Evaluating the practicality of using Blockchain in different use cases in the supply chain sector

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The lack of transparency and traceability in the supply chain sector can negatively impact organizations and their customers' experience. Blockchain is a distributed ledger technology which debuted in 2008 in the financial world, which was to become an application in various domains, such as health, education and business. Because of the hype around it, businesses started adopting the new technology without fully assessing its fit for their use purpose. The aim of this study is to reduce uncertainty when choosing a suitable database system for the supply chain sector, using the ten-step decision framework of [43] to study the feasibility of using blockchain in the supply chain sector of five different industries: egg, diamond, wood, clothing, and dairy.

Additional Key Words and Phrases: Blockchain, Database, Supply chain, Use cases

1 INTRODUCTION

The extent to which a business can keep track of its information exchange and the goods movement within its supply chain can determine the fate of that specific company, as it represents a key to meeting customers' needs and satisfaction[50]. Consequently, in the 1960s, once computers became popular and affordable, businesses started implementing database storage solutions to expand their data storage capacity [5] so they could ensure their competitive advantage.

Since databases are software systems, they are subject to constant change in complexity and form[51] such that their purpose is met as well as possible. Therefore, in 2008, by the desire to innovate the financial world, blockchain was firstly implemented in the context of Bitcoin [46]. The new blockchain technology came with several features compared to traditional databases, i.e. decentralization, immutability, security and transparency[57].

Being a decentralized system, the transactors do not have to rely on a third party which they might not trust to carry out their transactions[14]. Instead, blockchain relies on a peer-to-peer network, meaning that the whole record of transactions is shared within, checked and updated by its participants[40]. Therefore, the transparency of the transactions is enhanced. Besides, the immutability and security of the system come from the fact that each transaction that has ever taken place is stored on each participant's device, without giving him the ability to change the history of the records, as the writing permissions are done via public and private keys cryptography [24]. Because of its characteristics, the new storage system is described as a *distributed ledger technology* (DLT) [57][14]. Since 2008, blockchain wasn't used only for developing applications for financial sectors or domains or other crypto-currencies, but it became practical in many areas besides the financial world [9], identified nine main blockchain applications (See Appendix A), including education, health, the internet of things and business and industry.

This research will focus on a specific area of the latter mentioned applications, namely the supply chain sector, and will study whether blockchain is an adequate information storing system to be used in the mentioned area. In 2021, [29] reported in their article a decrease in blockchain interest due to failed implementations. Consequently, several use cases of blockchain implementation will be studied to check if their information management system choice is appropriate. Therefore, the main research question of this research is:

RQ: What data storage system would be adequate to implement in the supply chain sector of the selected use cases?

To answer the main research question, two research subquestions were created:

SQ1: What blockchain implementation use cases are there in the supply chain sector and how are their supply chains organized?
SQ2: What decision method should be used to determine whether the implementation of blockchain is justified for specific use cases or if other storage systems are preferable?

To answer the main research question, the thesis has been split into two phases, i.e. conducting the literature search and review to answer the two subquestions, and then using the decision method found by answering SQ2 to determine whether the use cases found in SQ1 made the right decision to use blockchain instead of a different type of database.

Answering the first subquestion requires the selection of the use cases to be further analyzed. To do so, a literature search was performed by querying academic search engines, such as Scopus, Google Scholar and IEEE Xplore. The name of several industries (dairy, food, agriculture etc.) was used along with keywords (e.g. blockchain, supply chain) such that the search results are limited (to at most 20 articles) and specific enough for a decision to be made. The resulting query were of the form:

```
( TITLE-ABS-KEY ( blockchain )
AND  TITLE-ABS-KEY ( "supply␣chain" )
AND  TITLE-ABS-KEY ( dairy  OR  milk
OR  cattle )
AND  TITLE-ABS-KEY ( "use␣case" ) )
```

Solving the second sub-question also implied a literature search and academic literature comparison such that the selected decision scheme could be used to distinguish between different storage systems and to provide a logic that can be used to establish whether the

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selected use cases blockchain choice was the right one. Therefore, the queries used were of the form:

```
( TITLE-ABS-KEY ( blockchain )
AND  TITLE-ABS-KEY ( use  OR  adoption
OR  versus )
AND  TITLE-ABS-KEY ( database* )
AND  TITLE-ABS-KEY ( decision
OR  method  OR framework OR  path OR scheme ) )
```

After the use cases and the decision scheme have been chosen, each use case had to be tested using the framework the ten-step decision framework created by [43] to determine whether the implementation of blockchain is feasible. The remainder of the paper is structured as follows. In section 2, the existing types of blockchain have been enumerated and a brief description of the mechanism for adding data to the ledger has been discussed. Next, in section 3, articles analyzing blockchain implementation in use cases of different fields have been studied and mentioned. Section 4 represents the research step of the article, where in the first part the blockchain use cases are identified and analyzed, followed by the framework search and selection in the second part. In section 5, each of the chosen use cases are evaluated using the ten-step decision framework. Next, the contributions of our article are enumerated together with the limitations encountered in section 6. Finally, the drawn conclusions are presented in section 7.

