, practitioners, consultants, and managers interested in the field of forestry about use cases or the applications of blockchain technology in the forestry sector. Based on content analyses of current literature, our work also provides a research agenda on related topics for researchers to further investigate.

This paper is structured as follows. Section 2 introduces an overview of blockchain, including definitions of blockchain and its related terms. Section 3 presents the systematic review methodology of how this paper collected, selected, and processed included data. Section 4 presents and analyzes the state-of-the-art blockchain applications developed (or proposed) in the forestry sector. Section 5 summarizes and interprets the benefits, future opportunities, and challenges that blockchain brings to forestry. Section 6 highlights the managerial implications for decision-makers, managers, consultants, and practitioners interested in forestry. Section 7 highlights the theoretical implications and provides future research directions. Section 8 presents the conclusion with limitations.

2. Overview of Blockchain

Blockchain was initially described as a 'chain of blocks' by Nakamoto [1] in 2008, the technology behind bitcoin. Nakamoto [1] introduced bitcoin as a peer-to-peer version of electronic cash. Blockchain is a decentralized digital database of timestamped transactions (distributed ledger) by hashing these transactions into a chain of hash-based proof-of-work [1,15]. Figure 1 demonstrates the blockchain data structure. As shown in Figure 1, the blockchain system records the data of timestamped transactions into a 'block' that is cryptographically linked like a chain of blocks [16]. The chain of blocks is constantly growing while each new block is added, and each block (block n) holds hashed code of the previous block (hash of block n − 1) [16–18]. The blocks in blockchain connect to the genesis block (the first block) in chronological order [17].

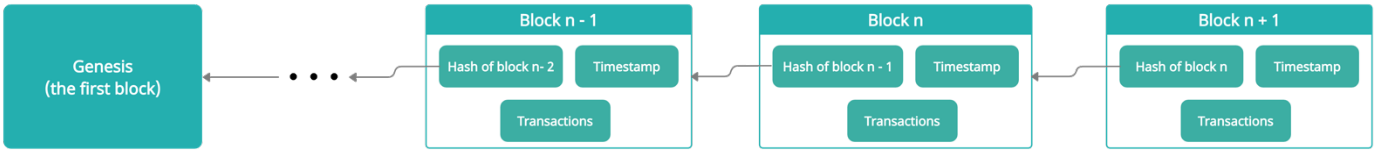

Figure 1. Blockchain data structure, adapted from [16–18].

Blockchain technology has been rapidly developed in the last decades. The evolutions of blockchain can be summarized into four stages [19]:

- Blockchain 1.0 was initially introduced in 2008 [1]. The first stage mainly focused on digital currency such as bitcoin. Blockchain technology was used for cryptocurrencies and payment systems to reduce transaction costs by removing intermediaries [19,20];
- Blockchain 2.0 was introduced for smart contracts in 2013. A smart contract is a piece of code executed while a transaction is performed [18]. The code in smart contracts automatically executes when all conditions are met [21]. Smart contracts can be used as agreements between all parties in transactions. All parties involved will be forced to perform the transaction once conditions are met. In other words, the transactions with smart contracts do not need to be monitored by a trusted third party which makes the transactions irreversible, secure, and decentralized [21]. Smart contracts are transparent and autonomous to eliminate manipulation and human error [19]. One famous example of platforms to implement smart contracts is Ethereum proposed in 2013 [22]. Ethereum is a platform for blockchain and allows everyone to program smart contracts by creating their ownership rules and transaction formats [22];
- Blockchain 3.0 was introduced in 2015 and mainly focused on the development of decentralized applications and computing [23]. In this stage, decentralized applications are formed by back-end codes running on the open-source platform [24]. Blockchain 3.0 is integrated with cryptographic tokens. Tokens are digital assets that can represent any value [25]. The token economy became the front-end face in this era;
- Blockchain 4.0 integrated artificial intelligence (AI) with blockchain technology to make better decisions without the need of direct human intervention in 2018 [19,23]. The combination of AI and blockchain can help solve complex issues worldwide. In general, AI predicts outcomes using algorithms based on probability. The outcomes of AI constantly change since the algorithm can 'learn' from new data. On the contrary, blockchain technology hash data and the outcomes are permanent and unchangeable. The characteristics of blockchain make data accurate which is helpful and useful to input it into AI systems. Moreover, blockchain could record and secure the outcomes of AI systems [19].

Based on the characteristics of blockchain technology, the types of blockchain technology are categorized into two types: public and private [15,18,23]. A public blockchain is also called a permission-less blockchain [23] or open blockchain [15]. The public blockchain allows everyone to join or check the transactions in the blockchain network with no privacy. All participants in the blockchain network are pseudo-anonymous, which means the parties in a transaction are anonymous prior to the transaction. Bitcoin, Litecoin [26], and Ethereum are examples of public blockchain [15]. In contrast, a privacy blockchain provides more privacy to transactions in blockchains. The private blockchain is also called a permissioned blockchain [23] or closed blockchain [15], allowing invited individuals or groups to join in. The private blockchain provides more privacy compared to a public blockchain. The parties in the private blockchain are only invited by an authentication authority [27]. Examples of permissioned blockchain are Hyperledger Fabric [15] and Ripple [2]. Furthermore, some literature defines the categories of blockchain technology types differently. Several studies argued that there is a third type of blockchain technology besides the private and public blockchain. Some studies listed consortium blockchain as the third type of blockchain technology [2,17]. The consortium blockchain is also a permissioned blockchain that is usually controlled by a group. A small number of validating nodes with pre-established features can validate transactions [17]. Consortium blockchain could be used in one or multiple industries and opened to the limited public (partially centralized) [2]. The debate of blockchain types continues in academia and the web community. The topic of blockchain types is not discussed further since the debate of this topic is not the intention or objective of this study.

To remain functional and reliable of the blockchain network, there is a common agreement in the blackchin to present the state of the distributed ledger called a consensus algorithm [2]. The consensus protocol can ensure that the version of new block added into the blockchain is the true one, and all nodes in the blockchain agree with it [17]. The most common consensus protocols used in blockchain are proof-of-work (PoW), proof-of-stake (PoS), delegated-proof-of-stake (DPoS), proof-of-importance (PoI), proof-of-activity (PoA), proof-of-burn (PoB), and proof-of-deposit (PoD) [2,23]. PoW algorithm was initially used in the blockchain in 2008 [1].

3. Research Methodology

This section presents the research method and characteristics of included studies. A systematic literature review was performed based on the topic and research objectives. A systematic review is an evidence-based literature review method that helps collect relevant studies and identify the state-of-art knowledge of the research topic by analyzing and synthesizing current literature findings without bias [28]. This research method was chosen because it aligns with the objectives of this study, which is to investigate the state-of-the-art knowledge of blockchain technology in forestry. This systematic review was adopted from the following guidelines: the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [29], and the systematic review guide written by Okoli and Schabram [30]. We conducted this systematic review in five stages: (1) research question; (2) search strategy; (3) data selection; (4) data extraction; and (5) analysis, synthesis and report.

