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Application of Blockchain Technology in Sustainable Supply Chain Management

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Abstract

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Due to expansion of the supply chain in terms of geographical scope and its complexity in terms of the number of actors and the services provided, utilizing the capabilities of new methods and technologies such as Blockchain, is essential. The purpose of this thesis, in addition to conceptually exploring Blockchain structure, is to investigate its role in improving supply chain performance and its impact on promoting various aspects of sustainability. This research firstly inspects fundamental theories related to supply chain and sustainable supply chain management, afterwards, the Blockchain technology, its features, and how it works. Then, this study focuses on how Blockchain could improve supply chain processes and its sustainability. The research approach is exploratory qualitative, and the data collection is done via primary data that is interview with experts. This study showed that, the most important advantages of using Blockchain as a database are: data accuracy, accessibility, transparency, traceability, trust, and decentralization. This research also came to this result that, Blockchain can play a remarkable role in improving sustainability in supply chain management, such as in labor rights, consumers' rights, equality among stakeholders, reducing environmental damage and emissions, third parties and intermediaries' elimination and unnecessary costs reduction.

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I would like to dedicate this thesis to my parents, who taught me about dreams and how to catch them. Thank you for helping me pushing my boundaries, motivating me when I was feeling down, and brightening my view when all I could see was darkness. Without you and your unconditional love and care, I wouldn’t be where I am now.

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Cheers to the journey ahead!

Bahar Bahramian Dehkordi

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1. Introduction

1.1. Background

There are plenty of goods produced and distributed daily through an intertwined processes of supply chains in which diverse actors and challenges are present. In these chains, numerous services are needed to be provided with appropriate quality, speed, price and etc. During the implementation of various stages of services, it is necessary to record the information, documents and the status of each stage in a transparent, reliable and immutable form. This information including, for example, purchase orders, shipping documents, invoices, payments, provenance of goods and much more than these, should be accessible, traceable and verifiable by all authorized persons in the whole chain, and that is why sharing of information by all effective members is essential to a well-driven and transparent supply chain (Dubey *et al.*, 2017).

On the other hand, in order to achieve the above goals, individuals and companies involved, need to exchange information with each other. While they have their own internal communication system and use it confidently, they may not have enough trust in using external data exchange platforms. In such a workspace, adopting a network that can gain the trust of its members for transparent and honest cooperation will be a great step towards improving the total supply chain performance and decreasing potential risks and losses.

According to Chandan A., Potdar V. (2019), With regard to evaluation of sustainability of the supply chain which begins from raw materials and extend up to consuming of the finished product, it is required to evaluate the entire supply chain performance. This could be accomplished by assessing sustainability condition at each phase of supply chain processes and collecting all results to get the overall sustainability grade. Any participant in the supply chain should share the relevant sustainability information, however, due to lack of reliable network for data sharing and discrepancy in common information, makes it difficult to specify the overall sustainability level in the supply chain. Thus, a transparent and reliable system is required to overcome this challenge so that all concerned parties can trust in each other and the shared information. A system that has the necessary features to

ensure transparent and reliable sharing of information for supply chain participants is Blockchain.

For the first time in 2008, the network called "Blockchain" was developed for the transactions of Bitcoin cryptocurrency. It functioned as a decentralized public ledger and controlled by not a third party like a bank, but handled and supervised by all its members. The network users were able to communicate in a safe and transparent environment and without the possibility of the information manipulation, they were able to exchange currencies peer-to-peer securely. Apart from taking advantage of Blockchain in cryptocurrency business, it can also be used for transactions relevant to documents or any valuable information that may be converted to a digital figure. Today, Blockchain is adopted in many businesses and industries thanks to its remarkable features such as decentralization, transparency, reliability and traceability (Alahmadi and Lin, 2019).

In a Blockchain platform, all authorized supply chain parties can share, trace and verify transaction records independently which leads to transparent and reliable information (Busse, Meinlschmidt and Foerstl, 2017). There is also a significant distinction between Blockchain and a conventional centralized network that is data remains undeletable and uneditable after stored in Blockchain. Given the transparency and other benefits in the follow-up of supply chain processes, the parties involved are more interested in utilizing it rather than traditional methods (Yli-Huumo *et al.*, 2016). For instance, the performance of suppliers and the shipping of raw materials, the place and time of manufacturing, and the situation of storage, all can be monitored and traced by stakeholders without the need of an intermediary entity. Therefore, from the beginning to the end of the supply chain path all concerned parties can access the required information through the recorded data and transactions in the Blockchain and they are confident that the received information is reliable enough due to transparent and tamper-proof performance of Blockchain.

All of these Blockchain features and impact on supply chain and its sustainability are explored in following sections of this thesis.

1.2. Research Method

In this thesis, an exploratory, qualitative research approach was employed to collect and analyze the data. Firstly, a comprehensive literature review of the concepts needed for becoming familiar with the research area, finding out what the research gap was, and then developing the research questions was conducted. The literature review was carried out by reading and analyzing different articles about the previous studies in the field of this research. The review of several articles and other scientific sources could help to realize what has been addressed in the existing studies towards the issue. The result of the literature review was the basis for collecting the primary data.

After carrying out the literature review the primary data was collected that could help with understanding different perspectives of those who have been active in this research area to gain some new insights and empirical material. The primary data has been compiled by taking in-depth interviews with experts, known as one of the proper tools of exploratory, qualitative research method for data gathering in brand new topics.

Thereafter, the data collected from interviews were analyzed through “thematic analysis” approach. Firstly, the interviews were transcribed and experts’ sayings were primary categorized manually by color coding. Then, using Nvivo software enabled the researcher to code collected data in detail and create the final categorization and eventually analyze the data and provide the results.

The research methodology has been discussed in detail in chapter four.

1.3. Research Gap and Research Questions

At the present time, sustainability is considered as a crucial subject in every field such as in business environment (Carter and Easton, 2011). Supply chain procedures are also confronting pressure from different sides to take this concept into account and try to keep a balance between different aspects of sustainability which are environmental, social and economic (Seuring and Müller, 2008).To do so, it is needed that companies and their supply chain management become capable of controlling all the operations and the quality of products and services in each step

of supply chain (Grimm, Hofstetter and Sarkis, 2014a). Such concern arises this question that if the present supply chains would be able to provide accurate information in order to increase trustworthiness, security, accountability and transparency in a supply chain. Blockchain could be the answer to this question (Saberi *et al.*, 2019).

Blockchain technology and its application in other fields rather than cryptocurrencies are considered as a new topic in the research community. Some studies concerning this technology focus on its technical aspects and in a complex way. In general, through these studies, it isn't easy to understand what exactly Blockchain is and how it really works, if the reader doesn't have any pre-knowledge about the topic. Besides, there are various researches over Blockchain technology in different areas of supply chain management and the impact of its capabilities for streamlining the supply chain processes such as logistics, payments, contracts, and such. For example, Perboli, Musso and Rosano (2018; Yuan *et al.* (2018); Alahmadi and Lin (2019); Kamilaris, Fonts and Prenafeta-Boldú (2019); Issaoui *et al.* (2020) are among many others who tried to research in this context. Nevertheless, the studies which strictly address the impact of this technology and its features on sustainability in the supply chain and argue around Blockchain technology effects on social, environmental and economic aspects of sustainability are scarce (Rejeb and Rejeb, 2020a). Thus, effects of Blockchain technology features on sustainability in supply chain management could be considered as the research gap which is illustrated in Figure 1. There are also few studies regarding the future of implementing Blockchain technology on supply chain management. Therefore, in this research, first the Blockchain technology and how it works are explained in a simple way and then a study over the mentioned research gap is conducted to answer two main research questions.

RQ1: How can employing Blockchain technology improve sustainability in supply chain management?

RQ2: What is the future of Blockchain application in supply chain management?

A. What would be the major drivers of applying Blockchain in SCM in the future?

B. What would be the major challenges of applying Blockchain in SCM in the future?

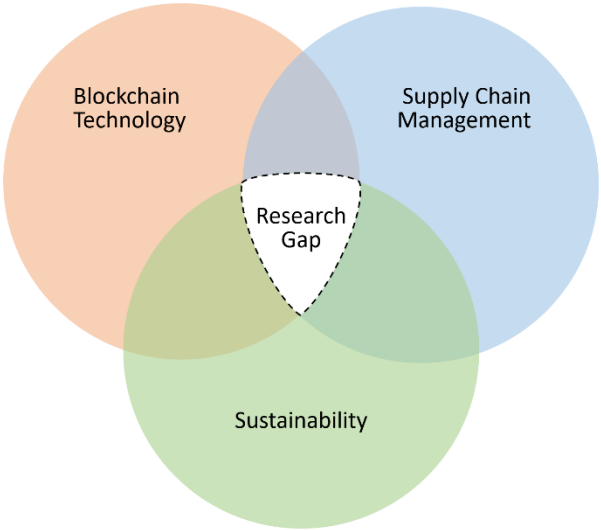

Figure 1. Research Gap

1.4. Research Delimitation

This research neither explores the implementation of Blockchain technology in a supply chain management from technical point of view nor studies how to design Blockchain-based supply chain. Instead, it investigates the problem if this technology is used, how its features could affect and promote each aspect of sustainability. Moreover, this study explores, the drivers and challenges of Blockchain technology application in SCM in future.

In this study, the author selected exploratory-qualitative research method for collecting and analyzing the data, because for new topics such as Blockchain technology and its application in other areas rather than cryptocurrencies, this type of approach is more efficient for collecting and analyzing data in a way to provide a better understanding about the topic (Saunders, Lewis and Thornhill, 2016). Therefore, the data was collected through in-depth interviews with experts based on their experience and not through studying the exact process of Blockchain implementation in SCM processes. Moreover, for conducting the interviews, the interviewees were selected from among those who were expert in both Blockchain and supply chain management to receive more accurate answers.

1.5. Research Structure

The structure of this thesis could be observed in Figure 2. In the first chapter, a brief background of the study is given. The research objective and questions have been stated and reasoned why it was decided to go through Blockchain application to improve sustainability in supply chain management. Afterward, in chapters two, three, and four a literature review over concepts related to supply chain management, Blockchain technology and its effects on sustainable supply chain has been carried out to provide the groundwork of the knowledge related to the topic discussed in this research. In chapter five, the research methodology and tools employed for gathering and analyzing data have been described. Moreover, in this chapter, the experts selected for interviews and their companies are introduced. In chapter 6 the findings obtained from these purposeful conversations including the experts' views concerning different aspects of this research have been presented and analyzed. In the seventh chapter, the results from the data analysis section are compared with what has been said in literature review part. Finally, in the last chapter, conclusion, the research questions are answered and research contribution, the limitations of the study, and future research are discussed.

Figure 2. Research Structure

2. Supply Chain Management

The purpose of this part is to review different definitions of Supply Chain Management (SCM), and then to provide a clear concept of Sustainable SCM (SSCM) considering its evolution as a growing topic. Subsequently, the enablers of SSCM are put forward, and finally at the end of this section, the existing challenges (inhibitors) of SSCM are explored.

2.1. What is Supply Chain Management

The SCM title has become more important as of 1991 due to driving forces such as increasing concerns towards time and quality of sourcing, globalization, and also uncertainty in the environment, which compelled companies to search for some routs of organizing the flow of resources more efficiently (Mentzer *et al.*, 2001). Presently, this takes place via the cooperation of the whole supply chain (Best, 1990).

It has been acknowledged that when a supply chain is well managed, many advantages would be provided for the companies and their stakeholders (Silvestre, 2015). As Lee and Billington (1992) propose, SCM could be considered as a strategic weapon for establishing a long-term competitive advantage via cutting down cost, but without customer satisfaction reduction. This cost reduction happens when different actors of the supply chain focus on consistent and fixed objectives so that extra work and double endeavor is reduced (Spekman, Kamauff and Myhr, 1998).

SCM mainly emphasizes collaboration and reliance. In other words, it is about directing the actual relationships between every party involved in the supply chain to obtain a more cost-effective outcome for all players (Christopher, 2011).

To better understand the concept of SCM, diverse definitions introduced by different authors from various prospects since the 1990s are indicated in Table 1.

Table 1. SCM Definitions

Author	***Year***	***Definition***
Gibson et al.	2005	"The planning and management of all activities involved in sourcing and procurement, conversion, and all Logistics Management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party serviced providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies" (Gibson, Mentzer and Cook, 2005).
Sweeney	2007	"Supply Chain Management is the systemic, strategic coordination of the traditional business function and tactics across these business functions within a particular company and across the business within the supply chain, to improve the long-term performance of the individual companies and the supply chain as a whole" (Sweeney, 2007).
Simchi-Levi et al.	2008	"A set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system-wide costs while satisfying service level requirements" (Simchi-Levi, D., Kaminsky, P. and Simchi-Levi, 2008).
Stock and Boyer	2009	"The management of a network of relationships within a firm and between interdependent organizations and business units consisting of material suppliers, purchasing, production facilities, logistics, marketing, and related systems that facilitate the forward and reverse flow of materials, services, finances, and information from the original producer to the final customer with the benefits of adding value, maximizing profitability through efficiencies,

		and achieving customer satisfaction" (Stock and Boyer, 2009).
Coyle et al.	2013	"The art and science of integrating the flows of products, information, and financials through the entire supply pipeline from the vendor's vendor to the customer's customer" (Coyle, B., Langley, C.J., Novack, R.A. and Gibson, 2013).
CSCMP	2016	"An integrating function with primary responsibility for linking major business functions and business processes within and across companies into a cohesive and high-performing business model. It includes all of the logistics management activities noted above, as well as manufacturing operations, and it drives coordination of processes and activities with and across marketing, sales, product design, finance, and information technology" (CSCMP, 2016).
LeMay et al.	2017	"Supply chain management is the design and coordination of a network through which organizations and individuals get, use, deliver, and dispose of material goods; acquire and distribute services and make their offerings available to markets, customers, and clients" (LeMay *et al.*, 2017).

The word cloud relationships, as could be seen in Figure 3, shows the most common words used in the definitions compiled in Table 1. As a result, the summary of the views would describe the SCM as follows:

Adopting management strategies for systematic approaches to integrating different business activities and processes within the network of participants concerning a supply chain, in which the flow of materials, information, services, and capitals are enhanced in a way that would result in creating more value for customers and stakeholders with minimum cost.

Figure 3. Word Cloud Relationship

Following the proposed description of SCM, a number of its important components could be displayed in the form of a supply chain management framework. As illustrated in Figure 4, three main factors in this framework may make it easier to understand the SCM and its elements (Othman *et al.*, 2015).

These three factors are:

1. The supply chain network architecture, in which the companies/partners are the members of this network.

2. Business processes of SCM that are those activities, which result in value creation for customers.

3. Managerial approaches, through which business processes are systematically run. And they are organized throughout the supply chain.

To successfully implement this framework for managing supply chains, in addition to the three factors mentioned above, three essential questions are also brought in this framework. The first question is about the key members of the supply chain and those who are definitely required to have a relationship with. The second question draws attention to the level of management and the linkage that should be set for

each process connection, and the last but not the least is about what processes are needed to be linked with any of the main members of the supply chain (Lambert and Cooper, 2000).

In the end, successful companies will be those who manage throughout all connections of their supply chain from “their supplier's supplier to their customer's customer” (Lummus and Vokurka, 2000).

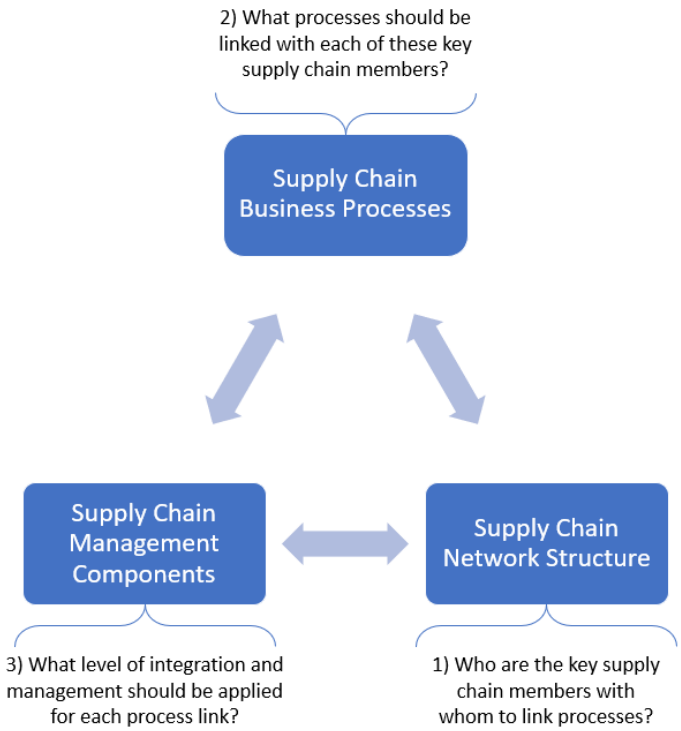

Figure 4. SCM Framework. Adopted from Lambert and Cooper (2000)

2.2. What is Sustainable Supply Chain Management

Nowadays, the concept of sustainability has become a popular subject not only in different social aspects but also in the business environment such as supply chain (Carter and Easton, 2011). In the field of the sustainable supply chain, it would basically mean that its performance should be evaluated not only based on the profits, but also based on the effects that it has on the environment and social system (Gladwin, Kennelly and Krause, 1995; Jennings and Zandbergen, 1995; Starik and Rands, 1995). Moreover, as it is growing in today’s world, the expectations of customers and other relevant actors, push the companies to have

complete responsibility for their activities, and to clarify their ecological and moral behavior (Ashby, Leat and Hudson-Smith, 2012), and obviously as many of the companies are associated with at least one supply chain (Samaranayake, 2005), the competition in the market is mostly between supply chains (Solér, Bergström and Shanahan, 2010), and that is why the organizations responsibilities over environmental and other sustainability issues should go beyond their supply chains to their "products, relationships and processes" (Ashby, Leat and Hudson-Smith, 2012).