2 BACKGROUND

Before diving further into the literature and making a blockchain recommendation for the selected use cases, some basic knowledge about blockchain will be clarified in this section, i.e. how transactions are validated, what the different types of blockchain are, and how the implied parties agree upon who is entitled to append new transactions to the chain.

To provide automation, improve efficiency and minimize cost, smart contracts can be implemented on the blockchain to enforce or self-execute contractual terms between the stakeholders [1]. Smart contracts are defined by [31] as sets of digital commitments (rights and obligations of the nodes) which have to be constructed, deployed, executed and then agreed upon by other participants using different consensus mechanisms for a new transaction to be created and linked to the end of the ledger, if eligible.

The consensus mechanisms used represents a crucial part of the logic of the blockchain, as it constitutes the rules of acceptance of a new block to the ledger, based on the collective decision of the participants of the network, directly impacting the security and reliability of the system [49]. Different consensus protocols exist. According to the survey of [20] on blockchain technology, the most frequently used are Proof-of-Work (PoW) [61], Proof-of-Stake (PoS) [38], Delegated Proof-of-Stake(DPoS) [59] and Practical Byzantine Fault Tolerance (PBFT) [58]. The choice of the consensus platform to be used depends on the type and use of the blockchain [49].

According to [63] and [45], there are four types of blockchain which differ in the rights and permissions (read, write, commit) offered to the users: public, hybrid, consortium, and private.

- The *public* (permissionless public) blockchain can be read by anyone around the world, also allowing them to make transactions and verify the validity of other transactions.
- A *private* (permissioned private) blockchain is held by a single organization, which might or might not give reading and/or validation access to others. Also, the organization responsible for managing the blockchain is responsible for issuing new transactions
- *Consortium* blockchain (federated blockchain) is controlled by multiple organizations and it has both public and private characteristics. It allows only a set of trusted participants to read, add and validate transactions [45].
- A *hybrid* blockchain (permissioned public) is a combination of private and public blockchain, as both permission based and permissionless systems are used to choose to whom and what access rights should be given. The level of centralization is lower than in a consortium blockchain because, instead of an organization deciding the access rights, smart contracts are used to carry the process out[19]. According to [43] the access rights in this type of blockchain are more finely differentiated.

3 RELATED WORK

Few articles have been identified that study the implementation of blockchain in the supply chain sector. The majority of writers (e.g. [3], [22], [62]) used different methods to evaluate the blockchain use in their use cases compared to the decision scheme used in this study. For instance, [22] identified in their research critical success factors, such as technical capability, organizational readiness a.s. when implementing blockchain technology in the pharmaceutical and cobalt mining supply chain. The motivation behind their study was also to solve the visibility and traceability problem in their chosen supply chains. Even if alternative databases were not suggested by the mentioned study, the proposed critical success factors could have been used when evaluating the use cases in this study to check whether the success/failure of the implementation is because of the right/wrong storage system choice or because of other external factors.

In contrast to the literature mentioned in the previous paragraph, [32] used a framework based on seven questions to assess the suitability of blockchain in four industrial trails: supply chain, electronic health records, identity and the stock market. By responding to the seven questions of the framework the user can conclude whether a conventional database or blockchain is better to be used. Although their framework was not used to test specific use cases within the supply chain sector, it represented a good starting point for answering SQ2 of the current research paper.

As this paper is aiming to do, [29] highlighted the hype of the companies to adopt blockchain solutions and discusses the problems they encountered when doing so. [29] also proposed a model to examine the feasibility of blockchain adoption and it is based on three condition sets that were scored and compared for each instance of use they have selected. Similarly to the use cases selected by [32], the chosen use cases were not supply chain sector related.

[26] identified key issues and challenges encountered by the companies when adopting blockchain. Their article is related to

our work because it can guide us to the direction in which our selected use cases could have failed to integrate blockchain technology. Concurrently, [54] differentiated between integration practices of blockchain in German and Russian pharmaceutical, food and energy supply chains. In their study, [54] compared five use cases from each country and found that the size of the company, the form of ownership and the scale of the blockchain implementation are important factors to be considered when making the decision to use blockchain.