3.1. Research Questions

Based on the objectives of this study, we formulated the following research questions (RQ). RQ1 and RQ2 were designed to investigate current blockchain-based applications in forestry and to understand how blockchain technology is applied in the forestry sector. RQ3 aim to assess the benefits and opportunities of blockchain applications implemented (and/or proposed) in forestry. RQ 4 was proposed to analyze the challenges that blockchain applications bring forestry.

Using this systematic review, we answer the following research questions:

RQ1. What blockchain applications have been developed or proposed for the forestry sector?
RQ2. How are the blockchain applications being implemented in forestry?
RQ3. What are the benefits and opportunities of blockchain applications in forestry?
RQ4. What are the challenges of blockchain applications in forestry?

3.2. Search Strategy

We created a search strategy for this systematic review to gather relevant papers. According to the research topic and objective, we set the searching string in two domains: 'blockchain' and 'forestry'. In the 'blockchain' domain, we included keywords: 'blockchain' and 'block chain'. In 'forestry' domain, the keywords were 'forest*', 'timber', and 'wood*'. The search string was formed by combining two domains by 'AND' as blockchain keywords AND forestry keywords. We did pilot searches to test these potential keywords before finalizing the search string. For instance, in the pilot search, we noticed that using the keyword 'blockchain' did not extract articles with a title containing the keyword 'blockchain-based', which did not appear in search results of some databases because the database recognizes "blockchain-based" as one word. We included 'blockchain-based' in the search string. The final version of the searching string used in this study:

("blockchain" OR "block chain" OR "blockchain-based") AND ("forest*" OR "timber" OR "wood*")

We chose Web of Sciences, Scopus, ACM digital library, and IEEE Xplore as search databases to collect relevant literature. Web of Science and Scopus are the most common and reliable academic databases with high-quality multidisciplinary articles. Since the topic of this study involves multiple disciplines, we decided to use Web of Science and Scopus as search databases. ACM digital library and IEEE Xplore are research databases on information technology (IT), computer science, and electrical engineering. Blockchain belongs to the computing and IT fields. We chose IEEE Xplore and ACM library as well in case some articles were not included in Web of Science and Scopus. The search string was applied to these four databases.

We set the inclusion criteria for this review to select articles. Since blockchain was originally introduced in 2008, this review only considered the literature published after 2008. This review only accepted articles written in English. The subject (and/or content) of included articles had to be related to the topic of forestry and blockchain technology, applications, solutions, and approaches. In Table 1, we present the inclusion and exclusion criteria applied in this review. We used filter functions for publication year and language criteria in the databases.

Table 1. Inclusion and exclusion criteria to select papers in this review.

Categories	Inclusion Criteria	Exclusion Criteria
Language	English	Not English
Publication year	Not earlier than 2008	Before 2008
Availability	Full text available	Full text not available
Source type	Original/Research articles	Non research articles
Subject/Content	Related to the topic of blockchain	Not related to the topic of blockchain. Only mentioned blockchain in abstract. The full-text content not consistent with its abstract and title.
Context	Forestry industry	Not related to the forestry industry

3.3. Data Selection

We retrieved 657 articles from four databases (281 records from Scopus, 139 records from Web of Science, 79 records from IEEE Xplore, and 158 records from ACM digital library). Figure 2 is the flowchart of data identification, based on the PRISMA 2020 guideline [31]. As Figure 2 shows, the search result was processed by identification, screening and inclusion. In total, 87 records were removed from search results, and 570 records were screened. To select the related articles, two screening steps were performed with the inclusion criteria in Table 1. The first step was to screen the titles and abstracts of included articles. A total of 525 articles were excluded after the first screening. These articles were removed because their titles and abstracts: (1) were not related to either topic of blockchain or forestry; or (2) only related to one topic. The second step was to screen the full-text articles. A total of 45 articles were screened at this step, and 24 articles were excluded for specific reasons. The reasons are mainly: (1) only mentioned blockchain in the abstract; or (2) full-text content was not consistent with the abstract and title. 21 academic articles were included as the dataset of this study for further data extraction, analysis and synthesis. Table A1 in Appendix A is the list of 21 included articles. The table includes the author(s), year, title, and publication type of included studies. The quality of included studies was ensured since all retrieved studies are from four high-quality scientific databases.

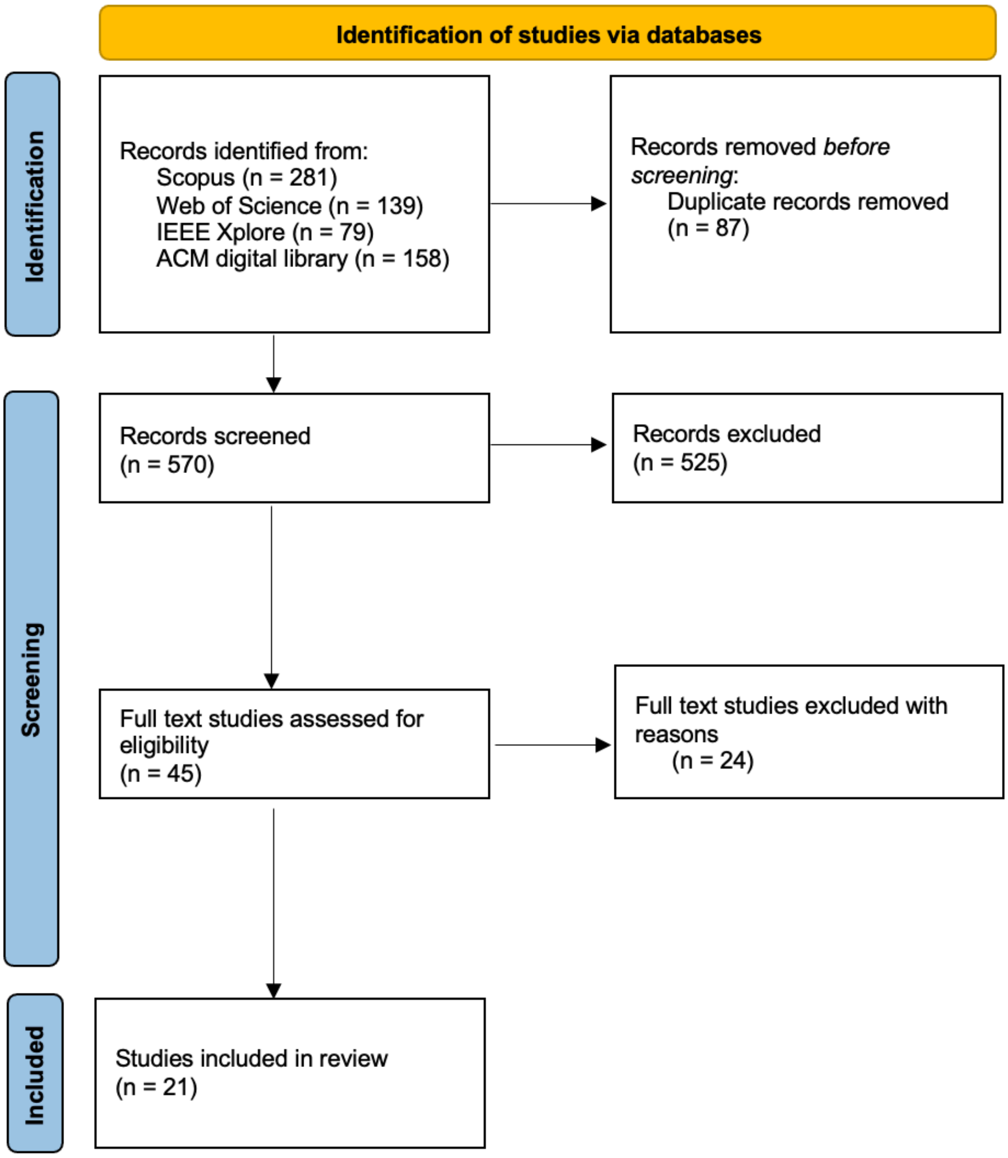

Figure 2. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart of this systematic literature review, based on the PRISMA 2020 guideline.