Supply chain management has turned out to be one of the most interesting topics for experts and scholars working in the field of sustainability (Dubey *et al.*, 2017), because more than 20% of greenhouse emissions worldwide are caused by around 2500 of the most significant international firms whose supply chains had a major impact on these emissions (CarbonDisclosureProject, 2011). Besides, the worldwide development of businesses forces companies to move through mere economic concerns and issues such as fair working practices or green products (Seuring, 2013). These factors and observations, among present studies about SSCM, obviously underline this fact that both scholars and practitioners have noticed how SSCM concept and the relevant knowledge are crucial, and they believe in its tremendous impact on building the future action plan of an "economy´s growth" (Rajeev *et al.*, 2017).

Studies indicate that the start point for incorporating sustainability into supply chain management was through the integration of "green" principles with SCM activities.

Pagell and Wu (2009) define sustainable supply chain management as conducting particular management activities, in order to increase sustainability in the supply chain and to provide an actual sustainable chain at the end. To present a more comprehensive understanding of SSCM concept, we could define it as the establishment of aligned supply chains via a combination of "economical," "environmental," and "social" factors (aspects) with the main business procedures in the organization to manage all supply chain activities more efficiently and effectively in a way that the needs of stakeholders are met. At the same time, the cost-effectiveness, competitive advantage, and flexibility of the organization are

improved (Ahi and Searcy, 2013). Therefore, sustainability-related issues must be integrated into major SC activities such as buying, designing, production, distribution, warehousing, consumption, recycling, and disposal (Linton, Klassen and Jayaraman, 2007). According to Carter and Easton (2011) and Dyllick and Hockerts (2002), developing the concept of sustainability through the three dimensions mentioned above are broadly approved by authors in different studies. These three elements are based on a sustainability framework, named Triple Bottom Line (TBL), that John Elkington proposed to analyze the "economical," "environmental," and "social" impacts that a firm might have (Kraaijenbrink, 2019). TBL could be a considerable tool for achieving sustainability-related goals (Slaper and Hall, 2011), and to carry out the actual sustainability functions, organizations more and more lean on their suppliers' network to adjust to sustainability directions (Silvestre *et al.*, 2018). To become more familiar with various TBL aspects, each has been explored in bellow.

2.2.1. The Environmental Dimension

Conventionally, the relationships presented in a supply chain have been based on "cost, quality, and delivery," and mostly the emphasis was on forwarding proceedings in SCM such as analyzing production processes and the flow from raw materials to the end-users and factors related to the environment were not taken into account as much as it should have (Simpson and Power, 2005; Seitz and Wells, 2006). However, nowadays, ecological concerns in SC are increasing dramatically, somewhat because of broader discussions about how sustainability-related challenges shall be fulfilled by industries (Zailani *et al.*, 2012). The integration of environmental aspects in supply chain management may result in organizing a set of SCM policies, taking steps, and developing relationships in regards to issues related to the natural environment (Hagelaar and van der Vorst, 2001) such as protecting natural resources, waste reduction and less emissions (Pagell, Krause and Klassen, 2008). As stated by Ji, Gunasekaran and Yang (2014), some of the actions which could be taken in respect of environmental dimensions are: enhancing the precision of "demand forecast," making an investment in technologies related to carbon offset, combined distribution, developing networks of "cross-docking,"

increasing the effectiveness of energy consumption, and designing environmental friendly take-back systems.

2.2.2. The Social Dimension

The social aspect of sustainable supply chain management incorporates people along with organizations as an entire. It should be understood by upper experts and supply chain managers all around the world, that while making decisions, they should take into account all the major values related to humanity and morality, since they have this duty to support a “healthy society”, in which their companies are operating (Panigrahi, Bahinipati and Jain, 2019). The social dimension is considered as one of the essential elements in SSCM of organizations, as in their processes numerous parties with different targets and viewpoints are engaged, and handling all of them is tricky (Matos and Hall, 2007). Sustainability in respect to social perspective, contains issues related to reducing poverty, supporting equity, human rights, and the entire well-being of individuals (Pagell, Krause and Klassen, 2008), which could be improved through the fundamental standards set by the International Labor Organization, which not only supports the workers’ rights, salary, and occupational safety, but also reduces child labor and immoral behavior towards workers (Leire and Mont, 2010) therefore, organizations have to enhance and care about the social and economic condition of the lower levels of society via creating opportunities across SSCM as well (Hall and Matos, 2010).

2.2.3. The Economic Dimension

The main target of any kind of business is to make money and profit. For this reason, adopting sustainability principles into different business processes and activities such as supply chain management should take place in a way that the profitability of the organization is guaranteed as well (Panigrahi, Bahinipati and Jain, 2019). To provide advancement in the long run and preserve economic progress, the managers need to consider the SSCM operations that are beneficial for a long-term period (Carter and Easton, 2011). In other words, economic advantages could be acquired through enhancing social principles and protecting the environment for posterity (Gopalakrishnan *et al.*, 2012). To be able to obtain sustainability in the economic aspect, several vital elements such as relations of cooperation through

exchanging information, maximized “logistics support,” and cost efficiency must be considered (Dubey, Gunasekaran and Papadopoulos, 2017).

Figure 5, shows a summary of the various variables of the three dimensions described above that could help with measuring the sustainability of a supply chain management. Based on this figure, the part that includes all social, environmental, and economic aspects is where sustainability develops.

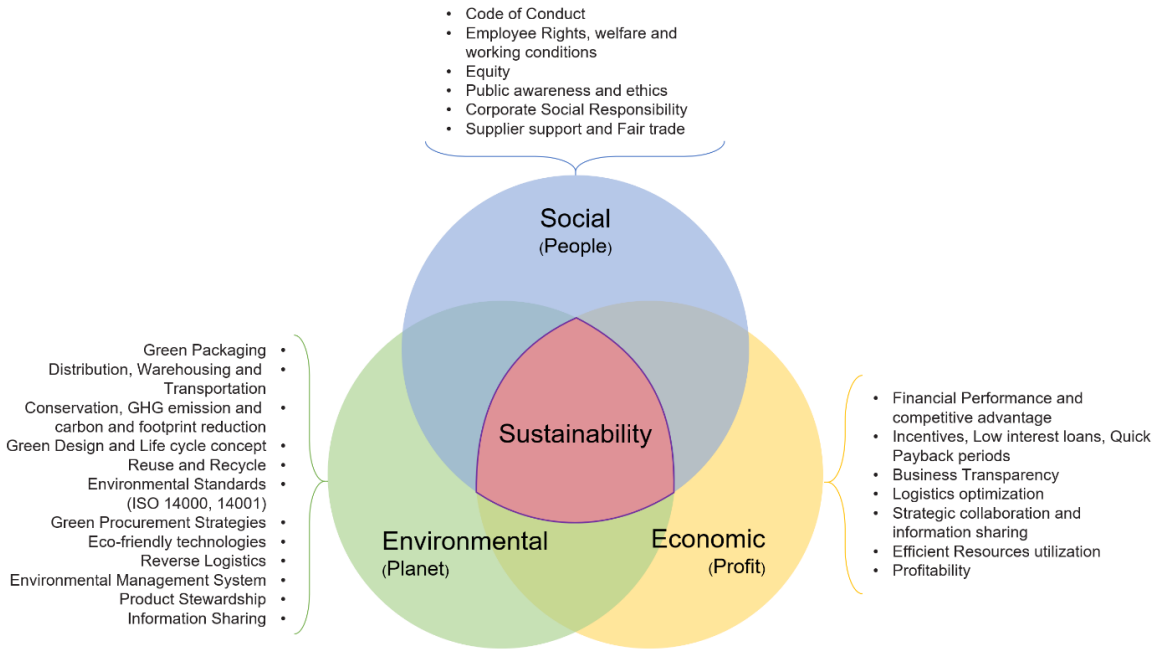

Figure 5. Triple Bottom Line. Adopted from Slaper and Hall (2011); Dubey et al. (2017)

2.3. Enablers of SSCM

Companies should support “environmental sustainability” via redesigning their goods and services lining up with the main values of the firm through forming eco-friendly processes, using raw materials which are sustainable, and recycling and managing wastes in a proper way, utilizing more green means of transport and taking into account the sustainability related legislations by governments (Andersen and Skjoett-Larsen, 2009; Gopalakrishnan *et al.*, 2012).

The core aspect of successful implementation of sustainable practices in SC is the linkage that exists between the company and the suppliers. When this relationship is in a good shape, it would definitely lead to more efficient operations, good

ecological effects, cost-cuttings, energy conservation and less carbon emission (Simpson and Power, 2005; Gopalakrishnan *et al.*, 2012).

An important point about SSCM definitions is that the term sustainability, not only comprises the three main aspects indicated in the mentioned definitions, but also embraces many other subcategories and factors which should be taken into consideration by buying firms concurrently (Busse, Meinlschmidt and Foerstl, 2017). In this part, enablers and factors which are important for developing a successful sustainable supply chain management are described.

Enablers are those elements that could promote the utilization of SSCM practices by the leading company (Sancha, Longoni and Giménez, 2015). According to Oelze (2017), the enablers of SSCM could be divided into internal and external main categories.

2.3.1. Internal Enablers

Previous studies show that one of the primary requirements of developing a sustainable supply chain management is the involvement and support of the top management (Chacón Vargas, Moreno Mantilla and de Sousa Jabbour, 2018). They are known as a powerful political authority in the company who are able to promote SSCM practices (Banerjee, 2003). The next most frequent enabler mentioned in various studies is adopting a set of standards that are related to different issues, such as “environmental management systems,” “health and safety,” “quality,” etc. (Mastos and Gotzamani, 2018). Another major enabler is employee involvement, which, according to Longoni, Golini and Cagliano (2014) is an essential factor for improving sustainability performance in the organization. Enhancing the capabilities across the buying and supply operations is another important component of developing SSCM. Besides, a sustainability strategy needs to be adopted into the organization's culture, which could line up with the overall strategy of the company (Walker and Jones, 2012). Also, drivers related to financial issues such as operational cost reduction and raising financial profitability are known as significant motivations for adopting SSCM practices (Chkanikova and Mont, 2015). As stated by Pullman, Maloni and Carter (2009), the existing sustainability plans, such as ISO 14001 system, could help companies with the economical dimension. Finally, via

developing sustainability in SC, organizations could significantly enhance their image and brand which may lead to more financial benefits and competitive advantages (Chkanikova and Mont, 2015) as a growing number of companies are interested in sustainability to secure their competitive advantage (Starik and Marcus, 2000).

2.3.2. External Enablers

Those elements that are related to the general environment in which an organization is functioning, are known as external enablers (Oelze, 2017). Those include different parties existing in the supply chain of the company, such as consumers, government, suppliers, competitors, media, non-governmental organizations (NGOs) and so on (Park-Poaps and Rees, 2010). According to Wolf (2011), for developing SSCM practices, it is imperative to incorporate all stakeholders into this procedure. In other words, companies need to have a clear understanding of the needs and expectations that stakeholders, especially customers, may have. Therefore, the establishment of a sustainable supply chain management happens, when the relationship between the leading company and other members of the SC is based on “trust” and “transparency” (Awaysheh and Klassen, 2010; Grimm, Hofstetter and Sarkis, 2014a). Another critical external enabler is the national and international legislation frameworks that are made mandatory by law or governments (Faisal, 2006).

2.4. Inhibitors of SSCM

Now, let’s see what the challenges or inhibitors of sustainable supply chain management of our time are. SSCM procedures could be restrained by diverse elements that might vary in different industries in terms of the “size, culture, location, and the number” of various members present in a supply chain (Mastos and Gotzamani, 2018). Generally, according to Abbasi and Nilsson (2012), the challenges related to SSCM are mostly linked to one of these five areas: increase in cost, implementation of sustainable economic growth, altering the existing culture and attitude towards sustainability, the actual pressure regarding handling and managing incertitudes and the complication of challenges.

The same as enablers discussed above, barriers of developing SSCM practices could be divided into two main categories; Internal and External.

Generally, when those elements mentioned as enablers of adopting SSCM actions do not exist in the organization and their supply chain, then they could be considered as barriers to developing SSCM. For instance, in terms of internal obstacles, the lack of top management support, corporate strategy, financial gain, sustainability goals, trust, and limited relationships among SC members are indicated as inhibitors. Besides, some other significant internal obstacles are large investment expenses required for adopting sustainability, absence of resources, capabilities, lack of control over supply chain actors, employing classical methods for accounting, little access to information about sustainability, and cultural diversity between partners due to the reason that they are distributed globally (Bowen *et al.*, 2001; Griffiths and Petrick, 2001; Min and Galle, 2001; Rao and Holt, 2005; Ageron, Gunasekaran and Spalanzani, 2012; Walker and Jones, 2012; Grimm, Hofstetter and Sarkis, 2014b; Chkanikova and Mont, 2015; Mastos and Gotzamani, 2018).

Regarding external inhibitors, when there is no governmental support and control for setting out sustainability goals, and customers are not conscious and interested in sustainability practices, it would be challenging to develop SSCM in organizations. On the other hand, the lack of a stable economy, a well-structured market, proper substructure for logistics, and customers' preference for the lower price may restrict the application of SSCM. Additionally, the competitive constraint in the market and the absence of strong commitment among SC members are recognized as other external barriers (Lambert and Cooper, 2000; Orsato, 2006; Walker and Preuss, 2008; Giunipero, Hooker and Denslow, 2012; Grimm, Hofstetter and Sarkis, 2014a; Ansari and Kant, 2017; Ghadge *et al.*, 2017; Mastos and Gotzamani, 2018).

With regard to significant challenges towards various sustainability aspects such as pollution, public health, means of production, proof of provenance, reliable contracts, consumer rights, corruption, illegal trade, workers’ rights and many more, which are globally and strongly under consideration, at least that is what is claimed, the fairly new technology in digitalization namely Blockchain could propose remarkable solutions and promote SSCM due to its unique features.

3. Blockchain Technology

To explore the Blockchain technology and its capabilities, we first introduce it and then describe its features. Next, its basic function and structure are explained in order to show how it can be applied for different objectives. Thereafter, the solutions to some typical cases addressed by Blockchain and smart contracts are studied, and finally their effects on Sustainable Supply Chain and the relevant challenges are discussed.

3.1. What is Blockchain?

Suppose there is a network involved in exchanging information or transactions. This would traditionally need a centralized system to manage and serve as a link for conducting any communication between the parties (Gonczol *et al.*, 2020), but after more than two decades of scientific efforts looking for enhancing techniques and theories, a huge progress emerged in the field of distributed (peer-to-peer) computer networking and data privacy. As a consequence, a modern technology known as 'Blockchain' popped up (Morabito, 2017), which initially developed and became popular for cryptocurrency and bitcoin in the course of the financial crisis in 2008 by Satoshi Nakamoto. While its main goal was on applications related to financial transactions, its unique characteristics, however, motivated wider uses also in other fields (Kouhizadeh and Sarkis, 2018). In Figure 6, various types of the Networks are illustrated.

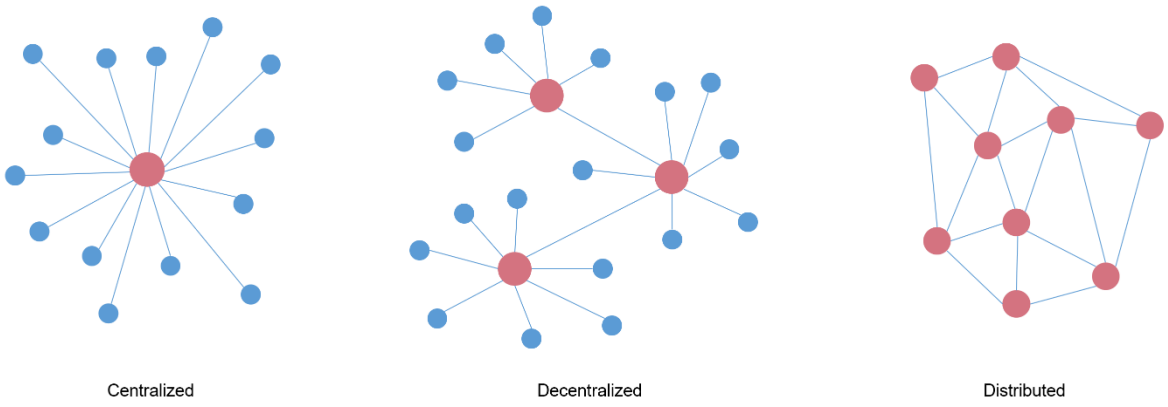

Figure 6. Three Networks Comparison. Adopted from Moro visconti (2019)

Blockchain is actually a digital database for a durable and tamper-proof storing and tracking transactional data records. This special type of database is a distributed

ledger whose data are shared, replicated, synchronized and kept by the members of a decentralized system, where each participant holds a copy of the data, that can be verified and refreshed at the same time, enabling them to monitor and stop any probable point of failure (Chang, Iakovou and Shi, 2020). As the name indicates, Blockchain contains a connected series of blocks, which carry time-stamped transactions (Tijan *et al.*, 2019). it consists of data blocks which are stringed and include information analogous to our DNA (Tieman and Darun, 2017).

Besides, the data protection and verification does not rely on third-party service providers, and the blocks of data are organized via relevant software programs that enables the data to be sent, processed, saved, and shown appropriately for all the participants in the network (Kamilaris, Fonts and Prenafeta-Boldú, 2019). It may also be employed in transactions used for exchanging digital money, financial or personal information, results of a system's operation, health situation or any other target data that can be transmitted digitally (Jovović *et al.*, 2019). Modifying the information in a Blockchain is not mathematically feasible due to its nature (Jamil *et al.*, 2019). In addition, as a shared ledger, it can be checked by the members in the system, and after writing the information therein due to a public monitoring, it can hardly be altered. If we use a similar comparison, we can say: it is easier to steal a candy from a candy bowl held in a secluded area, than from a candy bowl placed in a local market being watched by thousands of eyes (Crosby, 2016).

World Economy Forum (WEF) ranked Blockchain technology in the third place of the top ten emerging technologies in 2016, and many Information and Communication Technology (ICT) division experts believe that by 2025, at least 10 percent of global GDP will be stored in the Blockchain network (Grewal-Carr and Marshall, 2016). Blockchain technology may be named as the next industry revolution (Amr *et al.*, 2019).