Because the novelty of the studied technology, not enough research has been done since now to offer a definitive answer of whether blockchain should or should not be implemented in the supply chain sector of any industry, therefore the current paper intends to bring the knowledge building information necessary to diminish the mentioned knowledge gap.

4 RESEARCH STEP

In this step, the research sub-questions of this paper are addressed and answered. First, the selected use cases are analyzed and described in the first subsection, followed by framework selection and reasoning of selection in the second subsection.

4.1 Use cases Selection

Five industries were selected to carry out our research upon: egg, diamond, wood, clothing, and dairy. The literature search performed resulted in a total of 25 articles, which are illustrated in Table 1.

The criteria used for picking the use case of each industry were the details about how the supply chain of the industry is organized, the amount of technical details of the platforms and technologies used for integrating blockchain within the industry, as well as the data that had to be stored on the ledger. Besides, the number of citations and publication dates of the articles have been considered.

	Industry				
	Egg	Diamond	Wood	Clothing	Dairy
Inspected articles	[7]	[28],[12], [8],[23], [56]	[37],[17], [16],[36], [18],[48]	[11],[2], [42],[44], [55]	[39],[52], [10],[6], [34],[35], [53],[15]
Chosen use case	[7]	[56]	[16]	[2]	[10]

Table 1. Scientific articles discussing blockchain implementation in the chosen industries

To gather the information necessary to answer our research question, the method 5W1H[1] was used, which [60] described as being an effective tool to model domain knowledge and to scale user requirements. By using the aforementioned decision tool we aimed to get a good insight into how the selected industries are structured, how they work, and what their requirements are from a storage system. Hence, the next set of questions have been formulated to be further addressed to each industry in the following paragraphs:

[1]5W1H is an effective method to gather details about a fact using 6 questions: Who?, Where?, When?, What?, How?, and Why?[27]

- **Where** do the selected industry operate?
- **How** is the industry organized? *OR*
- **How** do the stakeholders interact?
- **Who** are the major stakeholders within the industry?
- **What** is the type of information that has to be stored?
- **Why** is it important for the industry to have the mentioned information stored?
- **When** do the stakeholders need/use the information?

4.1.1 Egg industry. The first supply chain studied is the egg industry chain. In their paper [7] analyzed and described a blockchain use case of an egg packing company in the USA, so their article was selected as a basis to answer the formulated questions. Hence, it was discovered that the company operated in the Midwestern region of the United States. At the bottom of their supply chain, there were about 100 farmers which collected and sent their products to the packing company. After the products arrived at the packing company, the eggs had to be cleaned, processed, graded and packed so they can be sent to the retailing companies from all around the Midwestern region of the US so they can be further purchased and consumed by the population. Therefore, the stakeholders of the supply chain have been identified: egg-producing farms, transporters, packers, retailers and consumers.

The information [7] identified as being relevant was collected when the products left the farm and when the packaging process was carried out. After the eggs have left the farm, the collection time, the farm of provenience name and address, and quality data of the eggs have to be collected. Next, at the packaging site, the name of the packer, certification data, arrival date of the eggs at the packing factory, grading and the packaging date should be stored. By storing the earlier mentioned data, the stakeholders of the egg industry could enhance the traceability of their products, could diminish food fraud and ensure consumers of the safeness and quality of their products by allowing them to check the details of the food they purchased.

4.1.2 Diamond industry. A second industry that is in high need of upgrading its traceability, authentication and certification is the diamond industry[12][47], due to the existence of cartel networks and illegal diamond trades [21]. The principal gem producers in the world are Russia, Australia and Botswana[4], so their supply chain models are researched.

To understand how diamond trading works the research of [56] was used. The entire process started from the mining and sorting phase (also called the upstream phase), which prepared the raw material to be sold to the producers and exporters, but not before being identified and certified by different certification houses. In the second phase (midstream phase), the producers had to cut, polish and trade the refined product to the jewellery manufacturers, which had to prepare the jewellery for the last phase, i.e. the downstream phase. In the downstream phase, the final product was marketed and sold to the consumer.

At each step of the chain, data had to be stored for the industry to be fully transparent: when mined and polished, quality data was essential such that an adequate price tag to be associated to the product; when sold, the product had to come with the data of the credentials of the previous owners and price of the product; when transported, the logistics details were crucial for the traceability of the materials.