3.4. Data Extraction

Based on the research objectives, we extracted data from the included studies. The extracted data has two categories: the characteristics of included studies and the information for content analysis. The characteristics of included studies include the publication year and types, which can indicate the research trend of the related topics. Figure 3 displays the distributions of publications by year. Figure 3 indicates that the related topic started to receive researchers' attention in 2017. And the tendency of the included articles in years is increasing from 2017 to 2021, which means the increasing interest in blockchain technology in forestry. The result shows that blockchain application for forestry is still in the early stage of development since the included papers only started in 2017.

Figure 4 shows the distribution of included studies by publication type. Ten papers (48%) were published as conference papers. Seven articles (38%) were published as journal articles. The 'others' type of included studies includes one book chapter, one position paper and one preprint paper.

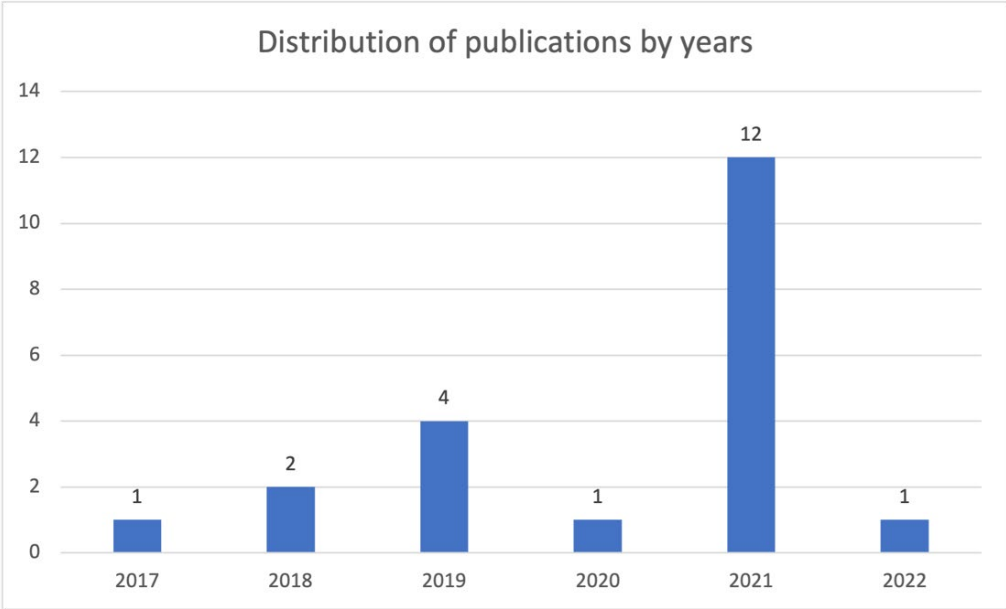

Figure 3. Distribution of publications by years.

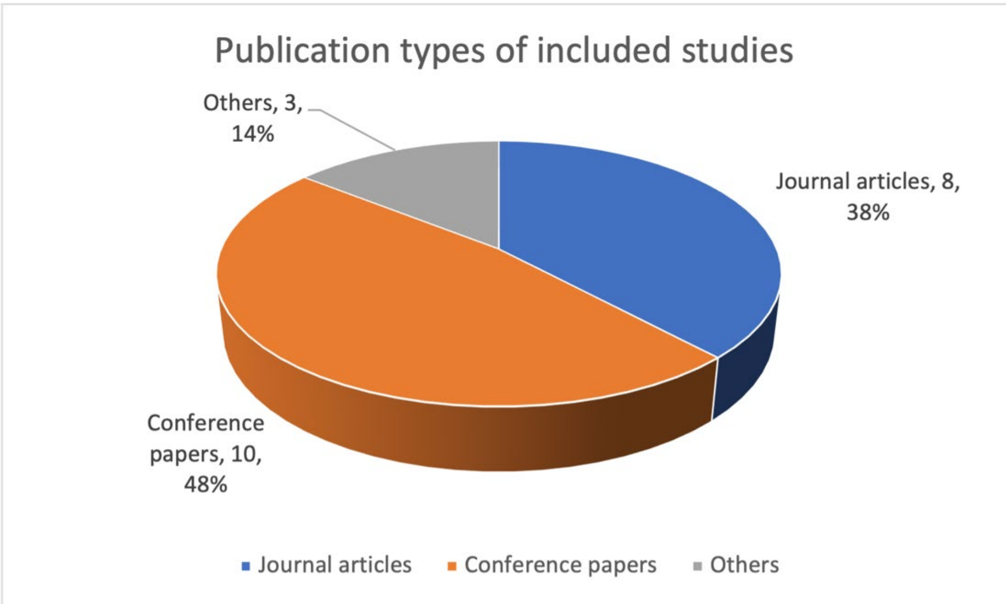

Figure 4. Distribution of included studies by publication types.

The categories of information extracted from included studies for content analysis includes (if appliable):

- Blockchain application area of forestry;
- Layers of blockchain architectures;
- Components of blockchain-based systems;
- Whether the smart contracts were used;
- Blockchain platform;
- Purpose of the blockchain applications;
- Reported benefits, opportunities and challenges.

If the category of information was not defined or mentioned in the included studies, the 'N/A' is recorded in the results.

3.5. Analysis, Synthesis and Report

The data extracted from included articles were analyzed based on research questions and objectives. The categories of information extracted from included studies are presented, analyzed, and synthesized in Sections 4 and 5. We report the search results and the characteristics of included studies in Section 3. The taxonomy of blockchain applications in forestry is presented and analyzed in Section 4. The results of extracted content from included studies are presented and analyzed in Section 4 as well, including layers of blockchain architectures, whether the smart contracts were used, blockchain platform and purpose of the use of blockchain. The results of reported benefits, opportunities, and challenges are presented and analyzed in Section 5.

4. Blockchain Applications in the Forestry Sector

Based on the content analysis of the selected studies, we summarized and synthesized the use cases of blockchain technologies in the forestry sector. The authors categorized the extracted information 'blockchain application area of forestry' in the results. We found that the blockchain-based applications in forestry are mainly developed (or proposed) in three areas: forest management, traceability of forest-based products, and forest fire detection. Figure 5 presents the taxonomy of blockchain applications in forestry. As Figure 5 shows, the majority of blockchain applications were focused on forest management (52%) and traceability (38%). Ethereum is the most used blockchain platform. Nine included articles developed or proposed blockchain applications on Ethereum in the forestry sector. Only one study proposed a blockchain solution on Hyperledger Fabric.