3.2. Blockchain Features

In recent years, Blockchain technology (BCT) has been utilized significantly and has established frameworks for diverse implementations in different contexts. Its features are well suited for applications in the fields where safe transactions need to be done. Peer-to-Peer transactions together with consensus processes in

Blockchains, guarantee safe identification and authentication in different forms of distributed databases without the need for a trustworthy third party. These features are very crucial in businesses with general mistrust and susceptible to corruption (Ølnes and Jansen, 2018).

The main features of the basic Blockchain, firstly used for cryptocurrencies, are listed below. This could also be employed for other applications by amending and adjusting some of these features (Batwa and Norrman, 2020):

- The whole database and its entire history are potentially accessible to each user in the Blockchain.
- The transactions between nodes are done peer-to-peer without any intermediary, and every user can check the records of the transactions individually. Nodes are any participant of a Blockchain who has a copy of the Blockchain database on his/her computer and interacts in the network is a node (Braun-Dubler *et al.*, 2020).
- Each party in the Blockchain has a specific address, and they may opt to stay anonymous or to reveal their identity to the others.
- Consensus algorithms are implemented to ensure that the database records are immutable and chronologically organized.

Kumar, Liu and Shan (2020) point out that the Blockchain helps parties to run a business transparently through a digital ledger of transactions which is distributed, decentralized, tamper-proof, and unchangeable. The major attributes of Blockchain are described in detail as follows:

3.2.1. Decentralization

It is the Blockchain's basic function that ensures the data no longer has to depend on a centralized entity for being registered, processed, modified, and distributed (Lin and Liao, 2017). The transactions can be processed peer- to- peer, without a central body control. This will lead to a meaningful decrease in equipment expenses and the overheads thereto. Moreover, this system is not affected by a single point

malfunction, therefore when any party returns to the network, after being offline for a while, it can synchronize with the latest ledger through other online parties (Alahmadi and Lin, 2019).

3.2.2. Tamper-Proof

The recorded data will be saved permanently and it is almost impossible to tamper with it, because at least 51% of nodes needed to be controlled by malicious users in order to manipulate the data in the Blockchain network (Lin and Liao, 2017). It is also too difficult to manipulate the transactions recorded in the network, because their validity has to be checked first and then registered in the blocks. Besides, to add this block to the chain, its validity should be checked by other users and therefore any falsification can be easily identified (Alahmadi and Lin, 2019).

3.2.3. Anonymity

Blockchain technology has solved the peer-to-peer confidence issue. Consequently, data transmission and transactions may be done anonymously, and just the user's Blockchain address has to be identified (Lin and Liao, 2017).

As such, every party can have an address to interact with the network, and even dissimilar addresses can be used to conceal their identity. Thus, no private detail is stored in a central body. Nevertheless, the Blockchain's underlying restriction cannot ensure full privacy protection, especially in permissioned Blockchains (Alahmadi and Lin, 2019).

3.2.4. Transparency and Traceability

The Blockchain information is transparent, because Blockchain data record is normally visible to any node, and also visible when the data is updated (Lin and Liao, 2017). Checking the validity of each transaction, as well as registering the timestamp for each of them, made it simple to search and track previous records throughout the network via any node which consequently promotes the reliability and traceability of the data under process (Alahmadi and Lin, 2019).

Kim and Kang (2017) emphasize the various Blockchain technology features such as the lower transaction rate, fast operation, improved privacy and security. They

mention that it is a shared ledger, distributed throughout a network and not owned by one entity, thus no need for a trusted intermediary to check the validity of the transaction and its authentication which subsequently leads to lower transaction expense. Another advantage of Blockchain technology is the data protection. There is a relatively low chance of tampering with the data since everything is handled by the network rather than just one entity. Except where the rules contained in the Blockchain protocol allow, the records history therein is too difficult to change. Additionally, transactions in Blockchain are handled more quickly than systems with conventional data transfer method.

3.3. Blockchain Foundation

A Blockchain is founded mainly on cryptography that is hashing and encryption (Conley, 2019). In this section, these two significant functions and their part in Blockchain foundation are conceptually argued.

3.3.1. What is Hashing?

Hashing is an essential function in Blockchain system, which is formed through a mathematical operation. This is a one-way function which converts an input of any length, but giving an output of a fixed length and in a way that the same input always leads to the same output. However, the original input data is impossible to be retrieved from the output data. (Di Ciccio *et al.*, 2018)

A string of any length of data or file is transformed via a hash function to a fixed-length output string, and often the output seems like a compact version of the input data. That is why the hash output can be named a “message digest”. (FIPS PUB, 2009)

The goal of hashing is not to conceal data, but to check that the input has not been altered at all. You cannot "unhash" the output of the hashing function in order to detect what the relevant input has been (Conley, 2019).

Now let's see what the hashing means in practice:

Table 2. Hashing Examples

Input	**Hashed**
Bahar	69d2e8689c15c0fcd82cc1d0617ebbe1ffec16759487331a9a84d8fdbcde37da
I study at LUT	27dd943958cb8ad2ff4e2a91318d075fc4e7fb400bf32ebe7bec507dbc2158fe
I Study at LUT	29b10dc9a91b021f9cd31452018be8bc7bcbcab44d99d6a32f2ff6666e4470bd

As can be seen in the table above, my name "Bahar", has the same hashed length as "I study at LUT" and as "I Study at LUT", irrespective of how many and what characters are in each of them (Yaga et al., 2018). It is good to mention that, "I study at LUT" and "I Study at LUT" have different hashes just due to using capital "S" in the second one. All three examples have been hashed by Keccak-256 hash generator which always has a 64-character length output with a hexadecimal format.

The hash function features can be summarized as follows (Conley, 2019):

- Hashing any data, regardless of its length, results in a fixed-length hash
- Even very similar data, lead to completely different hashes unpredictably
- The hash of any data is always the same, i.e., the same input data definitely generates always the same hash.
- Recovery of a data from its hash is impossible.

The role of hashing in Blockchain

As mentioned before, the Blockchain comprises of data blocks linked together. This linkage is done by hashing of the data in the immediately previous block (Alahmadi & Lin, 2019). Let's see how the blocks are chained one after the other by hashing, using below story:

Act 1: In the very beginning, let's assume we have a group of people who would like to have some kind of transactions, whatsoever, with each other. They decide to assign one of the group members called "Tony" to keep a table of all transactions in a ledger as shown in Table 3.

Table 3. Act 1 Scenario

1. John paid 15 Euros to Emma
2. Alex paid 20 Euros to Sam
3. Emma paid 10 Euros to Kate
4. ……

Act 2: Tony found out that someone has manipulated the ledger as shown in Table 4.

Table 4. Act 2 Scenario

1. John paid 15 Euros to Emma
2. Alex paid 20 Euros to Sam
3. Emma paid ~~10~~ 4 Euros to Kate
4. ……..

Act 3: In order to stop the manipulation of the ledger, Tony planned to insert a hash of each transaction, using Keccak-256 hash generator, in the ledger as shown in Table 5.

Table 5. Act 3 Scenario

1. John paid 15 Euros to Emma
9fc2410d37d9ffd2abaf1db37f24f9f90011f8fef1ab3a3e82fc7360085c1a9f
2. Alex paid 20 Euros to Sam
a5a02979dd233433104e9272408e50ee4bdacfdef9368a08e492c57c63809d8c
3. Emma paid 10 Euros to Kate
385172f4b29d35570894e820985ad08f1735290bed4ab8c8fb464e3c77fe1614
4. ……..

Now, it would not be sufficient just to change a record, without changing its hash simultaneously (Yaga et al., 2018).

Act 4: Tony surprised that despite of hashing each transaction, the relevant hash was manipulated too by someone as shown in Table 6.

Table 6. Act 4 Scenario

1. John paid 15 Euros to Emma

9fc2410d37d9ffd2abaf1db37f24f9f90011f8fef1ab3a3e82fc7360085c1a9f

2. Alex paid 20 Euros to Sam

a5a02979dd233433104e9272408e50ee4bdacfdef9368a08e492c57c63809d8c

3. Emma paid ~~10~~ 4 Euros to Kate

~~385172f4b29d35570894e820985ad08f1735290bed4ab8e8fb464e3e77fe1614~~

0fc85ad28c1f0c63341b4b15d098b260bb792f517369f315cb40d675388898e0

4. ……..

Act 5: Tony decided to make documentation of each transaction more difficult. He inserted a hash, created from the hash of (each record + the hash of the previous record). Therefore, each record as shown in Table 7, now depends also on the former record (Di Ciccio et al., 2018).

Table 7. Act 5 Scenario

1. John paid 15 Euros to Emma

9fc2410d37d9ffd2abaf1db37f24f9f90011f8fef1ab3a3e82fc7360085c1a9f

2. Alex paid 20 Euros to Sam

9fc2410d37d9ffd2abaf1db37f24f9f90011f8fef1ab3a3e82fc7360085c1a9f
4167bef502b637212e5d21cc98c6af24c565bb40759902906ec0cc311878a603

3. Emma paid 10 Euros to Kate

4167bef502b637212e5d21cc98c6af24c565bb40759902906ec0cc311878a603
c6ccf5780bb5ca83da0a72708fc498bfb16a9017e3a310993df119d2b681db1c

4. ……..

Consequently, if someone wanted to manipulate any record, he or she had to spend a lot of time to change all the subsequent hashes which for ledgers with many records would be practically unfeasible. This is where the foundation of a Blockchain and its power are laid, that is linking each block through the hash of the data in the former block.

3.3.2. Transactions

A transaction is an interaction between various participants in a Blockchain network. For example, a transaction with cryptocurrency indicates its transfer between users in the Blockchain, but for business-to-business operations a transaction may be a physical asset-related information to be transmitted to the parties.

Digital Signature

Concerns about security and privacy of digital communication or information sharing, long predates the emergence of Blockchain. As a remedy, in the year 1976, Diffie and Hellman proposed the use of Public-key or Asymmetric encryption. The system is based on a two-key combination, a public key and a private key (Badzar, 2016).

- **Symmetric and Asymmetric encryption:** In Symmetric-key encryption, the message is locked using a key, and the same key is used to unlock. But, Asymmetric-key encryption uses two different keys for locking and unlocking, namely private key and public key.

It is good to mention that Symmetric encryption can only provide confidentiality, while Asymmetric encryption can support confidentiality, authenticity and non-repudiation (Tiwari, 2020).

- **Private Key and Public Key:** As cryptographic tools, they are used for a cryptographic asymmetric algorithm. The private key is exclusive to the owner, and is not publicly disclosed and is used for making a digital signature whose validity can be checked via the relevant public key. The public key, as it sounds, is available to the public.

Transactions Verification

Normally, the users are identified in the Blockchain network by their key pair, that enables them to sign transactions in the Blockchain. That is why a public and private key is created for each network member at the time of their registration (Abeyratne, 2016). Asymmetric-key cryptography makes confidence between users who do not know or trust each other by offering a process for checking the validity and authenticity of transactions (Yaga et al., 2018). The participants use Asymmetric-key cryptography to sign the transactions before sending them to the network (Hackius and Petersen, 2017). Using the private key, all forms of messages are signed digitally by the sender, and the recipient can verify their authenticity by the public key of the sender (Alzahrani & Bulusu, 2018). In the other words, a common digital signature has two stages, signing the message and its verification as illustrated in Figure 7 (FIPS PUB, 2009).Suppose “A” is going to submit a message or document to “B”. In the signing stage, “A” generates the hash of the message or document, then encrypts it using own private key, and submits the original message or document with its encrypted form to “B”. In the verification stage, “B” the receiver, generates the hash of received message, let’s call it H_B, and at the same time, “B” decrypts the received encrypted message using public key of “A”, which results in hash value of the genuine message of A, let’s call it H_A. Lastly, “B” compares H_B and H_A, and if they equal, it can be concluded that no change was made to the message or digital document and therefore its authenticity is approved (Alahmadi and Lin, 2019).

It should be noted that user's public/private key in permissioned Blockchains, are usually created and approved by the authorized body of the network (Meng et al., 2018).

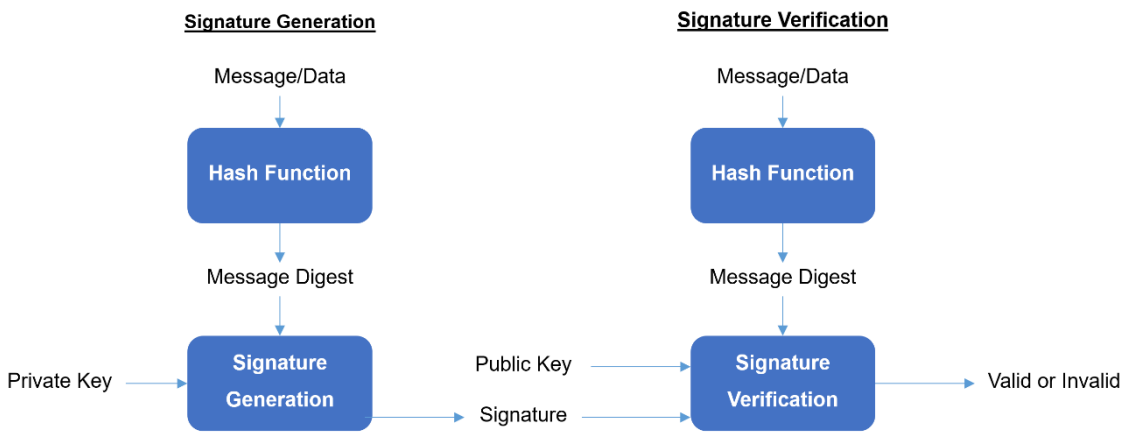

Figure 7. Digital Signature Processes. Adopted from FIPS PUB (2009)

3.4. Blockchain Structure

A Blockchain comprises several blocks linked together sequentially using a hash function. Each block in this chain includes a hash of immediately previous block data named "Block Header", and also some other transactional data as shown in Figure 8. Each immediately previous block is known as "Parent Block", and the very first one is "Genesis Block" because it has no parent (Alahmadi & Lin, 2019).

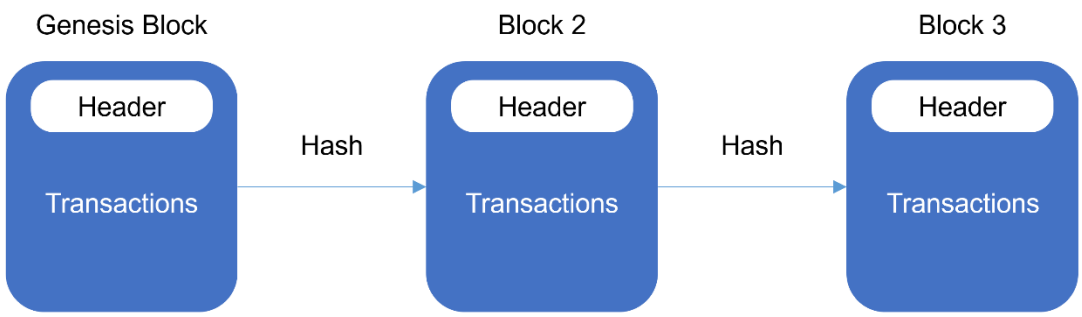

Figure 8. Blockchain Structure. Adopted from Alahmadi and Lin (2019)

Being more specific, According to Zheng et al. (2017), A block is made up of a header and a body as shown in Figure 9.

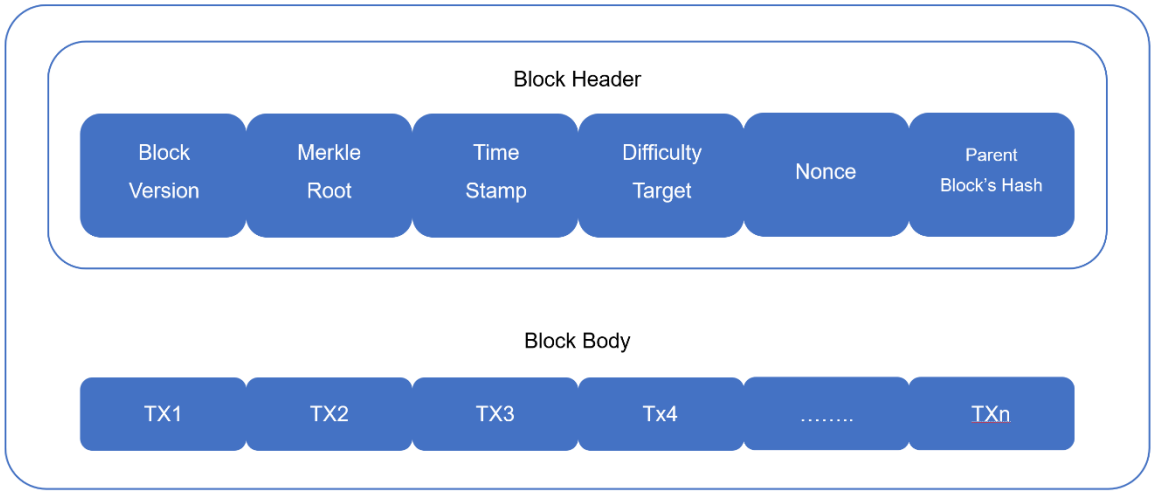

Figure 9. Block Header and Block Body. Adopted from Zheng et al. (2017)

3.4.1. Block Header

A header in a block is a crucial part, because its hash value is used as a unique index for identification of that block in a Blockchain (Zhang et al., 2020) and in addition, its hash is adopted to generate the hash value of the next block, and that is how the next block is linked to the former block (Lee et al., 2016).

Let's go in to detail of a block header content considering that every Blockchain can determine its own data fields (Yaga et al., 2018), nevertheless, many Blockchains use the following data as block header content:

Block Version

It is pertaining to the software version producing the block (Oliveira et al., n.d.).

Merkle Root

For more efficient and safer encryption of Blockchain data, every transaction in a block is hashed, then each pair of relevant hashes are linked together, and this will continue till there is one hash for all transactions in a block, as illustrated in Figure 10. In this figure, "T" represents a transaction, and "H" a hash.