4.1.3 Wood industry. Because illegal logging and forest-related crimes are not a novelty, with one of the problems standing in the transparency and traceability aspects [25], the third use case that is discussed comes from the wood industry. [16] investigated how a wood supply chain from Southern Italy (Province of Catanzaro) is structured, and proposed a blockchain solution for the info-traceability of the wood products within the wood supply chain. To further assess if the blockchain proposition [16] made was justified, the formulated questions were used to gather information from their paper.

The first activity of the wood supply chain described by [16] was marking the sapling according to the requirements imposed by the European and national authorities. This activity was done by a forest technician in order to identify the trees to be later authorized for cutting. At the cutting stage, the marking date, the species of the marked trees, the GPS point and other qualitative information about the wood were relevant. After the timber was authorized, the cutting process followed. The data to be stored at this point were the cutting date, and the tree diameter, length, and quality. Next, the logs were stacked and a production track was chosen according to the quality of the wood and the requests of the parties interested in the material. Soon after, the timber was transported to the sawmill, where each log had to be processed. At this point, the information of each log and the number of pieces it was decomposed was stored together with the date when the timber entered the sawmill and other information regarding the quality of the product. After the lumber has been produced, the material was sent to the producers, to be further processed into wood products (such as furniture) and sent to the last actor of the supply chain, i.e. the consumer, which could have been interested in provenience and quality of the product (therefore it is important to store this data when produced).

4.1.4 Clothing industry. From the studied literature it was clear that trust represents a problem in the garments industry, as all the identified case studies mentioned the word "traceability" and "counterfeit". In the subsequent paragraph, the supply chain described by [2] is studied in more detail, and the questions have been answered based on their research.

The supply chain studied by [2] was not located in a specific country, as the businesses in the textile industry often operates internationally and the specific region was not specified. Similarly to the other distribution chains examined until now, the clothing industry started from the raw materials producer, in this case, the natural or the chemical fibre producer, which was responsible for monitoring the quantity and quality, and obtaining the authenticity certificate of the production. From the producer, the raw material was sent to the yarn manufacturers, who produced the batches of yarn to be further distributed to the fabric manufacturer, which was responsible for transforming the yarn batches into fabrics and imprinting the created fabrics with a unique identification code. Afterwards, the apparel manufacturer processed the yarn further, to become garments, each with new identification codes attached and a reference to the identification code of the yarn batch it was manufactured from. Lastly, the retailer was implied in the supply chain, which could provide along with the products they sold to the customers the details of the products and the partners involved in their industry.

4.1.5 Dairy industry. The last examined use case comes from the milk industry. The authors of [10] proposed the implementation of a combination of blockchain, smart contracts and IoT within a use case belonging to the Greek dairy supply chain, which came as a desire to enhance food safety and the trust, efficiency and quality within the supply chain actors. The stages of the Greek supply chain as described by [10] are related in the next paragraph.

The first operation was the daily milk collection from the different breeders. To ensure the customer about the provenience and quality of the milk, the quality manager was responsible for collecting the necessary data, such as milk composition, presence of inhibitory substances, and microbiological state. Later on, the quantity and quality of the milk, the time and the transporter's information were collected before sending the milk to the processors, where the raw material had to be transformed into dairy products. Again, the bill of materials data together with the identification data of the packages and other raw materials and ingredients used had to be collected. In the end, the weight, identification code, date and time of the delivery and customer's details were also accounted for when the products were sent to the consumer.

Having the details gathered for all use cases, it is relevant to know the type of blockchain adopted/proposed by the authors of the articles, such that it can be assessed after decision framework selection whether it was the appropriate choice or an alternative is preferable. Table 3 displays the blockchain type, the platform and the consensus selection of each use case.

4.2 Framework Selection

From the literature search performed, six articles providing a decision framework with different levels of complexity were found, alternating between six to twelve decision points. When analyzing the decision points, similarities were found both in the classification of the databases they have suggested to be implemented and the questions asked at each decision point. For instance, the number of parties involved in the business/industry willing to adopt blockchain was relevant in five out of six articles [13, 30, 32, 41, 43]. Also, the trust between the parties is another important decision point mentioned in five of the articles [13, 32, 33, 41, 43].

An exclusion criterion that has been applied in choosing the scheme to proceed with was for the framework to make a distinction between the existing blockchain types (i.e. public, private, hybrid, and consortium), a criterion which was not satisfied by the articles of [30, 32]. None of the frameworks found did distinguish between all four blockchain types, but only between public, private, and hybrid blockchains. Having to decide between the four schemes left, the number of citations was used to make the final framework decision, therefore, the article of [43] was selected. Besides, the fact that [43] described and applied their decision tree on a use case from the Danish Maritime Authority helped in making the decision.