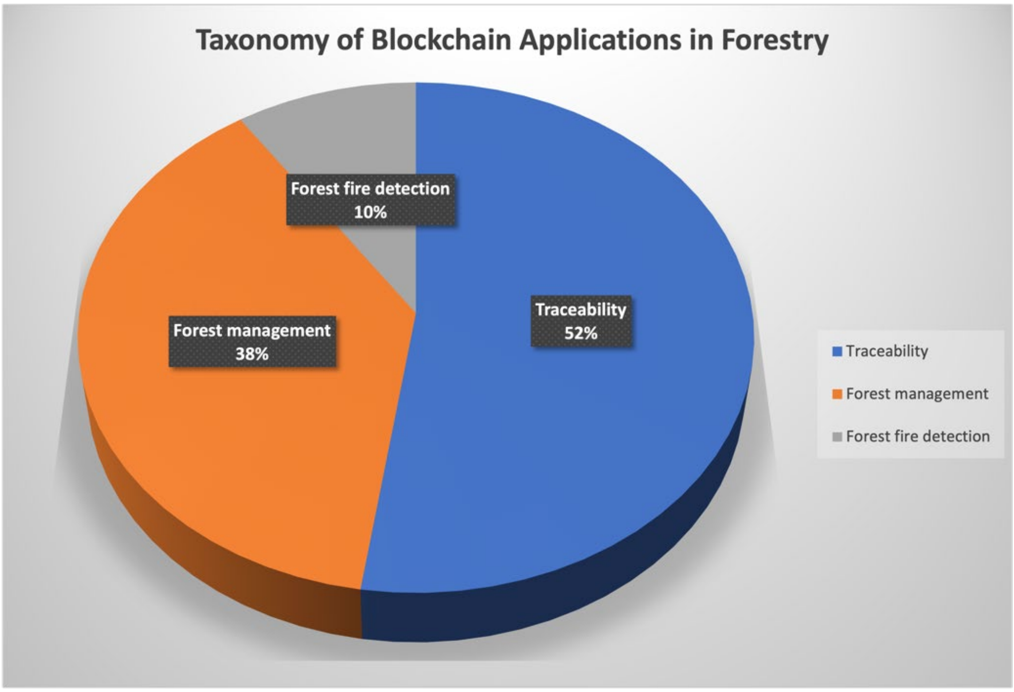

Figure 5. Taxonomy of blockchain applications in forestry.

In the following subsections, we analyze and explain the details of blockchain applications in each area.

4.1. Traceability

Eleven included articles (52%) proposed and/or investigated the blockchain-based applications on traceability of wood (products) in forestry. These blockchain-based traceability systems have been designed to prevent illegal loggings/timbers and increase the purchaser's trust. In general, blockchain technology has been applied to traceability systems to track forest-based (woody) products—information of each timber uploaded into blockchain by actors involved in the wood supply chain. The actors in the supply chain could include, but are not limited to, forest farmers, suppliers, transportation companies, manufacturing companies, and customers. All actors can access all the data in the wood supply chain. Table 2 shows the data extracted from included articles related to the traceability of wood products. This subsection presents and analyzes the details of these blockchain applications for the traceability of forest-based products in Table 2. In Table 2, only nine of eleven included articles are listed. That is because extracted data of these two included articles [32,33] are not suitable for this subsection. In reference [32], Lobovikov et al. analyzed the advantages, benefits, disadvantages, and dangers of blockchain in illegal wood. The included article [33] is a similar article that discussed the strengths, weaknesses, opportunities, and threats of blockchain for illegal timber trading. The data extracted from these two articles is presented and analyzed in Section 5.

Table 2. Blockchain-based applications in the traceability of wood products.

Reference	Smart Contract	Platform	Main Focus	Purpose(s) of the Use of Blockchain
[34]	Yes	Hyperledger Fabric	A blockchain-based technical solution	To provide a blockchain-based technological solution to prevent illegal logging
[35]	Yes	Ethereum	Azure Blockchain Workbench	To trace and validate wood from standing tree to the final user
[36]	N/A	N/A	A tamper-proof digital system	To combine blockchain with digital protocols for physical verification and authentication in timber tracking
[37]	Yes	Ethereum	LogLog: A Blockchain Solution for Tracking and Certifying Wood Volumes	To trace wood volumes in the timber supply chain
[38]	Yes	Ethereum	A Tamper-Proof Volume Wood Tracking System	To validate certified wood and record the origin of wood
[39]	N/A	Ethereum	Ethereum decentralized application (Dapp)	To trace and validate teak wood in the supply chain via Ethereum DApp
[40]	N/A	N/A	Image Identification of blockchain-based Wood traceability system	To improve wood product identification in blockchain-based wood traceability system by using AKAZE method replace the traditional image-based methods
[41]	N/A	N/A	Blockchain-based contract management platform	To control and manage the documents and permits to reduce complexity of contract management

Sun, Y. et al. [40] proposed a method to improve the blockchain-based wood traceability system using the AKAZE method. The study focused on improving the technology of wood product identification in the traceability system. The technology could distinguish the unique texture feature of wood products which can replace traditional image-based methods of wood product identification in the blockchain-based wood traceability system [40]. The workflow of this system has two processes: uploading and identification. The uploading process is to upload images (raw images) by workers. The workers take images of wood products and upload them to the systems. Once the image is uploaded, the AKAZE method detects the image feature's key points. Then, the dataset of key points is uploaded to the blockchain system. The identification or the matching process is processed by customers. When customers receive wood products, they could take an image of woodblock and match it with the dataset of key points downloaded from the wood blockchain system [40].

Sheng and Wicha [39] proposed a system based on blockchain technology to identify the validity of teak wood within the teak supply chain from farmers to end-users. The study presented the proposed system's workflow (physical and data). The teak wood supply chain's physical entities include farmers, forestry staff, manufacturers, and customers. Meanwhile, farmers, forestry staff and manufacturers upload digital data to the Ethereum blockchain. All entities can check whether the teak wood is verified wood via the Ethereum decentralized application (Dapp). The information, such as teak owner name, the identifier of planting teak, teak profile, location of planting teak, and verified date, can be uploaded and extracted from the systems [39]. The two-level architecture of the Ethereum Dapp includes front-end UI (NodeJS) and web3 library. The users register and input teak wood information through front-end UI to web3 library. The web3 library responds to the information from the front-end client to the Ethereum blockchain [39].

Gallersdörfer & Matthes [38] proposed a timber-tracking supply chain with smart contracts. The exchange smart contract embedded in the system may create a transparency supply chain with validated wood. The system can mark illegal transactions, transfer of goods operations and mis-labelled wood in the wood supply chain [38].

Munoz et al. [37] proposed an auditing system to trace wood volume in the supply chain. This study [37] indicated that blockchain technology could satisfy industrial demands by developing competitive single-database systems. Munoz et al. pointed out that the LogLog system they proposed has greater availability, traceability, and data integrity than a hybridized system [37].