On the bottom row, the hashes are named "leaves", the intermediate ones referred to as "branches," and the one at the top is the "root". That is why it was named “Merkle Tree” and its root “Merkle root”, after Ralf Merkle, the American inventor and computer scientist who proposed the procedure in 1987.

Since it forms a tree-like structure of all transactions hashes, it implies verifying every transaction on that block via its merkle root (Frankenfield, 2020).

For instance, when an untrusted user tries to switch a transaction in the bottom of a Merkle tree to a false transaction, this would cause the node above to change, and then again sequentially this change will go on to the root.

Changing the root and consequently the hash of the block, will cause the system finds it as a totally altered block, and therefore, it will not be confirmed (Buterin & Vitalik, 2014).

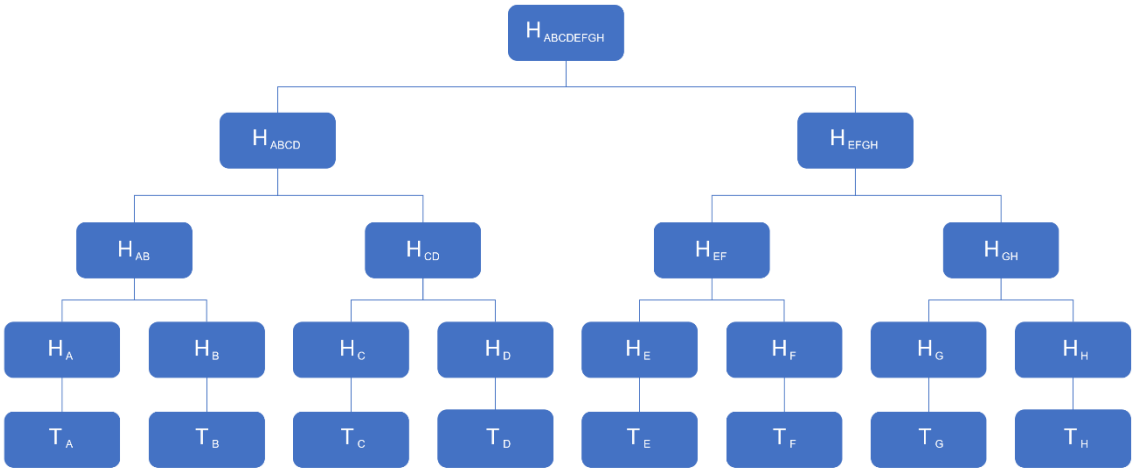

Figure 10. Merkle Root. Adopted from Frankenfield (2020)

Timestamp

The timestamp represents the estimated time of block creation (Patnaik et al., 2018), and in this way, confirming and registering each Blockchain transaction with a timestamp, helps participants to check and trace easily previous records in the distributed network. The present timestamp, is the past seconds from 1st January 1970 at Time 00:00 UTC (Alahmadi & Lin, 2019).

Difficulty target

It determines the difficulty of target hash, and it means that the header hash, should be less than this target. In the other words, there must be enough zeros at the left side of the generated block header hash, as dictated by difficulty target (Lee et al., 2016).

Nonce

Each participant of the network tries to generate a block header hash value in compliance with the difficulty target, and in order to do so, the nonce number in the header should be altered randomly and continuously until the header hash be equal to or less than the target hash (Zheng et al., 2017).

The application of nonce, as described above, is for a Blockchain like Bitcoin. The nonce may or may not be used in other Blockchain networks, or its use may be different from trying to solve a hash puzzle as it is in Bitcoin Blockchain (Yaga et al., 2018).

Parent's block hash

It is the hash of immediately previous block, which actually links it to the next block. This hash works as a reference, and it is evident that there is no parent's block hash for the genesis block as it is the first one in the Blockchain (Alahmadi & Lin, 2019).

3.4.2. Block Body

There are transactions details and other data in a block body (Yaga et al., 2018). Considering the above-mentioned key items in Blockchain structure, it is clear that the main digital information saved in blocks are:

1. The most recent transactions, such as the date, time, the details of each transaction and such.
2. The block header's hash which is a unique identification code that distinguishes each block from other blocks.

3.5. How is Blockchain formed?

A Blockchain is formed by adding the blocks one after one, linked by the hash of immediately previous block and through taking following steps (Lin and Liao, 2017):

1. The new transactions are registered and submitted by sending nodes to other nodes in the network.

2. The sent transactions are checked by receiving nodes, and in case of accepting their validity, they are saved in a block.

3. The nodes execute the appropriate consensus model to the block.

4. After consensus, the block admitted by the nodes will be appended to the chain.

3.6. Consensus Algorithm in Blockchain

There is no central body present to check and confirm the transactions, but any transaction is deemed entirely protected and validated in the Blockchain. This is only feasible due to the existence of the consensus algorithm which is a central component of every Blockchain. Consensus algorithm is a mechanism that makes sure Blockchain nodes have reached to an agreement on having received the same message, and also ensures the correctness of the latest block added to the chain (Lin & Liao, 2017).

According to Nguyen and Kim (2018), to make the system trustworthy in the process of decentralization, there are entities who keep the ledger, and are called nodes or parties. If any transaction is sent, and the sender confirmed it by signing its digital signature within the transaction, and some nodes validated its authenticity, then it will be entered in a block. To add a block of transactions to the chain, every node tries to distribute that block to other nodes to enable them to add it to their current chain, but this will lead to a confusion. To avoid this problem, a solution namely “consensus algorithm” is employed by all nodes to determine which block would be added and which node is allowed to add the relevant block to the chain.

To date, several consensus algorithms have been introduced. Two of them are more popular which are described briefly below:

3.6.1. Proof of Work (PoW)

This is the procedure: the nodes build a block with new transactions, and by altering randomly and continuously the “nonce” number in its block header, as described before, they try to calculate the block header hash. If the result is smaller than or equal to the target hash, which is determined by difficulty target, then the node that finds the desired nonce faster than the others will append the block to the chain.

The process of solving the above puzzle is called “mining” and those who try to solve it, are named “miner”, whose computers consume a large amount of electrical energy to mine (Morabito, 2017).

3.6.2. Proof of Stake (PoS)

The nodes who want to take part in the process should deposit a certain amount of cryptocurrency as their stake into the network. The more amount of the stake, the more chance of being selected as the node adding the validated block to the chain. To prevent the algorithm from favoring only the richest nodes in the network, more special methods are applied to the selection process. For example, the Coin Age Selection system chooses nodes on the basis of how long they have staked. The selected node is determined by multiplying the amount of the deposit by the number of the days on which the deposit was kept as stakes (Binance Academy, 2020d). It is worth mentioning that PoS is an energy-saving consensus algorithm compared to PoW (Zheng et al., 2017).

3.7. Types of Blockchain

Blockchains can be divided into three groups.:

1. Public: Anybody can see the transactions taking place in the network and can verify them. Joining the relevant network is simple through downloading the required software and the term “permissionless” is often used along with “public”, implicating that nobody can obstruct the route of participation. Cryptocurrencies use Public Blockchains as their platform.

2. Private: Since it is a permissioned network, participants are limited, and there are rules that specify who has permission to read and write in the Blocks. Private

Blockchains are more applicable to business environments, where an organization wants to employ it with allowing limited access externally.

3. Consortium: It is between private Blockchain and the public one by mixing their elements. The most significant difference that could be seen from either type is in validation. In contrary to public Blockchain, where everybody could validate blocks or unlike a private one, where only a certain body would select block validators, a consortium Blockchain considers a number of similarly-influential parties who can validate the blocks.

The consortium Blockchains are flexible, as chain access can be restricted to validators, viewable only by designated participants, or by both. It is evident, that the appropriate Blockchain type is chosen on the basis of what application we are expecting and where we apply it (Binance Academy, 2020c). Figure 11 shows Blockchain Types.

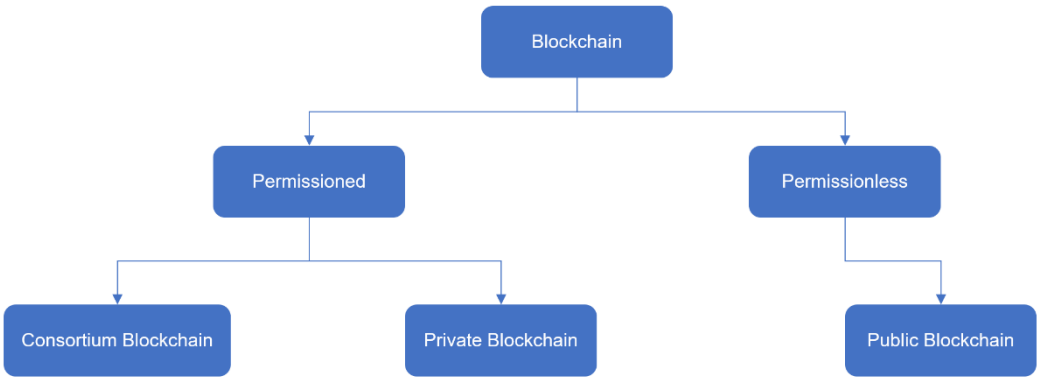

Figure 11. Blockchain Types

3.7.1. Comparisons Between the Three Types of Blockchain

As mentioned before, there are three types of Blockchain: Public, Private and Consortium. In the Public one, all information is openly available, and anyone can engage in the consensus process. Despite this, in a consortium Blockchain only some pre-selected nodes may take part in this process, while for a private network, only certain nodes in a particular organization will be authorized to participate in the consensus mechanism. A private Blockchain is centralized, because it is entirely regulated by one entity. As the consortium type is developed by a number of groups, it is partly decentralized, because only a limited number of the nodes will be opted

to participate in the process. Table 8 indicates the distinction between the three forms of Blockchains (Zheng *et al.*, 2017).

Table 8. Comparison among public, consortium and private Blockchain. Adopted from Zheng et al. (2017)

Property	***Public Blockchain***	***Consortium Blockchain***	***Private Blockchain***
Consensus Determination	All miners	Selected set of nodes	One organization
Read Permission	Public	Could be public or restricted	Could be public or restricted
Immutability	Nearly impossible to tamper	Could be tampered	Could be tampered
Efficiency	Low	High	High
Centralized	No	Partial	Yes
Consensus Process	Permissionless	Permissioned	Permissioned

3.8. Blockchain Use Cases

In the beginning, the Blockchain appeared to be a new high tech for financial uses, but recently, the researchers' focus has turned to applying the Blockchain technology to other fields too (Perboli et al., 2018). This part is a summary of the Blockchain use cases in different areas.

3.8.1. Energy Trade

Major power producers have dominated the industry and have until recently led the market and still account for 94 percent of the electricity generation sector (Murkin et al., 2016). Nevertheless, owing to reduced prices of green energy and improved prosumer activity, this demand opens up more possibilities for individual residential electricity producers, especially those who utilize solar photovoltaic panels in their homes and who generate a surplus of what they need to power their residence, to supply the extra electricity to their neighbors or to the grid. Trades are currently performed via major power producers, but microgrids handled by Blockchain have made this trade possible from the prosumer to the customer directly, and in a transparent way (Li et al., 2019).

3.8.2. Internet of Things (IoT)

IoT technology is essentially the internetworking of typically some groups of sensors and devices that exchange information via the internet with data processing devices. Level sensors, heart rate monitors, Gas sensors, and home security systems are examples of such sensors and devices. IoT technology advances, simplify remote control, automation, and status monitoring of a broad range of instruments and apparatus that can be utilized in diverse areas.

It's a perfect fit for Blockchain and IoT, because Blockchain is a decentralized system, and IoT networks are usually used to gather data from distributed sensors and devices. Blockchain helps companies to store securely the data that IoT networks are gathering, and the communications they have between each other. Blockchain provides a perfect environment for machine-to -machine (M2M) interaction. Since Blockchain is a technology focused on enabling accurate and safe transactions, it makes perfect sense to integrate it with IoT to ensure transparency, accuracy and protection of the data. That is why so many businesses have invested a lot of money into a Blockchain-powered IoT network (Binance Academy, 2020b).

3.8.3. Insurance

A claim takes a very long time to process conventional insurance scheme and there is much uncertainty that occurs during processing between various parties. A smart contract-based framework using Blockchain technology will simplify the process and makes everything more transparent and secure without a third-party involvement. As such, whenever smart contract terms and conditions are met, it activates the related events automatically (Mohanta & Jena, 2018).

Probably the most significant Blockchain insurance usage is via smart contracts. These contracts let people and insurers to assess claims in a clear and secure way. All contracts and claims can be registered and authenticated by the network which would nullify false claims, for example, numerous claims over same incident would be ignored by the Blockchain (Businessinsider, 2020).

3.8.4. Cargo Monitoring

Most logistics business documentation is still paper-based and cannot be utilized to the maximum capacity with adopting IoT systems, but without using Blockchain technology. Blockchain streamlines the development of a smart Bill of Lading (B/L) which is digitally recorded and exchanged with various parties involved in the shipping of the goods. All parties may therefore check if the terms and conditions stated in the digital B/L is complied with the data collected from IoT sensors. Moreover, since Blockchain saves data in a transparent and unchangeable database, there is no way to alter the data once it is stored. Thus, the regular paper-based operations can be digitized and the administrative costs related to supervising the cargo handling will be decreased (Soni, 2020).

3.8.5. Healthcare

Using newly developed technologies, a human can track his or her health, and plenty of appliances already provide data for checking various human medical conditions. This data can be gathered and processed locally and the relevant information can be stored in a Blockchain as a digital ledger which can protect patient privacy, and at the same time being shared by required parties. In that system, a smart contract can be used to activate necessary events based on pre-defined patient's conditions (Mohanta & Jena, 2018).

Blockchains can also provide a reliable mechanism for monitoring pharmaceutical products through the whole production and distribution process, thereby reducing the extended drug counterfeiting issue. Blockchain technology may also be used to verify correct storage and shipping conditions, or to authenticate medication quality in combination with IoT devices used to calculate variables such as temperature.

Blockchain may also be utilized to tackle medical insurance fraud, a problem that is supposed to cost billions of dollars annually to the healthcare systems. Unchangeable records saved on Blockchains and exchanged with an insurance company can eliminate some of the most prevalent forms of fraud, like billing for none-done procedures and charging for needless services (Binance Academy, 2020a).

3.8.6. Government Services

Despite many attempts to improve government services mechanism, it is still not clear and secure enough. Usually, the system is based on an IT platform which is highly centralized and consequently makes it more prone to external attacks. Furthermore, the system is heavily governed by persons which makes it vulnerable to error and leaves space for fraud. The decentralized Blockchain will answer the challenges in this regard and can improve protection, Immutability, accuracy and system accountability. It can be applied to a broad variety of government services, where process is not appropriate, and needs numerous individuals' involvement which leads to minimum transparent governance. In this case, the technology of Blockchain would improve accountability, confidence, cut costs and streamline the process (Diallo et al., 2018).

3.9. Smart Contracts

The conventional contracts are generally the agreements that specifically describe the contracting parties, a service provided against some form of reimbursement, and a number of contractual clauses such as delivery dates, penalties, payment terms, and etc. One of the main issues with the conventional form of the contracts is that they are not detailed enough and therefore the conflict between involved parties is highly probable. For example, one party may expect the presentation of a particular material certificate before paying the relevant cost, but the other party may believe the reverse. Such deadlocks may lead to expensive dispute settlement, or even a failure of the entire deal. Besides, in international circumstances, the implementation of conventional contracts is often too difficult, time-consuming or sometimes impossible at all (Norta, 2017).

In order to streamline contractual processes and prevent the probable disputes, "Smart Contract" emerged with the ability to safely automate many of the interface-related procedures, and the self-implementation of agreements in the context of enforceable programs (Thomas et al., 2019).

Cryptographer Nick Szabo first coined the word "smart contract" in 1994, but the usage and application of these types of contracts were only recently feasible due to technical advances. In these Blockchain-based contracts, the need for trust

between the parties is replaced by cryptography (Badzar, 2016). Mohanta, Panda and Jena (2018) describe a smart contract as a self-checking and self-executing computer software which is resistant to manipulation.

According to Yuan *et al.* (2018), the smart contracts are structured so that assuring it is enforced properly and malicious acts in addition to unexpected conditions are prevented. Alharby and Moorsel (2017) describe the key function of a smart contract in such a way that, the expected contract clauses are automatically executed when the relevant conditions are met. This will result in elimination of trusted third party for implementing the terms of the contract, and consequently leads to cheaper transaction charges in comparison with the conventional ones.

Diallo *et al.* (2018) divide the life-cycle of a Blockchain-based smart contract into following four phases:

- **Creation:** Contracting parties work together to create the smart contract, and after securing its authenticity using their digital signatures, it will be transmitted to the network.
- **Acceptance:** The concerned users who get the smart contract, verify its authenticity and record it in a new block and after the block approved, it is added to the Blockchain.
- **Execution:** The parties in the network who have approved a new block, holding the smart contract, will execute it individually as per instructions and get the result. After formation of a new block carrying the result, it is submitted to the network.
- **Result confirmation:** The parties who receive the block, holding an outcome of the smart contract, will check its validity to decide whether to approve it or not.

3.9.1. Appropriate Blockchains for Smart Contracts

The Blockchain technology employed by Bitcoin, is classified as type 1.0, and because of the constraints towards the scripting language, writing programs with complex logics is not feasible in this Blockchain. There are, however, other ones like Ethereum and Hyperledger which support such user-defined programs, so that smart contract codes can be stored and executed therein (Issaoui et al., 2020).

Ethereum, which is called Blockchain 2.0, is presently the most common platform for smart contract deployment, (Wang et al., 2018).

Ethereum's foundation is the Ethereum Virtual Machine, which can run and manage a wide range of arbitrarily complex algorithmic codes and operating logics. The features of the Ethereum, made it the most comprehensive Blockchain platform used in this field (Wang *et al.*, 2019).

In scientific terms, Ethereum is named “Turing Complete”, which refers to a computer, or software that can solve any complicated problem, provided that sufficient memory and time be given in addition to required instructions (Binance Academy, 2020e). It is worth mentioning that Ethereum creator is Vitalik Buterin (Duan et al., 2020).