The framework selected is based on ten questions which verify if the evaluated use case fits the properties of blockchain, resulting in either suggesting one of the three blockchain types discussed

Industry	Article	Type of blockchain system implemented/ proposed by the author				Platform	Consensus
		Public	Private	Consortium	Hybrid		
Egg	[7]		✓			Hyperledger Sawtooth v1.0	Proof of Elapsed Time
Diamond	[56]		✓			Everledger	Practical Byzantine Fault Tolerance
Wood	[16]		✓			Azure Workbench (Ethereum)	Proof of Authority
Clothing	[2]		✓			Not specified	Proof of Work
Dairy	[10]		✓			Ethereum	Proof of Work

Table 3. Type of blockchain suggested by the authors of each use case

(public, private, and hybrid) or not to use a different storage system. The structure of the decision scheme can be observed in figure 1. Next, the blockchain properties verified by each question have been identified.

The first blockchain characteristic to be respected is distributivity, as its resources are provided within all the involved members, therefore, the question proposed is "Need for a shared database?". Secondly, the divisibility property is verified by the question "Are there multiple parties involved?". The third step is to establish whether the parties can trust each other, as blockchain provides an environment in which the participants do not have to rely on each other, thus the question is "Do the involved parties have conflicting interests and/or are they trusted?". Fourth, the decentralization of the system has to be respected, fact checked by the question "Can or do the participants want to avoid a trusted third party?". The fifth question [43] asked in their framework is "Do the rules governing system access differ between participants?", and it addresses the functionality of blockchain to offer different validation, write and read rights to its participants. Next, because blockchain transactioning is based on smart contracts and inflexible consensus protocols (once adopted) it is not advised to implement it in environments where the transacting rules change frequently, so to prevent an incorrect adoption, the question "Do the rules for transacting remain largely unchanged?" is used. Immutability is another property specific to blockchain in comparison to traditional databases which is verified by the question "Is there a need for an objective, immutable log?".

A positive answer to all the previous questions means a green flag for blockchain adoption, otherwise, traditional database usage is recommended. To establish what type of blockchain is suitable for the evaluated use case, three decision points are left to be analyzed. The access rights given to the public make the difference between permissioned and permissionless blockchain. As the name suggests, in a permissionless blockchain any new came participants are allowed to read the contents and to add new blocks to the chain. Any restriction of those rights would result in suggesting a permissioned blockchain. Besides, in a use case where both the reading rights and writing rights should be restricted, a private blockchain is the right choice of blockchain. When only the writing rights are restricted while everyone is allowed to see the transactions, public blockchain should be used. Consequently, the eighth and ninth decision points were formulated by [43] as follows: "Is public access required?" and "Are transactions public?". Finally, the distinction between public and private permissioned blockchains could also be made by the question "Where is consensus determined?". If the consensus is established within the organization providing the blockchain service, i.e. intra-organizational, a permissioned private blockchain should be used. An inter-organizational consensus mechanism, i.e. within the implied parties, results in suggesting a public permissioned blockchain.

5 EVALUATION STEP USING THE TEN-STEP DECISION FRAMEWORK

In the current step, the adequate storage system for each of the five chosen use cases is determined by responding to the questions proposed by [43] for each use case.

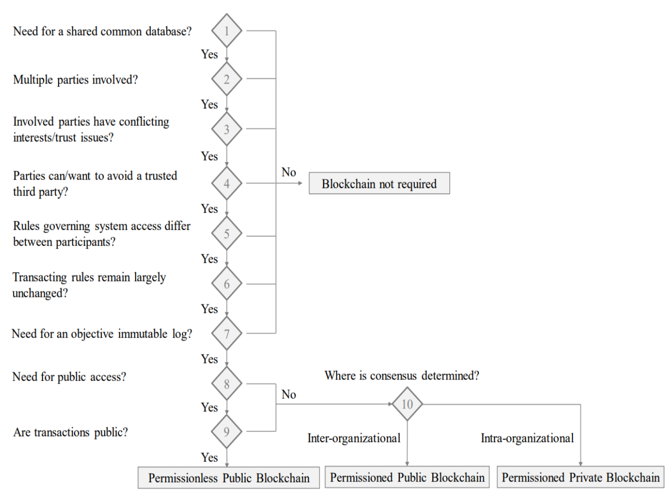

Fig. 1. Blockchain implementation decision framework [43]