Düdder and Ross [36] proposed a tamper-proof digital system with blockchain technology for digital tracking of timber to solve illegal timber trade between countries from a macroscopic perspective. This tamper-proof digital system combined blockchain with new digital protocols for physical verification and authentication [36]. Authorities can supervise the imported timber and verify its legal status in Blockchain-based systems. The transactions in blockchain can be linked to its DNA profile in digital form as a cryptographic hash [36]. The companies in timber supply chain can check the certification of a composite wood product in the blockchain [36]. This proposed blockchain system is better than Chain of Custody (CoC) systems. The CoC system is used in European timber companies, which is easy to manipulate [36].

Figorilli et al. [35] developed a prototype of a blockchain-based traceability system to trace wood using the Azure Blockchain Workbench. This open-source prototype system involved an integrated system using blockchain, IoT, RFID, smartphone application, and cloud technology to track wood in the wood supply chain from standing trees (timber marking) to final users (customers). In Azure Blockchain Workbench, it is simple to create blockchain applications by integrating several Azure services [35]. The applications can be developed by writing a JSON configuration file and a related smart contract [35]. The applications proposed in [35] support Ethereum smart contracts written in the Solidity language. This study introduced a smartphone application called SmartTree [35]. The SmartTree was modified to interact with the blockchain. It collects data from timber marking and cutting and upload data to a remote database (MySQL). This blockchain system has a 'security policy' which can consolidate and coherent the data collected before the permanent validation and storage in the blockchain [35].

The authors in [34] proposed a blockchain-based technological solution to eliminate illegal wood in the wood supply chain. The architecture of this system has four components (layers): CouchDB database, smart contracts, WoodChain channel, and API gateway. The CouchDB database store data in JSON format, which allow index information in the database. WoodChain channel is a private layer that only invited organizations (such as timber companies) can use. Based on the proposed architecture and blockchain technology, the authors in [34] developed web and mobile applications. In the mobile application, users can register documents and activities (cutting, logging/timber transportation, etc.) as assets into the blockchain. The modules in the web application are user management, traceability, certificate management, and report display in the wood supply chain [34].

Mechanik and von Hauff [41] proposed a blockchain-based contract management platform monitoring timbers from felled trees to end-users to minimize illegal timbers. The proposed platform allows organizations to control and administrate the permits and documents of the whole timber supply chain, including licenses for cutting, the volumes of cutting timber, the document of storage, sales and payments, payments, timber processing, and many other important documents [41].

4.2. Forest Management

Eight included articles (38%) investigated the blockchain applications in forest management. These articles were mainly focused on (1) the deforestation and degradation of forests; (2) protection/rational utilization of forest resources, including preserving biodiversity, and avoiding overexploitation and (3) carbon trading. Table 3 presents the data extracted from included studies in the area of 'forest management'. The subsection presents and analyzes articles in Table 3. Two articles [42,43] are not listed in Table 3 because they do not contain the information for this section, but they are discussed in the next section.

Table 3. Blockchain-based applications in forest management.

Reference	Smart Contract	Platform	Main Focus	Purpose(s) of the Use of Blockchain
[44]	N/A	Ethereum	A blockchain-based web application on forestry nurseries (inventory) management	To monitor the forest plants and record information of each plant for further validation
[45]	Yes	N/A	The use of blockchain on carbon trading market	To address the key concerns to REDD+ projects
[46]	Yes	Ethereum	A blockchain solution for REDD+	To improve the reliability of carbon sequestration monitoring and protecting global forests
[47]	Yes	N/A	Blockchain on forestry carbon sink projects	To optimize forestry carbon sink trading and reduce emissions
[48]	Yes	Ethereum	Participatory forest management with blockchain (blockchain-based governance)	For governance purposes
[4]	Yes	Ethereum	Image processing and blockchain for forest management	To save species of tree varieties and avoid overexploited by identifying the number and type of trees

Two included articles focused on adding blockchain technology in deforestation and forest protection, such as the Reduced Emissions from Deforestation and Degradation (REDD) and enhancing forest carbon stock in developing countries (REDD+) projects [45,46]. REDD+ projects aim to reduce emissions to enhance carbon stocks in developing countries from deforestation and forest degradation by local, regional, national, and global actions [49]. The authors in [45] focus on the carbon offset by forest protection and planting trees to reduce emissions. By implementing the blockchain in the carbon trading market, the information of the asset type represented by the credit is added to the user's blockchain account (wallet) as a token in the form of small pieces of data [45]. The owner of trees submits all information to request the carbon credit via smart contract algorithm. All information is evaluated by smart contract automatically. All owners can use tokens to perform transactions in the blockchain-powered carbon market [45]. Howson et al. [46] discussed how blockchain technology addressed issues in forest protection, especially in REDD+ projects: (1) blockchain-based technology can address funding issues in REDD+ projects by offering REDD+ credits to exchange cryptocurrencies. (2) Blockchain-based applications help to prove whether atmospheric carbon is removed permanently by improving the reliability of monitoring the carbon sequestration. (3) With the involvement of blockchain technology, REDD+ projects decrease the risk of corruption and secure the rights of forest owners and indigenous communities.

Nandhini et al. [4] proposed an application using imaging processing and blockchain technology to protect endangered species of wood varieties and avoid overexploitation in illegal ways, like smuggling or illegal trading. The workflow of this proposed application has three processes. At first, a drone takes images of the forest cover or a plantation and uploads the image to a module in the application. Then, the module can identify the type of trees and the number of trees using the Support Vector Machine (SVM) algorithm. The SVM algorithm has 90% accuracy in classifying the type of trees [4]. Then, the detailed information (such as cut down trees) is stored in smart contracts. The details of cutdown trees were stored in the blockchain using smart contracts. The smart contracts are stored in the blockchain network module. This blockchain module in this application is created using ReactJs, Ganache, Truffle, and Internet3 framework. All stakeholders (such as environmentalists and authorities) can see the number of cutdown trees and the information of trees' type, age, dimensions, locations, date, and time of the extraction [4].

Willrich et al. [48] proposed participatory forest management with blockchain technology. This participatory blockchain-based governance approach in forest management aims to reduce shareholders' inequalities. This proposed approach is to store the forest inventory data into the blockchain [48].

Figorilli et al. [44] introduced a blockchain-based web application for forestry nurseries management, implementing a traceability system using Radio Frequency Identification (RFID) and Near Field Communication (NFC) technologies. This application can trace individual forest plants in forest nurseries, monitor the plant in the nursery in real-time, and provide the final user (customers) the origin of the plant [44]. The workflow of using this application has two stages. The first stage is to record information and associate with NFC tags. The information includes the date of planting, species of plants, the origin of seeds, etc. Then, the second stage is to add and synchronize data with a remote database. The architecture of this blockchain-based web application was developed to integrate with the blockchain. The data manipulation software layer was added to communicate with the blockchain through the Gateway service API [44]. This blockchain-based application permits maintenance of this evolutive management and safeguards the production quality and select seedlings, trees, and timbers.

Sun et al. [47] analyzed the effects of applying blockchain technology on forestry carbon sink trading. This study [47] performed a game analysis on the forest farmers' incomes before and after applying blockchain technology.