3.9.2. An Ethereum-based Smart Contract

In the trade of goods, especially when there is not enough trust between the parties and the price of the goods is remarkable, it is always a matter of concern for both seller and the buyer, whether the buyer should pay the goods price to the seller before the delivery, or after the delivery. Because the buyer may pay, but the seller does not fulfill his obligations, and vice versa. The solution is normally via issuing a letter of credit by a bank, in which the bank acts as an intermediary. But, through a smart contract, there is no longer need for any intermediary bank.

The following case which has been simplified and presented by Hasan and Salah (2018) as shown in Figure 12, is a three-party smart contract for delivery of some physical goods from the seller to the buyer through a transporter. All the three mentioned parties have an Ethereum address and sign an agreement form, including all terms and conditions required in the contract. Their actions with regard to the contract are as mentioned below:

Seller: The seller prepares and confirms the contract, gives the necessary digital keys to both the transporter and buyer, and deposits the agreed collateral which here is equal to the goods price in Ether, that is the cryptocurrency used in Ethereum Blockchain.

Buyer: The buyer confirms the contract, requests the buyer's digital key (Key_B) in order to present it to the transporter, and deposits the goods price in addition to the agreed collateral, i.e., twice goods price as total collateral.

Transporter: The transporter confirms the contract, receives the transporter's digital key (Key_T) in order to present it to the buyer, and deposits the goods price in addition to the agreed collateral, i.e., twice goods price as total collateral.

Now let's see how it works:

1. The seller provides the goods and delivers them to the transporter with the Key_T.
2. The transporter hands over the goods to the buyer and they swap their keys, and then both of them enter the exchanged keys to the smart contract.
3. The smart contract calculates the hashes of the entered keys, and if the hashes completely fit, the validity of the goods delivery is confirmed and the payment is affected.
4. The buyer is repaid half of the total collateral, because the price of the goods is deducted from the total.
5. The transporter is refunded the total collateral, plus goods delivery service charge, because delivery process has been completed.
6. Finally, the seller receives the rest of deposited Ether, consisting of the goods price paid by the buyer and the own collateral minus freight charge.

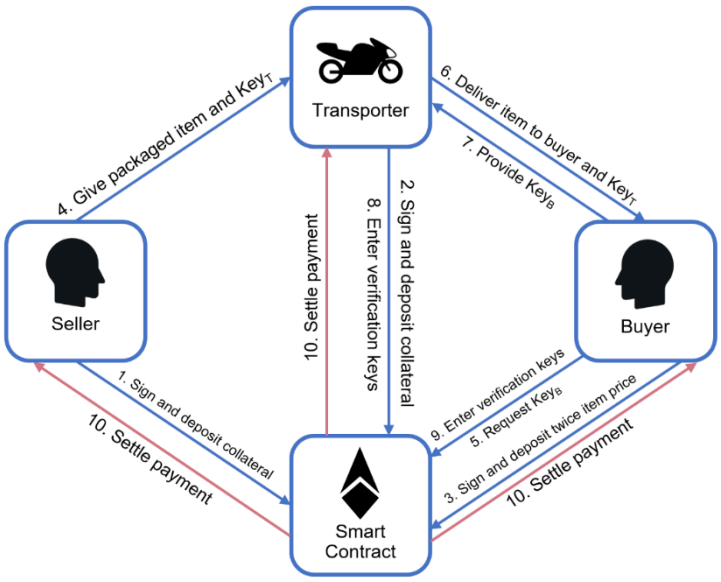

Figure 12. Ethereum-based smart contract structure. Adopted from Hasan and Salah (2018)

4. Blockchain Effects on Sustainable Supply Chain

Most of the Blockchain technology study seems to have hinged around cryptocurrency and the financial markets, but research and development of applications beyond finance, such as supply chain for example, are ongoing and under the spotlight. It is expected that Blockchain will change the supply chains in the future to much extent. Big companies such as Maersk and IBM are already cooperating with each other to make Blockchain applicable to the global supply chain (Elbek Linnet, Mikel. Wagner, Signe. Haswell, 2018).

Blockchain technology is to increase the accuracy of supply chain-related data and help companies to prevent fraud, deficiencies, waste, and threat to people and the environment (Sulkowski, 2018). With regard to supply chain management, the social and environmental aspects of Digital Transformation are projected to be less than its economic side. However, by increasing productivity, reducing energy use, and pollution through digital transformation, it is expected to deliver substantial environmental and social benefits.

Supply chain professionals claim that sustainability, as a movement, is becoming increasingly important in all its three aspects. Therefore, to ensure the implementation of technology as a sustainable resource, all three pillars need to be taken into consideration, i.e., economic, environmental and social. For instance, Blockchain can help track and monitor whether goods are manufactured and delivered in compliance with environmental norms. Likewise, regarding the social dimension, the traceability of Blockchain aims to enhance the human rights, and reasonable and healthy working practices (Junge & Straube, 2020).

The Blockchain role, considering its main capabilities in SSCM is elaborated below:

4.1. Effects on Social Values

The social aspect of supply chains is improved through Blockchain's ability to establish trustful relationships between supply chain partners. It can also promote humanitarian logistics, and support equality in society (Rejeb & Rejeb, 2020). In general, the social element of sustainability can be addressed both individually and organizationally, but the organizational factors are more effective because the

supply chain embraces a lot of operations done in several organizations. These include various activities such as selection of suppliers, purchasing and its relevant logistic, inventory handling, internal flow of data and material, production and the logistics thereafter (Kouhizadeh and Sarkis, 2018).

The Blockchain involves digital signature-based peer-to-peer transactions which facilitates contact and trust between the parties involved. As a result, it strengthens stakeholder relationships, firstly among vendors, contractors and consortium partners who rely on knowledge sharing and cooperative partnerships and secondly among consumers, governments and society due to the decrease in asymmetry of information and power (Gurzawska, 2020).

The essential ability which Blockchain provides, and may result in positive impact on social values are classified as high trust, and anti-counterfeiting characteristic (Yaga *et al.*, 2018).

The openness feature of Blockchain is noteworthy in terms of its potential effect on social side of sustainability, because the end-user will have the benefit of checking the authenticity of a product or service due to a better traceability. On the other hand, Blockchain provides easier communication by automation, and subsequently, social communications via digital spreadsheets, e-mails, and telephone contacts, that are daily manual operations in working office, can be reduced to a large extent. Additionally, since many parties involve in the logistics, openness and smart executions are the most exciting aspects of Blockchain which social framework will benefit from (Yigit *et al.*, 2020).

Blockchains can keep the product provenance information and it can be accessible to all members of the supply chain. It is also simpler to bring transparency, confidence, reliability and security for participants by Blockchain network which can effectively improve the social aspect of sustainability. Moreover, it is only with the consent of the authorized members that the immutable information saved on the Blockchain can be amended. This prevents the seizure of any assets by a corrupt person or company and also promotes the identification of dishonest partners in the supply chain (Chandan A., Potdar V., 2019).

Hard labor, child labor, the influence of living standards and decent wages for employees are some of the issues faced by supply chain sectors in relation to social values of sustainability (Rodríguez et al. 2016). These major issues in social context of supply chain need special attention, and the said problems arise mainly because of unethical manners in the industry, such as corruption, bribery, deliberate misinformation and such, which are shown in Table 9 with the relevant solutions through Blockchain technology (Chandan A., Potdar V., 2019).

Table 9. Blockchain solutions for social aspects of supply chain issues. Adopted from Chandan A., Potdar V. (2019)

Social aspects of supply chain issues	***Blockchain solutions***
Child Labor	The customer has access to the source of commodity data, based on which can decide to purchase or not to purchase a product involving child labor.
Employee Wages	Blockchain-updated wages are processed in an immutable way. Therefore, in paying to workers, the company will not make any violations otherwise they will suffer penalties.
Corruption	The transparency of supply chain information in Blockchain decreases the corruption.
Improving local sources	Transparent product sourcing details, will help to determine the origins of the goods, and whether the raw materials for producing the product come from the local region. This will help the local economy growth.
Public health	Food traceability is open to the general public, and they can find the origin of products, the date of manufacture and its expiry.

4.2. Effects on Environmental Values

Economics, quality and distribution issues have historically dominated the supply chain, while environment protection is seldom seen as a vital consideration for a long-term business performance. The management of environmental sustainability

is known to be the policies and acts taken by businesses in reply to changes in the natural environment. With growing concerns for global climate change, in recent decades, environmental sustainability has drawn interest from both business and academia. Rising competition and the internal costs, force companies to outsource and operate globally. Outsourcing, will lead to increasing the number of firms working in the supply chain, making it impossible to determine the true source or cause of environmental harm. Some companies have introduced supplier appraisal schemes to overcome this problem in the global supply chain. The supplier assessment framework, helps companies to classify potential suppliers who do not comply with the sustainability policy (Golicic and Smith, 2013).

Using a Blockchain is a straightforward way to explain what happens in the network of suppliers and discloses environmental deception, deceptive exchange of information and quality violations. Through Blockchain, it is possible to see whether the crucial environmental certificates are properly issued and also to get a summary of the transport methods used. The gathering of environmental data, enables the partners to see theoretically the cumulative environmental effects of a supply chain (Romare, 2017).

There is also a need for clarity of what happens at each point of the supply chain, and this knowledge must be accessible to the customer. Thus, the entire supply chain must be transparent, from the supply of raw materials till the delivery of the final goods to the end user. It is crucial to store information on each step to make the traceability of goods clearer and, if possible, to remove them from the market for health reasons. For example, identification of the goods used poisonous paint in a garment factory, can be well realized via Blockchain (Rosado da Cruz & Cruz, 2020).

Likewise, Mao *et al.* (2018) point out, that it has the potential to increase accountability and traceability in the supply chain which leads to enhancing the environmental aspect of sustainability. In addition, the data on Blockchain cannot be altered or manipulated easily, such as the data related to suppliers, product movement, and report of sustainability. This will facilitate auditing sustainability, such as tracing carbon emissions, and recyclability and environmental quality. The

Blockchain will not only assist the sectors of the supply chain, but will also help consumers to make better choices, so that the final customer will be able to access Blockchain sustainability data and pick a green product.

Golden and Price (2018) have the same view that auditors, social entities and organizations can take advantage of Blockchain-based platforms to address supply chain issues, including activities that are environmentally harmful. They also believe that Blockchain is not a flawless and quiet perfect approach to the problems of transparency in the supply chain, but it is a crucial piece of the solution to the puzzle.

Moreover, Blockchain helps with monitoring goods over their entire life cycle and gathers information required to determine their proportional shares of environmental impacts (Esmaeilian *et al.*, 2020). It will also accelerate the removal of a paper-based certification system, because the digital delivery process is easier and less complex (Grech, A., & Camilleri, 2017).

It is also good to mention, that the traceability and transparency will specify whether the presumed green goods are actually environmentally sustainable or not. The carbon dioxide emissions, for example, can be better measured and increasing the transparency will decrease data manipulation which consequently yield emission reduction (Saberi *et al.*, 2019). In addition, the use of well-established Blockchain within the supply chain can have a significant effect on the environmental discourse, because it leads to paperless services, removal of manual processes, and stop greenwashing (Yigit *et al.*, 2020).

Another example of the effective use of Blockchain is as a carbon credit trading platform to boost environmental sustainability. The supply chain members are able to share their carbon credit with each other. A carbon positive member can trade with a carbon negative member, which leads to decreasing the total environmental effect.

Likewise, in the supply chain, waste management is crucial. Waste management is much more important in the case of toxic waste. Toxic waste is increasingly growing with raising the use of batteries and other electronic products. Thus, the members in the supply chain should be accountable for the safe handling of such harmful

material. Nonetheless, they don't act responsibly and get rid of disposal costs because of inadequate monitoring of used goods and less visible systems. Blockchain network can assist in monitoring the toxic waste disposal and control misinformation and cheating by the manufacturers. Table 10 illustrates the environmental issues of supply chain with the relevant solution proposed by Blockchain (Chandan A., Potdar V., 2019).

Table 10. Blockchain solutions for environmental aspects of supply chain issues. Adopted from Chandan A., Potdar V. (2019)

Environmental aspects of supply chain issues	***Blockchain solutions***
Wastage	Partners can easily access and exchange information on the Blockchain, which leads to paperless documentation and consequently less wastage.
Pollution	The data of pollution saved on the Blockchain, can be simply tracked by both the regulatory authorities and the public. Therefore, the amount of pollution of an industry has to be in compliance with the standards.
Freight inefficiencies	The exchange of real-time data secures successful shipping schedule, and if any partner deviates from the scheduled plan, then they will be fined. It is also possible to enforce the penalty system using a smart contract.
Procurement	Local product procurement would boost environmental protection, and less consumption of non-renewable energy and pollution, because Blockchain network offers local procurement transparency and auditability.
Carbon Footprint	Through input-output analysis of information saved on the Blockchain, the carbon emission will automatically be measured using the smart contract. In this way, the results cannot be tampered with, in favor of the industries.
Illegally trade of plant species or components of animal bodies	By tracking the origin of the products, the authorities can monitor the illicit trade.

4.3. Effects on Economic Values

As a matter of fact, if an activity has a negative effect on the economy it cannot be sustainable at all, irrespective of how successful it is in terms of environmental or social aspects. Therefore, the economic impact can be presumed as the most important issue towards sustainability.

When assessing the effects of an emerging technology , economic factors are still the major ones (Junge & Straube, 2020), and that is why the majority of researches about Blockchains in supply chains concentrate on the economic issues (Rejeb & Rejeb, 2020).

The economic impact of Blockchain in supply chain can be argued from various point of views. For instance, when third-parties are sometimes not trusted, Blockchain systems have a big advantage for economies in providing necessary support for immutability and data integrity (Lo et al., 2018). They are also able to trace and track goods, which lead to a significant effect on the efficiency of the logistics and supply chain, through which decision makers can easily access clear and reliable data and knowledge on the logistics process. As a result, materials and resources will be saved, and companies can gain a substantial economic benefit (Tan et al., 2020).

According to Yigit *et al.* (2020), Blockchain transparency is a huge advantage for consumers in order to have more control over the items to purchase and consume. But it is a major drawback for bad supply chain actors, because they would not be able to take deceptive actions such as delivering counterfeit products with low quality. Likewise, systems with cybersecurity failures are more at risk of hacking crimes and malicious attacks that cost businesses a lot. Therefore, employing a more secure system like Blockchain can prevent such attacks. In addition, Smart implementations of smart contracts are considered to be one of the Blockchain's most significant capabilities which have a strong influence on economic issues. For example, smart executions from the logistics point of view, particularly with regard to payment and financial risks on a shipment, remove the arguments and mitigate the overhead costs that may occur.

It is generally accepted by the experts, that some solutions to economic aspects of supply chain issues, can be offered by Blockchain technology using its general features, such as data protection, decentralization, immutability, data verification, and smart execution. Table 11 presents the points in the supply chain over economic aspects and how Blockchain can address these issues (Chandan A., Potdar V., 2019).

Table 11. Blockchain solutions for economic aspects of supply chain issues. Adopted from Chandan A., Potdar V. (2019)

Economic aspects of supply chain issues	***Blockchain solutions***
Insurance claim	The best way to make an insurance contract is through a smart contract, where an insurance claim can be effectively executed after the contract terms are met. This will result in saving costs.
Procurement Contracts	Procurement contract using a smart contract makes it more reliable and cheaper.
High foreign transaction fee	International payment fee can be reduced through cryptocurrencies such as Bitcoin.
Data falsification for economic benefit	It is not possible to tamper with any data after saving it in Blockchain
Losses for differences in real-time information shared among partners in the supply chain	Authorized parties can quickly obtain the similar information saved in the Blockchain in real-time.
Enterprises Resource Planning (ERP)	An ERP based on the smart contracts can minimize costs and show reliably the product 's history.
Cost of monitoring sustainability	Due to data automation, a smart contract can easily track sustainability requirements, which leads to eliminating third parties for the job and the relevant cost thereto.
Bribery	The transaction data is clear on the Blockchain. So, the auditing entity will simply find any inconsistency.

4.4. Challenges and Barriers

Blockchain and its solutions provide great potential, but as a new technology, it also brings new questions and risks due to immaturity. Organizational resilience and technological skills are possibly the main concerns to the implementation of a Blockchain network. There are also other issues such as lack of awareness and understanding, required investment, and cooperation of suppliers and participants in the supply chain. In executing such plans, some questions may arise. Who should take the lead position, and who is trusted and functionally prepared for the implementation of a distributed Blockchain network between supply chain actors?

In order to employ the entire capabilities of Blockchain, careful consideration, planning and coordination between supply chain members are essential (Bajwa et al., 2020).

Many potential challenges and barriers exist that may hinder using Blockchain in sustainable supply chain, but only some of the common ones are elaborated below:

4.4.1. Technology- based Issues

With regard to processing large number of transactions and scalability, Blockchain technology is in its initial stages of growth (Yli-Huumo *et al.*, 2016). In supply chain, all participants need to access the necessary information and new IT resources are required to run the Blockchain for collecting and processing desired information but for certain supply chain participants, this may be a problem (Abeyratne, S. A., 2016).

For example, Considering the high level of IT network requirements, it is understood that many nations are not yet prepared to adopt Blockchain technology. Most supply chain partners who are in developing countries are not technologically prepared to utilize Blockchain-based solutions (Kshetri, 2018).

There are also some problems which may occur due to Blockchain features. For instance, when the employees of the first company in a supply chain, record the initial data, other companies enter further information towards the relevant goods based on the initial data. It is very unlikely, but it is still possible to make a mistake at the very beginning of the process. This implies that all the following data would

be incorrect if an error occurs in the first step, and since the data in a Blockchain from its technical feature point of view is unchangeable and nobody can alter it easily, consequently this can cause unplanned costs (O'Byrne, 2019).

With regard to another technology-based issue, as (Rejeb and Rejeb, 2020a) point out, supply chains consist of physical goods that are separate from the ledgers, but it is essential to find a way to connect digital ledgers to physical items if we want to use Blockchain for tracking the products. There are proper sensors and technology which can link physical product data to digital ledger in real-time across the supply chain.