5.1 Egg industry

(1) Need for a shared common database? → **Yes** → A shared database is needed because all the details regarding the product (from raw material to final product) are relevant for the end consumer. Besides, the product information has to be verified by the purchasers to ensure the quality is in accordance with the expectations.
(2) Multiple parties involved? → **Yes** → The stakeholders of the egg supply chain have been enumerated in section 4.1.1
(3) Involved parties have conflicting interests/trust issues? → **Yes** → The conflicting interests identified within the egg industry would be regarding the quality of the products. For instance, if an egg transport would get compromised because of specific reasons (wrong storage temperature, length of the delivery time, a.s.), an innocent stakeholder (could be the retailer, as it is located at the bottom of the supply chain) could face the consequences (unfair complains from the customers, monetary loss).
(4) Parties can/want to avoid a trusted third party? → **Yes** → Examples of such third parties would be the personnel involved in tracing the products and the people managing accordance certificates.
(5) Rules governing system access differ between participants? → **Yes** → The governing rules differ between the participants because there are parties which have to issue new blocks in the system (for instance, the egg farmers when they collect the eggs) and parties that only need reading rights (i.e. the final consumers interested in the details of the product).
(6) Transacting rules remain largely unchanged? → **Yes** → The transaction rules remain the same within the supply chain. The main activity that is going on when transacting is a monetary exchange for a good/batch of goods between two parts. The good is then moving from the upstream part of the supply chain to the downstream using the same type of transaction. The product might change in shape and quantity (because of the processing and staking phases of the products) but the item keeps its main properties that are relevant for the customer, only that more details are appended by the corresponding stakeholder, depending on the role he has in the chain.
(7) Need for an objective immutable log? → **Yes** → [7] emphasized in their article that transparency and traceability are highly needed in the egg industry, which an immutable log can provide.
(8) Need for public access? → **No** → In the studied use case, writing rights are not needed by all the parties because the retailers or consumers for example do not have to create new products, only carry out transactions, in comparison to the farmers. Therefore, writing rights should be restricted.
(9) Are transactions public? → **No** → The consumers should not be able to see all the details of the transactions, as they can contain sensitive data (for instance, the home addresses of the farmers or the daily production of the firms). Consequently, a private permissioned blockchain is desired.
(10) Where is consensus determined? → **Intra-organizational** → [7] specified that the parties allowed to validate and the transactions submitted to the network are regulated by a private network policy (which is managed by the blockchain provider).

5.2 Diamond industry

(1) Need for a shared common database? → **Yes** → There are multiple parties requiring access to data of the diamonds traded, so there is a need for a common database.
(2) Multiple parties involved? → **Yes** → There are multiple stakeholders implied in the industry: miners, producers, manufacturers, etc.
(3) Involved parties have conflicting interests/trust issues? → **Yes** → Trust issues between the parties exist with concern to the validity and quality of the items traded.
(4) Parties can/want to avoid a trusted third party? → **Yes** → In the use case described by [56] parties implied at each step of the supply chain in the authentication of the product and transaction reliability insurance exists, and could be avoided.
(5) Rules governing system access differ between participants? → **Yes** → There are parties with different attributions in the supply chain: mining, manufacturers, and consumer, which need different access rights to the system.
(6) Transacting rules remain largely unchanged? → **Yes** → The transacting rules remain the same because, as in the egg industry, a product/multiple products together with their specifications are traded for an amount of money at a certain time.
(7) Need for an objective immutable log? → **Yes** → Ensuring the genuinity and providing the history of the product to the customers is a desired feature in the gem industry, therefore, the immutability of the data is required.
(8) Need for public access? → **No** → A permissioned blockchain is desirable in the diamond industry as not anyone should be able to interfere in the authentication process of the diamonds for instance, because it is an activity that should only be carried out by the certification houses.
(9) Are transactions public? → **No** → The transactions should not be public because the price tags and details of the owners are included in the transactions. Also, because of the expensiveness of the materials, not everyone should be able to trace where a batch of diamonds is located or who the holder is because it would raise significant security risks. Consequently, a permissioned blockchain should be implemented.
(10) Where is consensus determined? → **Intra-organizational** → The consensus is determined intra-organizational because an intermediary is needed to establish the roles of the trading parties, in order to allow them to validate transactions.

5.3 Wood industry

(1) Need for a shared common database? → **Yes** → There is a need for a shared data storing system because the data about the wood quality, provenience, and identification have to be available for the actors implied in the wood supply chain.
(2) Multiple parties involved? → **Yes** → The stakeholders have been identified in section 4.1.3.
(3) Involved parties have conflicting interests/trust issues? → **Yes** → As specified by [16], the European forest authorities strive to stop wood trade of illegal origin from the market. Also, the final consumers of the wood products are interested in the quality and origin of the wood, which can not always be proven.