4.3. Forest Fire Detection

Only Two (out of 21) included studies presented two blockchain-based IoT smart systems for forest fire surveillance. There are some similarities between these two included papers. Both studies are written by the same first author Sreemana Datta [50,51]. Two smart forest fire detection systems have similar workflow and architecture with a few differences. This subsection analyzes and discusses these two blockchain-based IoT systems proposed for forest fire surveillance. Table 4 presents data extracted from these two articles. Based on the feature of these two articles, the categories in Table 4 have a slight difference from the tables in the previous two subsections.

Blockchain-based Sybil-secured smart forest fire surveillance (BSSFFS) was proposed to transmit secured and Sybil-protected data in the forest wildfire [50]. The architecture of BSSFFS was composed of three layers: IoT layer, Fog layer, and Cloud layer. The IoT layer consists of IoT sensing devices (sensors) placed in forests. The sensors (including temperature sensor, fire sensor, humidity sensor, and smoke sensor) collect related data from forests. The IoT layer is connected to the fog nodes of the fog layer [50]. The fog nodes are physical devices to process real-time data. The fog nodes in the Fog layer preprocesses data collected from the IoT layer to predict the fire status in forests. The Fog nodes implement blockchain technology to perform real-time decision making and mining of transactions. Datta et al. [50] also introduced an energy-efficient consensus algorithm called Proof-of-Confidence (PoC) to validate data. The Fog layer transfer mined data to the cloud layer. The cloud layer stores data and decrypt updated data. The Fog and Cloud layer (cloud storage) form the blockchain network. The cloud performs decrypted data to predict forest fire and alert the fire department [50].

Table 4. Blockchain-based applications in the forest fire detection.

Reference	Smart Contract	Platform	Blockchain-Based Systems	Layers of Architecture	Purpose(s) of the Use of Blockchain
[50]	N/A	Ethereum	BSSFFS	IoT layer (with sensors) Fog layer Cloud layer	To detect forest fire and validate the information
[51]	N/A	N/A	BESDDFFS	IoT layer (with drones) Edge layer Cloud layer	To detect forest fire and validate the information

Blockchain and EdgeDrone based secured data delivery for forest fire surveillance (BESDDFFS) was also developed for forest fire detection [51]. The architecture of BESDDFFS has three layers: IoT layer, edge layer, and cloud layer. The IoT layer in this system consists of drones to collect data. The drones are divided into leader drones (for adding data to blocks, collecting and processing data) and member drones (for data acquisition and data processing) to capture images of forests. The edge layer processes data at the local processing and routing station to trigger the alarm of the fire [51]. It communicates with both the edge layer and the cloud layer. The cloud layer performed on the Google cloud server reacts to the alarms generated from the edge layer [51]. Blockchain in the cloud layer validates the alarms. If the validation is successful, the system will alert the fire department immediately. If the validation is unsuccessful, the cloud layer will list the alarm in the buffer queue for subsequent alarms [51].

5. Benefits, Opportunities and Challenges of Blockchain Applications in Forestry

The use of blockchain technology provides benefits and opportunities to forestry, along with multiple challenges. Table 5 presents the reported benefits, opportunities and challenges of blockchain in the forestry sector. This table shows the results of content extracted from included studies.

We identify ten types of benefits, three types of opportunities, and five types of challenges from included studies. Minimizing illegal logging, increasing transparency, and efficient traceability are the three major benefits reported from included studies. Nine articles (42%) reported that blockchain could help minimize or illuminate illegal logging/timber-trading. Eight included articles (38%) noted that blockchain brings transparency to forestry. Six articles (28%) discussed that blockchain can increase traceability efficiency for tracking forest-based products. Most articles reported more than one benefit in their studies. However, only two articles (10%) reported each opportunity from results. The three major challenges were identified from included studies are lack of standardization, large energy consumption and loss of traditional jobs.

In the following subsections, we analyze and discuss the challenges, benefits, and opportunities of blockchain technology.

5.1. Benefits of Blockchain in Forestry

This subsection presents and analyzes ten benefits that blockchain technology brings to forestry reported in the included studies. The authors categorized the reported benefits in increasing forestry sustainability; minimizing illegal logging/timber trade; increasing the trust (of wood products)/trustworthiness; efficient traceability; increasing transparency; data integrity; competitive (positive); privacy; Anti-corruption; and cost reduction. Transparency and minimizing illegal timber are two benefits mentioned the most in the included studies.

Table 5. Benefits, opportunities, and challenges of blockchain in forestry.

	Categories	Reference
Benefits	Increasing trust/trustworthiness	[36–38,52]
	Efficient traceability	[33,35–37,42,44]
	Increasing transparency	[32–35,41,42,44,45]
	Data integrity	[32,33,37,39]
	Minimizing illegal logging/timber trade	[4,32–35,37–39,41]
	Competitive (positive)	[32,33,37,43]
	Confidentiality/Privacy	[32,33]
	Anti-corruption	[32,33,36,41]
	Sustainable forestry	[32,33,36,47]
	Cost reduction	[32,33,45,47]
Opportunities	Increasing new skilled job opportunities	[32,33]
	Growing investment opportunities	[32,42]
	New opportunities for small and medium-sized enterprises (SMEs)	[32,33]
Challenges	Lack of standardization	[32,33]
	Large energy consumption	[33,53]
	Loss of traditional jobs	[32,33]
	Implementation risk	[33]
	International timber trade transactions	[33]

Transparency: Transparency is one benefit and characteristic that blockchain brings to forestry. This benefit has been reported in many studies and industries. In forestry, transparency means that sellers and buyers of forest-based products can rapidly access all related information (origin of wood, harvesting time, etc.) [32].

Confidentiality/Privacy: Confidentiality is one characteristic of blockchain as well. All information is anonymous because all transactions are encrypted and recorded in the blockchain [33].

Data integrity: Due to the characteristics of blockchain technology, data stored in the blockchain cannot be compromised [39]. The encryption and cryptography of data can reliably protect from hacking and data breaches [32]. Vilkov and Tian [33] also concluded that the transaction data in the system of smart contracts could not be changed or deleted. And the risk of loss is minimal.

Anti-corruption: Data integrity and transparency are the enablers of anti-corruption. Blockchain applications can exclude corruption, embezzlement, and deception in forestry [32]. All parties involved in the activities of forestry can check and compare data from the database. Düdder and Ross [36] indicated that a blockchain-based tamper-proof digital system provides social benefits such as anti-corruption from sustainable forestry.

Eliminating illegal timber: Each timber is registered in the database. Blockchain technology can validate the legality of each wood/timber [39]. The blockchain-based technical solution proposed by Cueva-Sánchez et al. [34] could reject 99.17% of illegal trees in a logging area. Moreover, since timber transportation routes are planned, any deviation from the route is recorded, making illegal timber trading impossible [32]. The smart tree management system with drones and blockchain technology could prevent over-exploitation and monitor illegal activities such as smuggling and illegal timber trading [4]. Blockchain technology has a great potential for identifying illegal timbers.

Competitive: Improving the competitiveness of forest-based products is a benefit of blockchain as well. The certificate of forest products can be a part of smart contract [33]. The certification can improve the competitiveness of forest products. Customers may be willing to purchase forest products with certification and legality. Moreover, the legalized and certified timber could increase the rating of companies from customers' perspectives [33]. From a global point of view, Lobovikov et al. [43] pointed out that implementing blockchain technology would improve the quality of forestry and make the Russian forest sector more competitive in the domestic and global timber market.