It should be also mentioned that the technology currently available, like 3D stamps, sensors, barcodes, and RFID tags, are not perfect and can be copied. For instance, the RFID of a standard product or the barcode of a pharmaceutical item can be replaced with the forged ones in order to represent misinformation. Effectively linking physical goods to digital ledgers is a technical issue that should be addressed properly, otherwise the Blockchain networks will receive and process false information.

4.4.2. Organizational Issues

Running Blockchain technology needs an investment in new IT systems, which is normally expensive for companies and network participants. Additionally, although there is an increasing tendency in the market for Blockchain utilization, the limited number of Blockchain applications, programmers, and restricted technological experience, are the obstacles in the way of exploiting this emerging technology for supply chain (Mougayar, 2016). In Blockchain technology, one of the biggest issues is to employ programming professionals, because handling smart contracts are technically a complex operation. There is a shortage of skilled workers to be able to run such complicated processes, and the high demand for these professionals will result in high wages. This implies that in the early phases of implementation, the design of a smart contract be an expensive process that needs more than one specialist to accomplish (Powell, 2018).

It is also important to achieve higher knowledge and technical expertise so that participants can be familiar with different perspectives of the use of Blockchain such as how to manage data, how to involve people, how to process security issues and regulatory problems (Angelis and Ribeiro da Silva, 2019). The Blockchain project execution is very time-consuming, and it forces businesses to develop a strong base along with comprehensive technological experience before the project begins (Helo and Hao, 2019).

In the meantime, company leadership support, is a crucial element in successfully adopting any supply chain activities. Some directors, however, do not have long-term dedication and enthusiasm for applying of emerging technologies and adhere to the values of sustainability. Without management serious intention and support, supply chain systems cannot back any sustainability practices effectively (Govindan and Hasanagic, 2018).

Additionally, in order to apply various aspects of Blockchain, its implementation in supply chain processes needs fresh positions and responsibilities in addition to new skills, which may lead to changing the present culture of the companies (Mendling *et al.*, 2018).

4.4.3. Partners Issues

Partners relationships can be challenging when using Blockchain in sustainable supply chain. According to Kshetri (2018), the gathering of supply chain members to implement and manage Blockchain solutions in the supply chain network is a difficult process. In order to all involved participants agree on the acquisition of Blockchain expertise and value-added practices, all parties should have a cooperative act with maximum commitment (Helo and Hao, 2019). Besides, the Blockchain type of the participants' access right and the authority distribution play a crucial role in the network.

With regard to data sharing between companies, on the one hand, Blockchain technology promotes exchange of information between supply chain partners with transparency and verifiability, but on the other hand, some companies are reluctant to share their essential information due to their willingness to keep them confidential

(Sayogo *et al.*, 2015). As a result, the reluctance of some partners to disclose information could impede having the complete advantage of Blockchain technology. According to (Block and Marcussen, 2019), Data sharing is a fundamental process of collaboration between partners in the supply chain. However, data sharing takes place only quite selectively and sometimes to a limited degree, which is mandated by legal requirements and company policies. Strategic data exchange often poses a risk of losing economic profit, therefore it is a very strategic and selective process. For instance, the benefits of information exchange such as perfect product details, are overshadowed by the drawbacks of disclosure of price calculations. Consequently, on the one hand, increased data sharing is fine but on the other hand for competitive purposes, it may have some drawbacks.

4.4.4. Miscellaneous Issues

Some social and governmental push and encouragement towards observing sustainability and technical practices are required to motivate the organizations. Lack of an adequate governmental and industrial strategy and a desire to sustainable and secure practices is an obstacle to achieving sustainability and advanced systems for relevant technical support (Mangla *et al.*, 2018).

Another challenging issue is the lack of an entity that could settle conflicts between parties. For instance, even if consumers and suppliers enter into a smart contract with all contractual conditions, but certain smart contracts do not freeze the amount of cash required for the customer. Such a situation could lead to a delay in payment or a lack of payment, while there are no third parties, such as banks, who could deal with this issue (Browne, 2018).

To summarize literature review based on chapter 2 and 3, the most important advantages of a Blockchain as a database are: transparency, traceability, decentralization, tamper-proof and immutability. These characteristics can improve the three aspects of sustainability of SCM, i.e., social, environmental and economic. Blockchain can play a significant role in enhancing sustainability in supply chain management, such as in labor rights, consumers' rights, equality in society, trustful relationships, easier social communications, preventing corruptions which all affect social aspect. Reducing of environmentally harmful activities, environmental

deception, pollution, carbon emissions and toxic waste, all enhance environmental issues, and lastly, third parties and intermediaries' elimination, more efficient logistics, materials and resources saving, smart contracts and business costs reduction, improve economic side of sustainability. With regard to the future of Blockchain technology, it depends on how effective its drivers will address the diverse businesses and industries requirements. The drivers are essentially its unique features in addition to the customers and governments support. On the other hand, the challenges and inhibitors are crucial to the prevalence of Blockchain use in the future.

Figure 13 which is based on literature review conducted in this research, proposes Blockchain features influence on different SSCM aspects while drivers and challenges of implementing BC technology may affect the impact. This model acts as a guide for the researcher to form the questionnaire of the interviews mentioned in the next chapter.

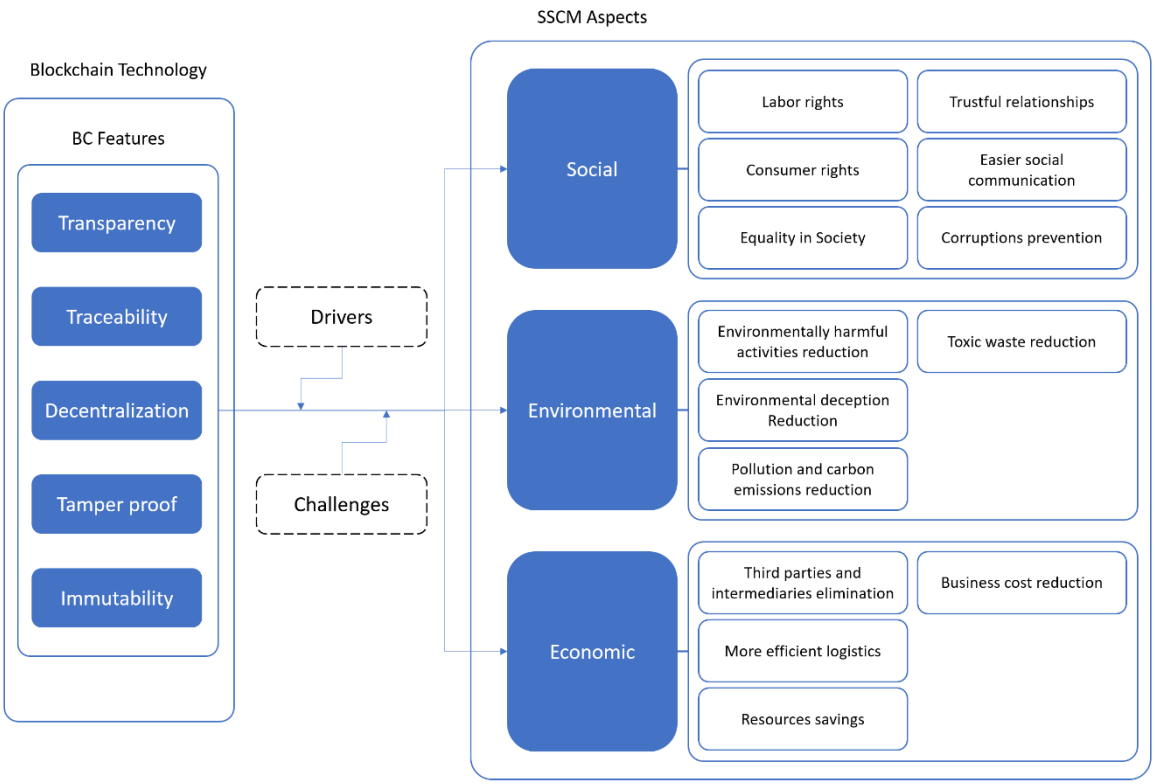

Figure 13. Theoretical Model

5. Methodology

In this chapter, in addition to presentation of the research design, approach, and strategy of this thesis, the data collection process and methods are elaborated. Afterward, it is discussed that how the data collected from the interviews were analyzed.

5.1. Research Design

“Research Design” is an outline for carrying out research. It provides details of the processes needed to collect the required data to answer the research questions. A proper research design ensures the research effectiveness and efficiency (Malhotra, Dunan and Birks, 2017).

In other words, it is a layout to manage the procedure of the research by presenting how the research proceeds, and it is known as the core of academic research in various fields such as social sciences. There are different types of research design which are “exploratory”, “descriptive”, “explanatory” or “evaluative” (Saunders, Lewis and Thornhill, 2016; Abutabenjeh and Jaradat, 2018).

In this thesis, the research design is exploratory. According to Saunders et al. (2016), an exploratory study is an essential tool to find out what is happening and obtain some perception about a topic. This type of study is beneficial if the researcher is going to make a clear understanding of a subject or an event. Usually, those questions that start with “what” or “How” could be answered through an exploratory study.

Based upon the topic of this research and questions discussed, it could be well justified that exploratory study is the proper research design, as Blockchain Technology and specifically its application in supply chain management is a pretty new context which has not been implemented practically widely in the real world; therefore, this type of research design has been selected to provide a better understanding of the topic. Several methods of conducting the exploratory study are presented, including literature review or different types of interview (Saunders et al., 2016). Therefore, the concepts and theories related to this study´s subject was addressed in chapters two and three of the literature reviews. According to Bryman

(2012), the existing literature is considered as an essential component in all studies. The literature review helps the researcher to present the outline on which their study is formed (Saunders et al., 2016), and that is what has been followed in this thesis too. After building the framework of this study, the interviews were conducted to gather data. This Would be described more in the data collection section.

5.2. Research Approach

Two major research approaches which are usually applied in different studies are inductive and deductive. The inductive approach is used when the researcher gathers data to investigate an event or subject to develop a new theory at the end. On the other hand, the deductive approach is utilized when the researcher tries to test an existing theory and not to generate a new one (Saunders et al., 2016).

In this study, the researcher applied an inductive research approach since the application of Blockchain technology in supply chain management is still a fresh topic in both literature and industry field, and the author of this research was trying to make a new theory that could fill the research gap and present it as the literature related to the topic of the study.

5.3. Research Strategy

Bryman (2012) declares that there are two main strategies for conducting research: qualitative and quantitative. Qualitative research regards qualitative facets (Kothari, 2004), which implies approaches of gathering and examining the data that are not numeral and are applied to comprehend conceptions, ideas, and experiences (Bhandari, 2020). This research approach is in accordance with different observations and explanations of what people might perceive from various incidents (Khan, 2014). Using qualitative methods for gathering data would enable the researcher to establish a degree of detail from those who were highly engaged with a real experience (Williams, 2011).

A qualitative approach is applied when an idea or event needs to be investigated and scrutinized while there are only limited references available. This type of method might be required when the subject is brand-new, and the research in this theme is scarce (Morse, 1991).

In this thesis, since the study's subject is more or less a new topic, and there are not many relevant cases, thus, a qualitative research method is utilized for data collection and analysis.

5.4. Sampling and Data Collection

As already mentioned, this study is exploratory and the research strategy chosen is qualitative and one of the tools of exploratory qualitative research is in-depth interviews, which help perceive the context in more detail, therefore a few interviews carried out for data collection (Saunders et al., 2016).

Showkat and Parveen (2017) explain that in-depth interviews are carried out when needed to discover detailed information about the views or experiences people have about a specific subject. In this kind of interviews, it is required to come up with questions that are open-ended and have a semi-structured format. This means that firstly, the questions have to be phrased in a way that interviewees would be able to explain the subject and respond to the questions through their own words and secondly, despite pre-planned core questions, the interview allows to have a discussion with the respondents as well (Guion, Diehl and McDonald, 2011). Usually, in-depth interviews are conducted with a small number of participants (Boyce and Neale, 2006).

For data collection in this thesis, in-depth interviews were held considering the nature of the study and its type of strategy and design. These interviews were done with five people from four different companies, all more or less active in Blockchain technology. The information about the companies and the interviewees would be presented in the Data Analysis section.

For collecting the required data to help answer the research questions, it is essential to know that sometimes if be possible to gather it from the whole population when its size is controllable, but this does not mean that gathering data from a selected sample of an entire population is not beneficial. Conversely, sampling could be a proper approach for collecting data, especially when there is a limit in terms of time, budget, etc. Considering the method used for data collection, there are different ways of sampling that researchers could choose from. Among all techniques the

purposive-expert, known as a non-probability method in sampling, was employed in this research. Within this technique, the researcher could determine what is needed to be known and plans to look for those who could provide the required information based on their expertise and experience as in “Non-Probability” approach the samples are taken based on “subjective judgment” and not randomly (Saunders et al., 2016). This technique is useful when enough knowledge or understanding is out of reach about a subject or event (Etikan, 2016).

All the people chosen through sampling for interviews were experts in both Blockchain technology and supply chain management. They had several years of experience in the application of Blockchain technology in projects related to supply chain management, especially logistics.

The interview guide was prepared based on the findings from literature review that illustrated how Blockchain technology and its features improve sustainability in supply chain management (Figure 13), in addition to the drivers that motivate companies to benefit from Blockchain technology, and challenges that might prevent them from doing so. The interview questions were classified into-- four main categories which were warm-up question, Blockchain technology, Application of Blockchain technology in SCM and the Future of Blockchain Technology Application in SCM.

The questions in each category were designed so that the researcher could get the relevant answers through interviews. They were benchmarked from the questions created in other studies in this research field.

Before the interview, selected experts received the interview questions which could improve the “validity” and “reliability” of their answers, because in this way, the interviewees could prepare themselves for the interview in advance (Saunders et al., 2016).

All of the interviews took place via different online meeting platforms such as zoom, google meet, and Skype and took 15 to 50 minutes. All the interviews with experts were recorded and, accordingly, transcribed into text. As the type of interviews conducted was in-depth, all the questions were open-ended and semi-structured to

provide this opportunity to develop some new questions during the interview based on the interviewees' answers and the interview flow.

5.5. Validity and Reliability

Reliability and validity are essential when assessing the quality of research. Reliability is about being consistent and replicable in research design and research procedure. The research could be rated reliable if another researcher suggests the same findings and results through the same research process. Validity is about precision in the analysis of data and tools used during the process of research (Saunders et al., 2016).

Several strategies could be adopted to achieve reliability and validity in the research method, including:

- standardizing the conditions of the research;
- assuring the researcher's personal biases do not affect the findings;
- keeping a clear, transparent and precise record of data collected from samples;
- demonstrating a transparent thought process during the data analysis procedure (Noble and Smith, 2015).

In this study, in order to assure validity and reliability, the researcher firstly searched for those experts who had a rich background in the fields related to this thesis topic, which are Blockchain technology and supply chain management. As already mentioned, all interviewees were involved in different projects where the Blockchain technology was actually applied in the supply chain management, and they were knowledgeable enough to share their experience in this subject. Secondly, while creating questions for the interview and asking from the interviewees, the author tried to stay neutral and not affect the answers in any way. Besides, the interview questions were sent to the experts to make sure that they would be well-prepared, and, enough time was given to respond to the questions conveniently. Afterward, the recorded interviews were transcribed to ensure the data's transparency and clarity for later analyzing.

5.6. Data Analysis

For analyzing the data collected from the interviews conducted with experts, the “thematic analysis” approach, which includes coding the qualitative data collected by the researcher to specify themes for further analysis was employed. This approach was selected as it is flexible and convenient for analyzing qualitative type of data. The sources of coding in this study were data and theory driven, as the categorization of data was not only based on the existing theory, but also the actual terms mentioned in interviews (Saunders et al., 2016).

The researcher has firstly defined categories based on the research questions presented in this study manually. The categories are illustrated in Table 12. Then, all of the data related to each category was extracted from each interview transcription. This has been done to specify experts' opinions about each category important for this study. After that, to identify what relationship exists between categories, the author used Nvivo software and defined new codes based on what experts mentioned in the interviews.

Table 12. Interview Analysis Categories

Categories	*BC Features*	*BC Effects on SSCM*	*Future of BC Technology*
Sub-categories	BC Use Cases	Social Environmental Economic	Drivers Inhibitors/Challenges

5.7. Introduction to Experts and Their Companies

In this section a short introduction to the experts that the interview was conducted with and their companies is brought.

5.7.1. Expert 1 - VTT

VTT, founded in 1942, is known as one of the foremost research organizations in Europe. Their task is to enhance the application of research and technology in business and the community. They have around 2000 employees, and their turnover in 2019 was 245 MEUR. One of their projects related to Blockchain technology was “BOND (Blockchains Boosting Finnish Industry),” in which using Blockchain

technology for other use cases rather than cryptocurrency was explored, and an overview of present tools or platforms of Blockchain was created (Backman *et al.*, 2017; *What is VTT | VTT*, 2020).

The expert from VTT company that the interview was conducted with is a mathematician, working with VTT company for seven years. He has been working in the cybersecurity area in VTT and has been involved in many projects. Also, He has been active in the Blockchain technology field for five years. During this time, he participated in projects related to Blockchain utilization in other areas rather than cryptocurrencies, such as the BOND project. He also has experience in projects in which the Blockchain was applied in supply chain management processes like logistics, tracking products, and such.

5.7.2. Expert 2&3 - DBE Core

DBE Core Ltd, founded in 2018, is a Blockchain-based service provider of neutral ecosystems to many industries, securing and facilitating business-to-business communications via its main product, Core Platform, a distributed data transfer layer. DBE Core Platform digitalizes and automates business transactions, technical data transfers, and documenting processes to promote global trade (*DBE Core*, 2020).

The researcher interviewed two experts from the DBE Core company. The first expert is the CEO of DBE Core. He has a good background in logistics as he has done his doctoral dissertation on Information Logistics Integration, which is about integrating different information systems in the supply chain. He mentioned that they studied Blockchain technology in the process industry, maritime industry, logistics, and transportation areas for three years before establishing their company. They coded a Blockchain solution based on a Linux foundation, Hyperledger fabric.