(4) Parties can/want to avoid a trusted third party? → **Yes** → Once the trees have been marked in the marking phase and identified (in this use case using radio-frequency identification tags, their data being stored on blockchain), makes the timber identification easier in the later phases, thus partly reducing the presence frequency and rigourosity of the wood controls that have to be regularly carried out by the national authorities.
(5) Rules governing system access differ between participants? → **Yes** → Each stakeholder has different attributions within the supply chain.
(6) Transacting rules remain largely unchanged? → **Yes** → The details of the wood material are passed by from the upstream stakeholders of the supply chain to the downstream actors, with more specifications being added. The product could be divided into different products, but each created item is identified by the specifications of the product it was created from.
(7) Need for an objective immutable log? → **Yes** → An immutable database would ensure each tree is identified and tracked through the supply chain, reducing the probability for unidentified subjects to intervene in the normal resources flow without the implied parts not suspecting the irregularity. Also, it could help avoid false paper claims when the wood is transacted.
(8) Need for public access? → **No** → Different access rights are needed in the wood supply chain. Only the forest authorities should be able to approve new raw wood material being placed on the market, for instance, while only the producers are allowed to create a product using multiple components which may have different origins.
(9) Are transactions public? → **Yes** → There is no sensitive information being passed between the stakeholders, therefore, anyone should be allowed to read the data of the supply chain.
(10) Where is consensus determined? → **Intra-organizational** → The consensus is determined intra-organizational because the regulating agency should decide who should be entitled to carry out each activity within the supply chain and who are the parties deciding whether the rules have been fulfilled.

5.4 Clothing industry

(1) Need for a shared common database? → **Yes** → Different parties around the world need access to the data of the products they use, so a shared database is needed.
(2) Multiple parties involved? → **Yes** → In section 4.1.4 the most important stakeholders have been enumerated.
(3) Involved parties have conflicting interests/trust issues? → **Yes** → The customers have trust issues regarding the authenticity of the clothes and they present interest in knowing the origin of their clothes and materials used in the manufacturing process.
(4) Parties can/want to avoid a trusted third party? → **Yes** → Parties implied in the management and accounting of the resources can be avoided.
(5) Rules governing system access differ between participants? → **Yes** → The participants have different attributions within the supply chain, therefore they need different rights to fit their role.
(6) Transacting rules remain largely unchanged? → **Yes** → The shape of the products is changing at each step of the supply chain, but the main characteristics remain the same.
(7) Need for an objective immutable log? → **Yes** → An immutable database is needed because of the desire of the parties for improved traceability.
(8) Need for public access? → **No** → Public access rights are not desirable because according to [2] the raw materials producer is the only one capable of adding new textile mass in the supply chain, therefore requiring different access rights.
(9) Are transactions public? → **No** → The persons interested in the products should be able to track the provenience of the product back to the raw materials producer and should be ensured that the quality of the product is in accordance with the expectations. Although, some of the information (designs, financial data, IP data) should not be shared, because, according to [2], it might affect the competitive advantage of the businesses implied in the industry.
(10) Where is consensus determined? → **Intra-organizational** → The organization responsible for managing the blockchain is the one in charge to name the peers to validate the transactions.

5.5 Dairy industry

(1) Need for a shared common database? → **Yes** → The data regarding the quality and validity of the dairy products are crucial details which have to be known by the customer before the products are consumed. At each step of the supply chain, parts of data are collected from each actor such that the final required shape to be presented to the customer is formed. Therefore, a common shared database is needed.
(2) Multiple parties involved? → **Yes** → As identified in section 4.1.5, there are multiple parties involved.
(3) Involved parties have conflicting interests/trust issues? → **Yes** → The parties cannot entirely trust each other when it comes to the quality and storing conditions of the products, hidden costs a.s.
(4) Parties can/want to avoid a trusted third party? → **Yes** → According to [10] the handling of the traceability process can be reduced, therefore, the parties implied in those activities are superfluous.
(5) Rules governing system access differ between participants? → **Yes** → Each stakeholder has different attributions in the supply chain.
(6) Transacting rules remain largely unchanged? → **Yes** → Similarly as in the other discussed use cases, specifications are being added to the products but the base of the transaction is the same.
(7) Need for an objective immutable log? → **Yes** → An immutable database is needed because modified data within the milk supply chain could lead into potential food poisoning of the customers (in case the temperature or validity data of the products are changed), and substantial monetary losses of the firms implied.
(8) Need for public access? → **No** → There is no need for public access, because, for example, the consumers do not need to modify in any way the data of the product, therefore not needing writing rights. Also, the cow farms should be the only stakeholder able to issue raw material to the database, consequently needing different writing rights compared to the other stakeholders.
(9) Are transactions public? → **No** → Public reading rights are limited because sensitive information is shared within the blockchain.
(10) Where is consensus determined? → **Intra-organizational** → The blockchain distributor is responsible for determining the transaction validators.