Forestry sustainability: Blockchain technology can use forest resources more rationally to increase forestry sustainability. Blockchain systems with drones can store the volume of cutdown trees [4] to reduce deforestation, monitor the utilize of forests, and protect biodiversity. Lobovikov et al. [32] draw a similar conclusion that the use of satellites and drones with blockchain technology can monitor forest resources continuously to guarantee sustainable forest management. Moreover, blockchain technology increases forest farmers' willingness to reduce emissions [47].

Cost reduction: Saving cost has also been reported as a benefit of blockchain to forestry. Even though the implementation cost (investment) of blockchain is costly [33,35], the use of blockchain technology could bring forestry cost reduction in reducing transaction cost [33,45], abatement costs of forest farmers [47], and makes processing wood products cheaper [32] in forestry. The investment of blockchain increases the efficiency and profit of wood production. Since blockchain eliminates the intermediaries during transactions, the tasks of transactions can be done automatically. All participants receive the processes of transactions and product promotions, the risks, and mobilizes finances would reduce, making processing wood products cheaper [32]. Blockchain technology reduces forest farmers' abatement costs by influencing carbon prices to improve their emission reduction efforts [47].

Efficient traceability: One benefit of blockchain in tracking wood/timbers/wood products is increasing traceability. With the help of blockchain, the forestry industry could monitor wood continuously [33]. With smart contracts, all parties in the wood supply chain follow the planned route to building the next block [33,36].

Increase trustworthiness: Increased trust is another benefit that blockchain brings to the forestry sector. The trustworthiness/trust in forestry has been reported in increasing the trust of purchasers (of wood products) [36–38,52]. The blockchain-based traceability systems can help purchasers understand the origin of timbers, whether the timber is environmentally friendly wood, and whether the processes of wood products involve child labor. Komdeur and Ingenbleek [52] pointed out that tracking the origin of timber products using blockchain-based applications would positively impact the purchaser's trust. Munoz et al. [37] indicated that the blockchain solution with tracking and certifying wood volumes could address customers' concerns regarding wood products' source and environmental impacts.

5.2. Opportunities of Blockchain in Forestry

Other than the benefits, there are some opportunities that blockchain could provide to forestry. This subsection analyzes and explains these three main opportunities that blockchain bring to forestry:

New job opportunities: Blockchain technology will increase employment and wages in forestry companies. It provides new job opportunities for skilled jobs based on new technology such as programmers, system administrators, and high qualified computer employees [32]. With the implementation of blockchain technology in the forestry sector, Vilkov and Tian [33] concluded that forestry companies may require new employees who specialize in cryptography, distribution of ledger technology, and smart contracts.

New investment: Blockchain technology provides opportunities for investments and attracts investors to forestry. Due to the transparency of blockchain, investors worldwide have open and full access to the information of transactions in forestry. It increases investors' confidence in the reliability of blockchain systems [32]. The transparency and traceability of blockchain can attract investors with different backgrounds [42].

New opportunities for SMEs: SMEs with blockchain technology may be the new trends for new startups [33]. SMEs could simultaneously take over the accounting, financial and legal functions of several small, medium, and large forest companies and retail chains as a hub [32]. Enterprises can create cryptocurrencies of their own with their specific products [33].

5.3. Challenges of Blockchain in Forestry

Although blockchain technology has great potential in forestry, there are also several challenges of blockchain implementation in the forestry sector. Blockchain technology is a new and complex technology that may not be accepted in forestry enterprises. It is difficult to apply into practice. Blockchain technology has not been well adapted in the forestry sector. Most blockchain-based applications are developed or proposed but have not yet been widely applied in forestry. Some forest companies may not want to apply blockchain technology in their system in the forestry sector since they do not want to open their database to the public [33]. Some forestry companies still want traditional payment and transactions in timber trading. This subsection presents and discusses the categories of challenges.

Loss of traditional jobs: Blockchain technology increases the risk of losing traditional and low-skilled jobs. The implementation of blockchain will eliminate many traditional jobs in accounting, credit, and international entities [32]. Vilkov and Tian [33] draw a similar conclusion that specialists in accounting and foreign trade departments of timber companies may lose their jobs since all transactions and smart contracts are not involved banks and intermediaries. All transactions will be handled by cryptographers and experts in smart contracts [33].

Implementation risk: The implementation of blockchain technology could be a challenge for forestry in some countries. The cryptocurrency is illegal or not recognized in some regions and countries (such as China), therefore, using blockchain in timber trading is only theoretical and conceptual in these countries [33]. It also makes international timber trading become a challenge. If timber trading occurs in these countries, cash-out cryptocurrency will become a problem.

Large energy consumption: Blockchain-mining operations require a large amount of energy, which could be a big challenge for forestry [33]. Although blockchain technology brings cost reduction to forestry, blockchain itself has a huge energy ad financial consumption. In 2021, a single bitcoin transaction consumed approximately 2290 kWh of electrical energy, equivalent to an average U.S. household's 78 days of power consumption [53].

Lack of standardization: Regulation is also a challenge that blockchain technology brings to forestry. Cryptocurrency transactions in forestry and wood products trade lack international standard regulations between countries. Some conflicts and dispute resolution may require higher authorities to resolve [32].

Moreover, for blockchain-based traceability systems, all participants of the forest supply chain were required to use the proposed system. If one participant does not use the system, the system will fail to provide all users with the proposed functionality [38]. If any participants in the forest supply chain fail to upload in the blockchain, there might be a difference between on-chain data and off-chain data [38].

6. Managerial Implications

This study provides several important managerial implications related to the blockchain applications for decision-makers, managers, consultants, and practitioners in the forestry field. The primary applications are implementing blockchain-based applications for forest products, forest fire detection, and preserving forests' biodiversity and resources. The main managerial implications include (1) blockchain-based IoT systems can increase the efficiency of traceability to establish the purchaser's trust in wood products and minimize illegal logging; and (2) the features of blockchain, such as decentralization, transparency, confidentiality, and data integrity, could provide competitive advantages for enterprises in the forestry sector. If managers would like to use cryptocurrency and blockchain, they may need to hire new skilled employees to specialize in cryptography and smart contracts.

Although blockchain has multiple benefits in global timber trading and forest management, there are a few risks and disadvantages that managers and practitioners should consider before implementing blockchain in their enterprises: (1) due to the nature of blockchain, data breach and hacking is relatively difficult, but not impossible. In fact, in the last ten years, there have been multiple cybercrimes, such as cryptocurrency hackings, data breaches, and Sybil attacking reported worldwide [54]. It is important to understand that the blockchain is not un-hackable and immutable [55]. The security of blockchain should be listed as a potential risk for forestry enterprises. (2) Even though blockchain was reported for cost reduction on forest farmers' abatement and processing of wood products, the enormous energy consumption and electric waste of cryptocurrency transactions is also a disadvantage. The infrastructure of blockchain would be costly for startups. It should be considered by consultants and decision-makers in the forest sector. (3) Every startup could create its own cryptocurrency. However, there are many unsuccessful cryptocurrencies. The enterprise should realize that not every cryptocurrency is successful as bitcoin.