The second expert is one of the early adopters of Blockchain technology's practical application in supply chain management in late 2014. He has experience in the supply chain and logistics industry, working on various IoT projects. He also cooperated with IBM to develop concepts and prototypes regarding using Blockchain technology in the supply chain funded by the EU.

5.7.3. Expert 4 - Hedera

The Hedera company, established in 2016, has introduced a new public decentralized ledger for transactions that use Hashgraph consensus and its founders believe that it is better and faster than Blockchain (*Hedera Hashgraph*, 2020).

The fourth expert has been an ambassador of Hedera Hashgraph and has worked on some noticeable international and commercial projects and government projects concerning Blockchain technology. His primary specialization is supply chain management, and he has worked as a chief manager in a railroad car manufacturer in Russia that produces around 13 thousand cars a year.

5.7.4. Expert 5 - Load

The Load company, founded in 2012 in Portugal, is known for being active in research and creation of novel digital products in different fields like “Mobile, Web, Internet of Things, Big Data, Artificial Intelligence, Blockchain, and Virtual & Augmented Reality”. Through these activities, Load helps companies to gain growth in their businesses (*Load Interactive*, 2020).

Expert 5 has been a project manager in Load company since 2015 and has been involved in many projects funded by different organizations in different areas. He has experience in the application of Blockchain technology in supply chain management as he was a part of projects related to implementing this technology in the fields other than cryptocurrencies.

He mentioned that almost three years ago, the company decided to learn about Blockchain and its application by running a project, which he was a part of. He familiarized the members of the company with this technology to see how they could utilize Blockchain technology internally and explore its potential to be able to bring it to other companies in the future if possible. Table 13 presents a summary of all experts and their companies.

Table 13. Interviewed Experts

Name of the Company	***Name of Respondent***	***Respondents´ position in the Company***	***Interview Duration***
VTT	Visa Vallivaara (Expert 1)	Cyber Security Researcher	15 mins
DBE Core	Kari Korpela (Expert 2)	CEO	50 mins
DBE Core	Mika Lammi (Expert 3)	CTO	35 mins
Hedera	Sergey Belets (Expert 4)	Ex-Ambassador	25 mins
Load	Pedro Colarejo (Expert 5)	Project Manager	26 mins

6. Results

6.1. Interview Findings

In interviewing the experts working in various companies, several goals were pursued. First, what do they think about Blockchain and its features, and which one is used the most. Therefore, interviewees were first asked to talk about Blockchain's characteristics such as decentralization, tamper-resistance, immutability, transparency and traceability, and the impact on their business. Analyzing the information provided by each of the interviewees, revealed which feature they pay more attention to.

Then, they explained about which parts of sustainability are affected by the use of Blockchain in the supply chain. They were also asked about the impact on the social, environmental and economic aspects of sustainability. It turned out that they are in agreement towards positive effects on society, environment, and economy.

In addition, the interviewees expressed their opinions on the future of Blockchain as well as the obstacles and challenges ahead. From the eyes of them, they were in agreement towards the main obstacles for deploying this new technology in the enterprises.

6.1.1. Category 1: BC Features

The experts talked about the features or characteristics of Blockchain technology, which were the most important ones in their opinion.

Expert 1 mentioned that one of the most interesting features of Blockchain is that it is immutable, and due to this factor, more trust is built over the records; therefore, it results in high accountability between different parties involved in all transactions. The second important feature mentioned by the first expert was decentralization, which enables everyone to access the records as they all have a copy of all transactions on their systems. Building trust between the actors was the main characteristic that was specified by all the experts.

Expert 2 said that he considers Blockchain technology as a "trust technology". In other words, while selling this to the companies, they don't sell it as "Blockchain

technology" nor "distributed ledger technology," but they sell it as a "trust technology." Then he mentioned the data sharing capability of Blockchain technology as another significant characteristic. He elaborated that in global trades, which different businesses and companies have, many documents should usually be transferred between them, and Blockchain technology allows to share data in real-time instead of exchanging the data. And it is an important point about Blockchain, as sometimes when the documents of transferring the ownership of a product or service to another company are shared, it is essential to know precisely when it happened. Based on the second expert's opinion, none of the earlier technologies could make this happen on such a large scale. Ensuring that the data is safe and nobody rather than those who are allowed by the company to access the data is feasible with the help of private and public keys used to lock (encrypt) or unlock the data in the database.

Another feature that he mentioned was that all of the records are timestamped, which means that when transactions are stored in the Blockchain, there will be an international timestamp for each one of them, and the exact time the transactions took place is evident for all the members of the database. In the end, he discussed that Blockchain technology could enable companies to establish channels and networking within their business partners such as buyers, suppliers, and banks.

Expert 3 explained that ownership of the data is the keystone of Blockchain technology based on his experience. For the first time, it is possible for all of the actors in any given business network to own and control their data physically due to Blockchain. It can help companies to improve their businesses because they generate an enormous amount of data. They usually do not know how important they are, so there is a lack of a clear understanding of how to control all these data, but once they own the data and can manage it, it could make them capable of making business decisions based on them. According to the third expert, they would realize the value of their data, so this data ownership is the most crucial feature of Blockchain technology. He also indicated that the other capabilities of Blockchain technology, such as transparency and tamper resistance that are usually mentioned, are derived from the ability to own and control data, so basically, they are considered as secondary effects, and the data ownership is the primary effect.

The fourth expert first mentioned decentralization as a critical feature. This can help increase equal rights for all the actors involved in any transaction via mitigating monopolies. He clarified that the quality, sustainability, and credibility of the supply chain actors' processes would diminish when there are inequalities. That is why decentralization could help the actors reach a better and more trustworthy agreement by recording and sharing the data in the Blockchain database. Second, he stated that the other useful factor of this technology is traceability, especially when there is a lot of data. With the help of Blockchain technology, all the data could be tracked precisely. Also, he admitted that since the data would be stored in the Blockchain database permanently, all the database members can have a backup of all the transactions and data. Finally, he explained that companies usually have different systems, such as accounting systems, that it is challenging to integrate them because they function differently, but using a Blockchain database could help make this integration between different companies' systems possible.

Expert 5 named several features of Blockchain technology that he thought to be the most critical ones. Firstly, he pointed out immutability as the data could not be changed in Blockchain. Secondly, he mentioned decentralization as a factor that would provide the same access to all members and everybody contributes to the ledger. Besides, he explained the security of this technology: since it is based on cryptography, the reliability of the ledger and the data recorded on it, relies on the infrastructure itself and no one is in charge of the security. The last feature said by expert 5 was the consensus algorithm, which is the main reason for the reliability of transactions in Blockchain.

BC Use Cases

It was asked from the experts to name some use cases of Blockchain applications in different fields, where they were involved.

The first expert described one of the projects he is involved in, which is about using Blockchain technology for border controls and identity management in European Union countries. This project aims to make all the identity documents of people copied to the Blockchain system from their home country. Therefore, when they are at the border, if they do not have the original documents with them, it could be

accessed by the controller in the border through Blockchain system records. Every data on Blockchain is time-stamped, so they could understand when exactly those documents were granted as well. Another use case presented by the first expert was using Blockchain technology for tracking the fish sold in markets. Customers could scan the QR codes and check when the fish was taken from the water and from where it comes based on its supply's recorded history on the Blockchain database.

According to the second expert's information, only about 5% of invoices in the world are generated and transferred digitally, and the rest is done manually. This means wasting a lot of time and money. Here, the Blockchain's role as an enabler can be very prominent. By digitalizing invoices based on the Blockchain platform, related processes can be performed more quickly and accurately. In recent years, they have tried to work on it in different projects.

Expert 3 had a significant role in a project related to facilitating the supply chain processes by utilizing Blockchain technology. This project´s goal was to connect various ERP systems of different parties involved in the supply chain process, such as road transportation, storage, and shipping industries.

One of the Blockchain use cases that the fourth expert mentioned is that, for example, in an order given to a supplier in a supply chain, the most accurate measurements and numbers can be calculated using this technology as quickly as possible. Therefore, the least possible error occurs in the ordering process as a result of using these features.

Expert 5 described some interesting use cases of using Blockchain in supply chain management. One of them was designing a shelf bot in supermarkets that would start talking with the buyer when they are willing to buy a product, and the robot could give information about the product, based on the data stored in Blockchain. This robot would be able to provide information about the whole supply process from the origin of the product until the time it gets to the supermarket. The scenario imagined for this was for products like meat, to be able to know everything about it in the shop from the farm, where the cows were raised until the slaughtering and shipping to the shelf. In addition to the use case above, he described that they are

working on a proposal for using Blockchain technology in the agriculture industry at the European Union level in order to give more power to the producers and farmers via providing more transparency in the agriculture supply chain.

6.1.2. Category 2: BC Effects on SSCM

Experts expressed their views about how applying Blockchain technology in supply chain management can improve sustainability based on three main aspects: Social, Environmental, and Economical.

Social aspects

Expert 1 assumed that Blockchain technology can provide this opportunity for consumers to check all the information about a product from its history, which has been recorded from the beginning of its supply process on the Blockchain database. In this way, customers could check whether the food they want to buy is produced locally or not and could choose ones that are made locally. This way, they can purchase those products that are healthier and more beneficial for the community. Or another example is that they can ensure that the producer of the product cares about human rights and doesn't have any child labor or such with the help of data related to the production procedure of the products stored on Blockchains.

The second expert also pointed out the same results that using Blockchain technology in supply chain management could provide in the social aspect of sustainability with a different example. He described the process of sending Salmons from Norway to Japan, which takes 36 hours, and many actors participate in its transportation from Norway to Japan. A considerable number of documents are transferred every time between different organizations involved. During this procedure, around twenty documents should be filled manually by those who are a part of this process. Usually, these documents are sent via email. Still, as the integration between different systems that each of these participants has is low, the social stress and the load of people increases, and when they are in a hurry, they might make some mistakes and correcting those mistakes and transferring information from paper to paper or system to system would be difficult and time-consuming. Blockchain could provide a network for all the members of the supply

chain process to insert and share data in real-time with each other, which could reduce human errors and make the data sharing faster.

Expert 3 believed that the effect that Blockchain technology has on the social aspect of sustainability in supply chain management is that it can enable companies to “create” or “recreate” their business processes in a way that they can operate with a potentially large pool of access that was not in their reach previously. Therefore, it would help with improving networking with proper clients and suppliers.

Based on what Expert 4 already mentioned in Blockchain features, he said again that equality between the buyer, shipping company, and the customer could be improved due to Blockchain’s use in supply chain management, which would result in more equality in social rights and social situations.

Expert 5 believed that Blockchain could bring transparency to all processes in a supply chain, and in this way, those partners who didn't have enough power in the supply process, could benefit through Blockchain technology and observe what exactly the powerful partners are doing and make sure that the data shared through this database is reliable and accurate. Bringing more equality to all supply chain members could be considered as a notable effect on sustainability’s social aspect.

Environmental aspects

Expert 1 stated that as long as supply chain members know their work process is monitored and this could affect the sales of their products and, their customers care about the environmental issues and would like to make sure their production processes are green and environment friendly, they produce their products in a way that causes the least harm or no harm to the environment.

Expert 2 raised the issue of pollution and waste management in the field of environmental impacts and admitted that, for example, in the process of moving a product from one country to another by ship, using Blockchain technology and transportation manifest make it possible to determine the best route a ship can take to produce the least pollution. In other words, from a logistical point of view and by predicting the best time to reach the destination, Blockchain technology can help prevent unneeded activities through product delivery processes, which lead to a

reduction in traffic, carbon dioxide emissions, and ultimately waste generation volume.

Expert 3 stated that environmental issues are discussed in today's world and are considered as an important topic. He argued that Blockchain enables the ecological impact of an issue in the supply chain to be accurately measured in a standard way and shared with other partners in the supply chain. Previously, the best method was based on statistics and possible estimations. But now, it is possible to access the original data using Blockchain. For example, it is possible to measure how much CO2 is emitted if a particular container is carried so the carbon emission can be minimized. Through this way of controlling the environmental impacts, the measurements would occur in a certain framework. This leads to encouraging businesses to make responsible environmental decisions and take actions in advance. Also, from a governmental point of view, governments have the ability to legislate that companies in different processes of a supply chain must meet certain standards that can be verified and tracked using Blockchain technology.

Expert 4 pointed out that in the absence of Blockchain technology, companies have the opportunity to hide information about issues that may lead to environmental damage during their operations. However, with Blockchain, there is the ability to have complete and accurate access to the right information about the activities of businesses available to everyone. As there is close monitoring of the various stages of the supply chain, hiding the information could be prevented.

Regarding the environmental impacts that using Blockchain could bring, the fifth Expert said that increased transparency in supply processes using Blockchain technology would result in access to exact data and statistics that enable the members to make proper decisions about making good changes in sustainability and ecological issues. In addition, by implementing Blockchain in supply chain management, the environmental footprint of each step could be monitored and improved if needed.

Economic aspects

Expert 1 said that by using Blockchain, intermediaries' presence can be avoided during supply chain processes, so producers and businesses could benefit the most. Because in this case, the money goes directly from the buyer or consumer to the manufacturer or service provider.

Expert 2 emphasized that reducing costs and increasing profits during supply chain processes have always been among the company's main goals. To achieve this, digitalization is one of the most influential factors, while presently, only about 5% of transactions in the world are done automatically, and the rest are manually. This means that a considerable amount of time is spent for transferring information of a request in a supply chain from the written format to the system, and this large amount of time is considered wasted. Therefore, if digitalization implementation is taken seriously, this excessive cost can be avoided. On the other hand, one of the things that makes this issue more important is that in developed countries, if the costs of manually doing tasks in various supply chain processes are not eliminated, the competitive advantages over developing countries will be minimized practically. This urges the use of Blockchain in the digitalization process in order to gain logistical benefits as much as possible.

Expert 3 mentioned the importance of data ownership, as already discussed in the Blockchain features part. He said that if a business could control its large amount of data and make decisions based on them, it could eventually result in economic advantage, but Expert 4 discussed that transparency during the production process in addition to economic transparency in a supply chain, can lead to the identification of various problems and issues, and although sometimes absolute transparency may lead to the fact that if a business has a unique innovation, this achievement will be exposed to the competitors, but finally, it would be interesting for the end consumer to see there is more probability to produce a better product in the competition cycle with the least possible problems, and this will result in customer and consumer satisfaction which eventually means more economic growth for the industry.

Expert 5 was emphasizing the transparency feature of Blockchain technology in all aspects related to sustainability, and again he admitted that this feature would result in accessing accurate data and statistics which would help to improve supply processes and bringing economic advantages.

6.1.3. Category 3: Future of BC Technology

About the future of the application of Blockchain technology in supply chain management, the first expert answered that recently he has been in the United States, and he has observed that some organizations such as Walmart have already started to benefit from Blockchain technology. They have used it to improve the traceability and transparency of food supply chain processes. He admitted that he believes the future of Blockchain technology application in SCM would be mostly in the same way that Walmart utilized Blockchain in its operations.

On the other hand, the second expert explained that Blockchain technology would be the key solution for digitalization and automation at many industry levels in the future. Besides, he mentioned that there wouldn't be any differences, whether it is healthcare, manufacturing, maritime, logistics, or any other industries; they all could benefit from Blockchain to automate supply chain processes. And besides that, the ability to share the data and digitalize the traditional types of documents would be a part of the future impacts of using Blockchain in different industries.

Expert 3 said that almost a year has passed since the peak of excitement and hype over the advent of Blockchain, and now everyone is waiting for this technology to be used on a broader field and more efficiently in various industries. Previously, we have only seen Blockchain technology on a small scale or in prototypes, and now it is time for this technology to open its way to larger scales gradually. Although in some cases, such as Fintech, industry consortiums have almost given up on the use of pure Blockchain and moved to less distributed technologies, they are still trying to take advantage of some of the Blockchain features aspects. He also pointed out that we will see the use of Blockchain and its various features in supply chain management soon. Many companies in supply chains have already concluded that they will definitely fail with the methods they have been using over

the past 20 years. So today, they are slowly starting to use Blockchain technology in their work processes.

Expert 4 expressed his hope that in the future, the facilities provided by Blockchain could be used more. He said that the various ecosystems involved in this field should provide the conditions to advance the goals pursued by this technology. If we move towards this goal, the speed in the supply chains will increase, and the work will be done more efficiently, and also, we will eventually see the production of better products.

Expert 5 mentioned that the future is unpredictable and even though someday in the future, cryptocurrencies like bitcoin might go away, still Blockchain or other similar technologies would be applicable to the industry due to the principles and mindset that exists behind it.

Drivers

In terms of the drivers which could motivate companies to use Blockchain technology in their processes, Expert 1 discussed that probably one of the main elements could be the customers. When they are interested in Blockchain and are aware of its benefits, there is this possibility that they purchase those products that are backed up with Blockchain technology effectively. This could encourage companies to use this technology to attract more customers.

According to the second expert, Blockchain would not solve any problem by itself. It is beneficial when it is combined with information models for processes, and data sharing to generate the interaction between different systems. Integrating the systems, could motivate the companies to apply Blockchain in their operations. He also mentioned that one of the main challenges that businesses have is the trust issue in collaborating with partners or members of the supply chain, and since they don’t want their information to be exposed to anybody else, increasing trust and protection of the data might encourage companies to implement Blockchain technology in their supply chain management procedure.

Likewise, Expert 3 believes that one of the key drivers that encourage companies to use Blockchains in the supply chain, is to provide a standard data or information

model for all organizations. This means that different companies and actors in a supply chain will be able to communicate easily and without error, which consequently results in high productivity. At present, most companies follow different methods and paradigms, which leads to inconsistency between the relevant parties. However, implementing Blockchain features and having a simple and user-friendly interface to provide the users all the necessary information with high accuracy, can act as a driver.

According to Expert 4, achieving better products by having an error-free manufacturing process can motivate companies to use Blockchain. Different supply chain participants can use this technology's different capabilities to do all matters related to procurement and purchases in the best way and ensure that all these tasks and processes are getting done accurately.