6 DISCUSSION AND LIMITATIONS

The usage of the ten step decision framework determined that the implementation of private blockchains in the supply chain sector of the selected industries is a just but not a mandatory choice. The fact that the public reading access can be granted in the wood supply chain indicated that a public permissioned blockchain would also be a good choice if the confidentiality of information stored on the ledger is low. Besides, the choice of using an intra-organizational method to establish the transactions validity is not a must for neither of the industries. If smart contracts can be elaborated in enough detail for all the roles and transaction types within an industry to be covered, it would mean that inter-organizational consensus can be used, which would change the blockchain choice in the wood sector to a hybrid blockchain, thus reducing the level of centralization. Therefore, to respond the main research question of this article, private blockchain is a just choice for the selected use cases, even though one or multiple organizations are chosen to control the supply chain.

The contributions made by this article to the current knowledge regarding blockchain use are:

- We study the current state of art regarding blockchain implementation in the supply sector of five different industries: egg, diamond, wood, clothing, and dairy.
- We identify the existing decision frameworks for deciding whether the use of blockchain is appropriate for different use cases and make a recommendation for such a scheme.
- We reduce the uncertainty when choosing the data storing system by making a blockchain type recommendation for the supply chain sector based on the evaluation of the supply chains of five chosen industries.

A major impediment in conducting our study was the lack of articles researching already implemented blockchain solutions in the selected industries. This represented an issue because it led the research to focus on pilot and prototype studies, which lack detailed complexity in comparison to full-scale implementation cases. Moreover, the analyzed articles cannot encompass all the details and circumstances of the industry they present, therefore the information available in the research studies was a limitation factor. Besides, the blockchain recommendations made for each industry might not apply to other resembling cases, as the data and information to be stored could be dependent on the region and regulations from which the use cases belong. Furthermore, all the decision frameworks found excluded the consortium blockchain from their reasoning, and distinguished only between three types of blockchain (public, private and hybrid), therefore limiting the results of this study to three possible result types.

7 CONCLUSION

In this article, a literature review of blockchain use cases in five different industries was performed: egg, diamond, wood, clothing, and dairy. For each of the selected industries, one use case was selected to be analyzed. The processes and stages of the supply chains of each industry were described, and the relevant data for the stakeholders implied in the processes were identified. The authors of each selected use case proposed a blockchain type to be implemented in the studied field. To assess if those propositions were funded, a literature search was performed to identify a decision tree to help us assess the feasibility of blockchain adoption in different use cases. The ten-step decision path proposed by [43] proved to be an adequate tool for the evaluation task of this article, even if flaws were found in its structure.

When studying the use cases, it was discovered that all the authors of the articles encouraged the use of permissioned private distributed ledgers in the supply sector to diminish trust issues and enhance traceability and resource management. By using the ten-step decision scheme it was confirmed that the decisions of permissioned private blockchains is appropriate in the supply chain of all the selected industries, considering the data to be included in the database and the circumstances of the supply chain. Although, the implementation of consortium blockchain is completely feasible, as there could be multiple organizations responsible for deciding the access rights of the implied parties. Besides, hybrid blockchains could also be adopted if all the possible role scenarios can be covered in the smart contracts. Therefore, more research is needed to establish whether the existing roles in the supply chain can be covered by smart contracts, and what consensus protocol represents the best option for the studied use cases.

Furthermore, it was found that the amount of detail to be uploaded to the ledger depends on the businesses' strategy to be adopted, the trade-offs to be decided, and the scale to which the blockchain is wanted to be adopted (locally/nationally/internationally). The sensitivity level of the data to be included can determine the type of blockchain to be used, hence the level of centralization of the supply chain. Although it ensures more privacy, the usage of private blockchains may become a problem later as the party responsible for maintaining the blockchain service may seek to follow its own interests rather than the common interest of the supply chain, due to the decision power possessed, leading to corruption. Instead, the usage of public blockchain, although more secure and transparent due to its decentralization, may not serve all the desired business requirements. Therefore, the business leaders and practitioners have to consider personal circumstances and make trade-off decisions when seeking to implement the technology within their business if they want to maximize their business capabilities and build a strong, long-lasting relationship with their partners and customers.

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A FIGURES

Fig. 2. Mindmap abstraction of the different types of blockchain applications [9].