7. Theoretical Implications and Future Research Directions

From the academic perspective, this study provides insights to academic researchers interested in advancing or researching related topics further. The study found that there is an increasing interest in this topic in academics. The topic has gained growing attention from researchers in the last few years. Blockchain technology can be used and has great potential in the context of forestry. The authors expected there would be an increasing number of publications on related topics.

This study reviews the research articles on blockchain applications in forestry, along with reported benefits and challenges from academia. Our study revealed that there are only a small amount of empirical research studies focusing on the implementation challenges, risks, and disadvantages of blockchain to the forestry sector, especially in the security issue and scalability of blockchain. Cryptocurrency stealing and data breaches have been discussed in academia [54,55]. There is a need to investigate more on the risks and threats of blockchain in the forestry field. Moreover, the research on blockchain in the forestry sector currently lacks regulations. Since blockchain is a relatively new technology, most research articles were just theoretical and conceptual blockchain solutions for forestry.

This study provides the research agenda on the topic of blockchain in forestry as an essential contribution. Table 6 shows the proposed research agenda for future research. We suggest research directions focus on the maturity of blockchain in forestry and the open issues of blockchain applications in the practice of forestry. In Table 6, we present five areas of research gaps with possible research directions.

Table 6. Research agenda for future research.

Research Gaps	Further Research Directions
Studies reporting risks, threats, and challenges of blockchain implementation in forestry	To investigate the challenges, threats, and risks of blockchain implementation and identify the solutions to overcome these barriers
Security of Blockchain	To investigate the security level of blockchain in forestry
Blockchain integrated with other Industry 4.0 technologies	To assess the main benefits of blockchain with artificial intelligence (Blockchain 4.0), blockchain-based IoT systems
The adoption of blockchain in forestry	To investigate the elements of adopting blockchain in different regions and countries
Suitable practices of blockchain in forestry	What are the practices of blockchain in other industries that can be applied to forestry?

8. Conclusions

This study investigated the current blockchain technology in forestry. To address the research objectives, a systematic review method was performed. A total of 570 articles were retrieved from four high quality databases. With a careful and specific data selection process, 21 highly relevant articles were selected from these 570 articles. The included articles were analyzed and discussed. The first and second research questions were addressed in Section 4. The third and fourth research questions were answered in Section 5.

Our findings indicate that blockchain technology has a great potential in increasing purchasers' trust of wood products, sustainable forestry, minimize illegal logging, conserve biodiversity of tree species and many other areas related to forestry. However, managers and practitioners interested in using blockchain in the forestry sector should consider the potential risk of data breach and cyberattack. The study also shows there is limited research on challenges and risks of blockchain adoption in forestry. The blockchain is relatively complex and hard to apply in forestry because blockchain adoption requires cryptography and smart contract experts. The disadvantages of blockchain application should receive more attention from researchers and practitioners.

The main contribution of this was to provide understandings and details of current blockchain applications/solutions in three categories of the forestry sector: forest management, traceability of wood products, and forest fire detection. This study also clarified the benefits, challenges, and opportunities that blockchain brings to forestry. It also helps practitioners and managers interested in the field of forestry to learn about the use and the application of blockchain technology in the forestry sector including identified benefits, risks, and challenges. It offers research gaps and future research directions for researchers to investigate related topics. To the best of our knowledge, this systematic review is the first study that presented a detailed systematic investigation of blockchain technology in the forestry sector.

There are several limitations of this study. This study only considered and included articles written in English. There might be highly relevant research articles written in other languages but were excluded. Moreover, even though we carefully designed the search string and spent a considerable amount of time on article searching and selection, there might be potential flaws in the searching process.

Blockchain technology is still in the early stage of development in forestry. It also has great potential in the forestry sector, especially in preventing illegal logging and sustainable forestry. However, the risks and threats of blockchain cannot be ignored. Future research directions could focus on the adoption of blockchain into forestry enterprises, threats on the security of blockchain and investigating blockchain-based IoT systems in forestry. The related topic is worth to investigated in further research.

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Appendix A

Table A1. Included articles of this systematic review.

No.	Author(s)	Year	Title	Publication Type
[40]	Sun, Y. et al.	2021	Wood Product Tracking Using an Improved AKAZE Method in Wood Traceability System	Journal article
[36]	Düdder, B. and Ross, O.	2017	Timber tracking: reducing complexity of due diligence by using blockchain technology	Other: Position paper
[39]	Sheng, S.W. and Wicha, S.	2021	The Proposed of a Smart Traceability System for Teak Supply Chain Based on Blockchain Technology	Conference paper
[52]	Komdeur, E.M. and Ingenbleek, P.T	2021	The potential of blockchain technology in the procurement of sustainable timber products	Journal article
[38]	Gallersdörfer, U. and Matthes, F	2018	Tamper-Proof Volume Tracking in Supply Chains with Smart Contracts	Conference paper
[4]	Nandhini, J.M. et al.	2021	Smart Tree Management with Biodiversity Preservation Using Image Processing and Blockchain Technology	Conference paper
[9]	Willrich, S. et al.	2019	Rethinking Forest Management: A Participatory Blockchain-based Governance Approach	Conference paper
[48]	Sun, R. et al.	2021	Mechanism Analysis of Applying Blockchain Technology to Forestry Carbon Sink Projects Based on the Differential Game Model	Journal article
[37]	Munoz, M.F. et al.	2021	LogLog: A blockchain solution for tracking and certifying wood volumes	Conference paper
[50]	Datta, S. et al.	2021	BSSFFS: blockchain-based Sybil-secured smart forest fire surveillance	Journal article
[32]	Lobovikov, M. et al.	2021	Blockchain–killer of illegal wood	Conference paper
[42]	Tavares, E.C. et al.	2019	Blockchain in the Green Treasure: Different Investment Objectives	Conference paper
[43]	Lobovikov, M. et al.	2021	Blockchain–booster of the Russian forest information systems	Conference paper
[33]	Vilkov, A. and Tian, G.	2019	Blockchain as a solution to the problem of illegal timber trade between Russia and China: SWOT analysis	Journal article
[51]	Datta, S. and Sinha, D	2021	BESDDFFS: Blockchain and EdgeDrone based secured data delivery for forest fire surveillance	Journal article
[35]	Figorilli, S. et al.	2018	A blockchain implementation prototype for the electronic open-source traceability of wood along the whole supply chain	Journal article
[34]	Cueva-Sánchez, J.J. et al.	2020	A blockchain-based technological solution to ensure data transparency of the wood supply chain	Conference paper
[46]	Howson, P. et al.	2019	Cryptocarbon: the promises and pitfalls of forest protection on a blockchain	Journal article
[45]	Kotsialou, G. et al.	2021	Forest carbon offsets over a smart ledger	Other: Preprint paper
[44]	Figorilli, S. et al.	2021	A Blockchain implemented App for forestry nursery management	Conference paper
[41]	Mechik, E. and von Hauff, M.,	2022	The Fight Against Deforestation of Tropical Forests—The Contribution of the Blockchain-Based Contract Management Method to Minimize Illegal Logging	Other: Book chapter

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