Expert five expressed that companies exist to make a profit. Therefore, when they understand how this technology could bring sustainable growth and benefit to their businesses, they would become motivated to implement it. Also, Blockchain could provide a safe and fair environment for competition.

Challenges

One of the challenges in applying Blockchain technology in different fields, according to the first expert, could be the lack of a clear understanding of this technology and its potential. When companies, including their employees and managers, are not familiar with Blockchain and how they can benefit from it, they will not be motivated enough to have it in their organization. In addition, spending money and changing the system is usually risky for any company, and the organizations are usually reluctant to make any significant changes, such as using Blockchain technology in their supply chain management processes. Expert 1 also mentioned that this technology and its adoption might be too expensive for some companies, which could be seen as another inhibitor. In addition, he explained that it is important that governments support these types of technology. For instance, in countries like Estonia, Switzerland or Singapore, Blockchain is supported by the government and many opportunities are provided for its development. On the contrary, in some other countries like South Korea, there are many regulations

towards using Blockchain technology so that its application in many fields is not allowed.

In the second expert´s opinion, the biggest challenge for implementing Blockchain in different operations is the legacy systems. He explained that various companies already have different ERP systems, for which they have spent lots of money to establish. Therefore, it would be difficult to convince the decision makers to change all those systems. As a result, it is considered as a big problem to address. Consequently, Blockchain technology developers need to make a premium presentation of Blockchain so as to convince companies to adopt it.

Expert 3, Like the first expert, believes that one of the problems that always arises is to explain the concept and function of a Blockchain to the general public or to those who are not already familiar with it. He also pointed out that one of the main obstacles to applying Blockchain technology in different companies is the incompatibility of their current IT infrastructure with respect to Blockchain technology's infrastructure. Companies have already spent much money for building their IT infrastructure, such as the high cost of building an ERP system. Blockchain can perform the same tasks as existing ERPs at a much lower cost and greater efficiency. It practically means ignoring previous spending, which acts as a demotivating factor for companies. From a governmental point of view, he noted that governments should employ experts in the field of Blockchain technology as much as possible in order to define an ecosystem that will help the Blockchain growth and implementation in various areas. Governments should refrain from imposing restrictions and should not specify when Blockchain can be used or when it cannot be used. The imposition of such restrictions, which is not beneficial to companies, only leads to the fact that no one can do anything other than what is set by the government.

In this regard, Expert 4 pointed out that one of the main challenges of using Blockchain in the supply chain is the high cost and slow process of its application. High costs as well as time-consuming processes, and on the other hand, the effort required to create adaptability and integration with other systems are some of the issues that are challenging in this respect. Nonetheless, we see that companies,

especially those in the supply chain, are moving towards using Blockchain's various features in their business.

According to Expert 5, one of the main challenges could be the lack of interest of big companies and suppliers who use the traditional supply chains as they might not want transparency in all of their processes. Because this would result in more monitoring from other parties, which could put them under pressure for lowering the prices or acting differently. The lack of interest could also be a result of the "absence of a clear understanding of Blockchain technology and its benefits.

Besides, companies have their own systems for doing different processes. Changing them to new ones would need lots of investment, and convincing the other members of the processes would be difficult and challenging.

In Table 14, the summary of findings from interviews with experts is presented.

Table 14. Interview Findings Summary

	Expert 1	***Expert 2***	***Expert 3***	***Expert 4***	***Expert 5***
BC Features	• Immutability • Trustworthiness • Accountability • Decentralization • Accessibility	• Trustworthiness • Real-time data sharing • Safe data sharing • Timestamp	• Data ownership • Control over data • Transparency • Tamper-proof	• Decentralization • Trustworthiness • Data sharing • Traceability • Control over data	• Immutability • Decentralization • Safe data sharing • Transparency • Consensus algorithm
BC Use Cases	• Border controls and identity management • Tracking food supply processes	• Document digitalization • Tracking food supply processes	• ERP systems integration • Facilitating logistics	• Quick and accurate measurement in SC orders • Mitigating errors in SC processes	• Tracking food supply processes • Agriculture supply processes
BC Effects on SSCM					
Social	• Customers´ reliance on SC processes from different aspects such as human rights, healthiness of products, supporting the local community, and etc.	• Reducing social stress • Reducing human errors	• Enlarging the networks • and integration between companies	• Improving equality between different actors involved in the supply chain. • Enhancing equality in social rights and social situations	• Improving equality between different actors involved in the supply chain
Environmental	• More control over the environmental effects of companies processes which may results in minimizing ecological impacts caused by companies	• Better pollution and waste management through making better logistical decisions • Minimizing traffic, CO2 emission and waste generation volume	• Accurate measurement of different environmental impacts of SC processes • Minimizing CO2 emissions • Encouraging businesses to make responsible ecological decisions • Governments' ability to monitor and verify if companies are following the ecological standards	• Preventing companies from hiding information related to any environmental damage they may cause	• Monitoring environmental footprint in each step of SC processes • Accurate data and environmental statistics accessibility
Economic	• Eliminating intermediaries in transactions which would result in more benefits for buyers and suppliers	• Excessive cost could be avoided via digitalizing processes • Logistical financial advantages	• Economic benefits as a result of data ownership in Blockchain	• Industry economic growth due to consumers satisfaction with better products as a consequence of transparency in SCM	• Economic benefits due to accessibility to accurate data
Future of BC Technology	• More benefits from utilizing Blockchain's transparency and traceability	• The key solution for digitalizing and automation in many	• Implementation of BC in a larger scale and efficiently in the near future	• Wide use of BC in different industries • Faster and more efficient SC	• Wide use of BC in different industries

	features in food supply industry	industries' SC processes	• Wide use of BC in SCM	processes which results in better quality products	
Drivers	• Customers´ awareness	• Possibility to integrate different systems • Improving trust in collaborations among SC partners • Enhancing data protection	• Providing a standard data/information models for all companies • Easy and error-free communication between partners • Higher productivity • Providing consistent, necessary and accurate information to all users	• Achieving better products by having an error-free manufacturing process • Assuring that all tasks and processes are getting done accurately	• Sustainable growth and benefit for businesses
Inhibitors/ Challenges	• Lack of clear understanding about BC technology and its potentials • High risk of making big changes in existing systems • High cost of converting existing systems • Governments´ restrictions towards using BC technology	• Difficulty of convincing decision makers to change their established and highly cost legacy systems	• Difficulty of explaining BC concepts and its features • Incompatibility with businesses´ current IT infrastructures • High cost of integration with existing systems • Governments´ restrictions towards using BC technology	• High cost and slow process of BC application • Much effort needed to create adaptability and integration with existing systems	• Lack of interest to have more transparency in their business processes • Lack of clear understanding of Blockchain and its benefits • Difficulty to convince companies to change their old systems to new ones

6.2. Data Analysis Results

After summarizing the key findings from interviews with experts and categorizing them, the researcher used Nvivo software to analyze the data more accurately and find the possible relationships between different categories. To do so, the categories mentioned previously, in addition to new ones, which were based on what experts mentioned during the interview, were coded. It was then specified in the software, which part of the experts' sayings belongs to the codes defined and by running matrix coding queries, further precise analysis was conducted.

The following section includes the results obtained from analyzing the data and suggested propositions (Bordered texts) by the author.

The most important Blockchain features used in supply chain management

Based on the analysis of the data gathered from the interviews, the Blockchain technology features that are the most important in supply chain management, in

order of times mentioned by the experts, are Accuracy, Accessibility, Transparency, Traceability, Trustworthiness, Secure Data Sharing, and Decentralization (Table 15).

Table 15. Number of times Blockchain technology features mentioned by each expert

	A: Expert 1 - Visa	*B: Expert 2 - Kari*	*C: Expert 3 - Mika*	*D: Expert 4 - Sergey*	*E: Expert 5 - Pedro*	*Total*
1: Accessibility	3	3	2	2	4	14
2: Accuracy	1	5	3	4	3	16
3: Anonymity	0	0	0	0	0	0
4: Data Ownership	0	0	2	0	0	2
5: Decentralization	2	1	0	2	1	6
6: Integration	0	4	1	1	0	6
7: Real-time	0	2	0	0	0	2
8: Secure Data Sharing	0	6	1	1	1	9
9: Tamper-proof	1	1	1	0	1	4
10: Timestamp	3	2	0	0	0	5
11: Traceability	6	0	1	1	1	9
12: Transparency	3	1	1	1	5	11
13: Trustworthiness	2	3	0	2	2	9

Figure 14 presents all the Blockchain technology features that were mentioned by the experts during the interviews and those discussed in literature.

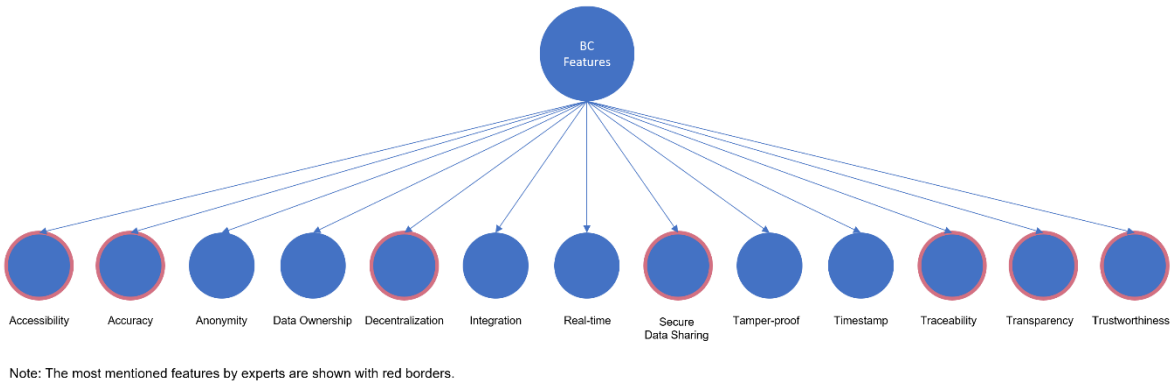

Figure 14. Blockchain Technology Features. Mentioned by the experts and literature

1- Accuracy

Among all features mentioned by the experts, the accuracy of the data and transactions was the most important one pointed out by most of them. For instance, according to Expert 4, in supply processes, “the most accurate measurements and numbers can be calculated using Blockchain technology as quickly as possible”. This is because the process of data verification on the Blockchain database is done

by nodes involved in the Blockchain, so nobody can cheat or record misleading data on the database.

2- Accessibility

The second most mentioned feature of Blockchain was accessibility. It was considered many times by experts as the structure of Blockchain is in a way that "enables everyone to access the records as they all have a copy of all transactions on their systems" (Expert 1, VTT). This feature is important since equal access to all data related to the supply chain is provided through Blockchain technology. Of course, this feature is due to Decentralization.

3- Transparency

Transparency was the next important characteristic of Blockchain technology and is the main feature that could make this technology exciting and beneficial for different use cases rather than cryptocurrencies. "Blockchain could bring transparency to all processes" (Expert 5, Load). This feature results from the fact that all data and transactions can be monitored and controlled by all members.

4- Traceability/Trustworthiness/Secure Data Sharing

These three features were mentioned the same number of times by experts. When all the Blockchain database members have access to all records, the verification can be done by all of them which results in trustworthiness, secure data sharing, and traceability. Therefore, "Blockchain technology could be considered a trust technology" (Expert 2, DBE Core), and traceability is a useful feature "especially when there is a lot of data" (Expert 4, Hedera). Also, in terms of secure data sharing. "since it is based on cryptography, the reliability of the ledger and the data recorded on it, relies on the infrastructure itself and no one is in charge of the security" (Expert 5, Load).

5- Decentralization

This feature was discussed by experts several times. It is vital as it "could help the actors reach a better and more trustworthy agreement by recording and sharing the data in the Blockchain database" (Expert 4, Hedera) since "all have a copy of all

transactions on their systems" (Expert 1, VTT). Many features of Blockchain technology are due to the decentralized structure of this technology.

Blockchain impact on supply chain management sustainability

After realizing what features are the most frequent ones mentioned by the interviewees, the researcher explored how they could affect the different aspects of sustainability in supply chain management.

Table 16 illustrates how many times, in the interviews, each feature was known effective towards a particular aspect of sustainability. As demonstrated in this table, based on what experts mentioned, the Blockchain features mostly impact the environmental aspect of sustainability in supply chain management.

Table 16. Number of times each feature was known effective towards an aspect of sustainability

	A: Social aspects	*B: Environmental aspects*	*C: Economic aspects*
1: Accessibility	2	4	1
2: Accuracy	2	4	1
3: Anonymity	0	0	0
4: Data Ownership	0	0	1
5: Decentralization	0	0	0
6: Integration	1	0	0
7: Real-time	1	0	0
8: Secure Data Sharing	1	1	0
9: Tamper-proof	0	0	0
10: Timestamp	1	0	0
11: Traceability	1	3	0
12: Transparency	2	1	2
13: Trustworthiness	1	1	0

Social aspect

Blockchain technology features that have the most effect on the social side of sustainability in supply chain management, from experts' point of view, were Transparency, Accessibility, and Accuracy (Figure 15). According to these experts, Blockchain technology could bring transparency to all processes of a supply chain. This means, for example, "consumers can check all the information about a product from its history, which has been recorded from the beginning of its supply process." (Expert 1, VTT). Transparency could provide more social benefits and awareness, especially for customers, to ensure the products' quality and origin. Moreover,

transparency of the processes and transactions could reduce inequality among the partners as “those partners who didn't have enough power in the supply process could benefit through Blockchain technology and observe what exactly the powerful partners are doing and make sure that the data shared through this database is reliable and accurate” (Expert 5, Load). Also, as mentioned before, all the members could access the data recorded on Blockchain database. Accessibility could make communication of supply chain members easier through providing real-time data sharing by Blockchain (Expert 2, DBE Core). Moreover, as said before, the data and transactions are accurate in Blockchain, because they can be monitored and verified by all members. As a result, implementing Blockchain technology in different processes of the supply chain, enhances the accuracy of transactions and operations which would lead to mitigating human errors.

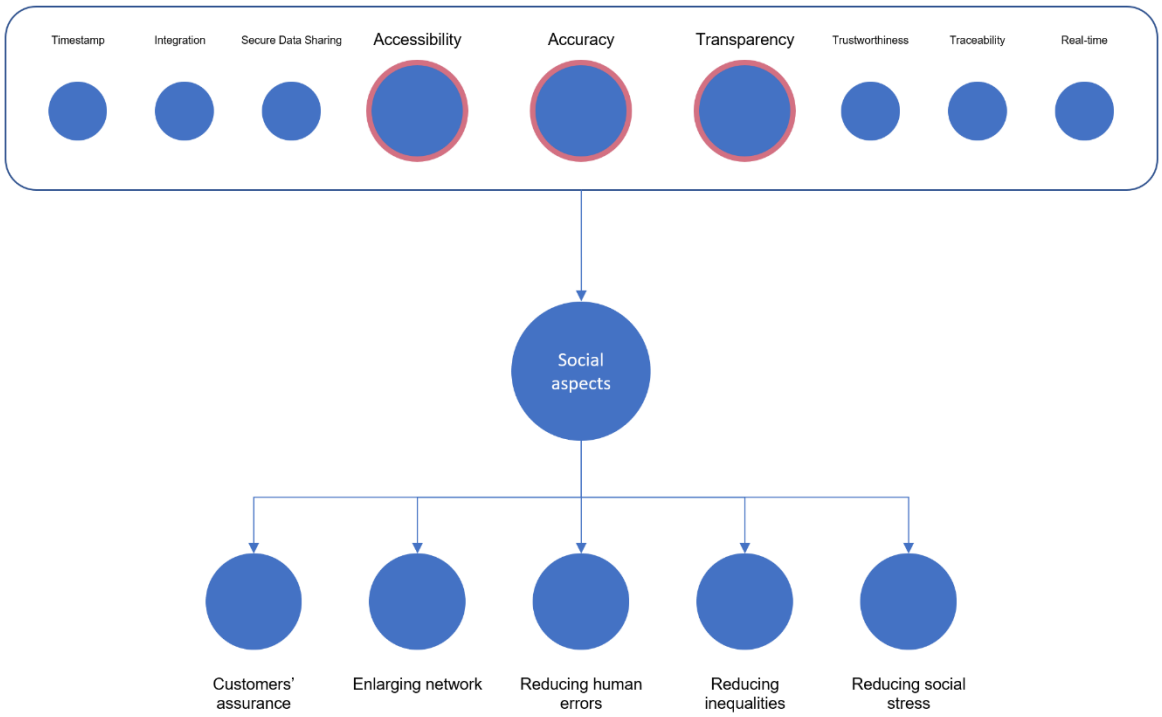

Figure 15. Blockchain technology impact on sustainability social aspects

Environmental Aspect

Based on exploring the data collected from the experts, the researcher figured out that Accessibility, Accuracy, and Traceability in the Blockchain network, have more impact on the environmental aspect of sustainability (Figure 16). In a Blockchain

database, all parties involved in supply chain processes could access all the records stored on the database. Moreover, “Blockchain enables the ecological impact of an issue to be accurately measured in a standard way, and shared with other partners in the supply chain” (Expert 3, DBE Core). As a result, instead of only statistics and possible estimations, the accessibility and accuracy features would provide direct access to original data related to the effects that each process has on the environment. “Therefore, it enables the members to make proper decisions and changes in sustainability and ecological issues” (Expert 5, Load). Both accuracy and accessibility make easy traceability possible. Traceability is a useful feature for monitoring the impacts that companies’ operations might have on the environment, which results in preventing companies from hiding crucial environment-related information. “As long as supply chain members know their work process is monitored and this could affect the sales of their products, they try to make sure that their activities do not have a detrimental effect on the environment” (Expert 1, VTT).

Also, by utilizing accessibility, accuracy, and traceability, there would be the ability to manage waste and pollution produced during supply chain processes by “predicting the best time and the best route to a certain destination and minimizing unnecessary activities, traffic, CO2 emissions and waste generation volume” (Expert 2, DBE Core).

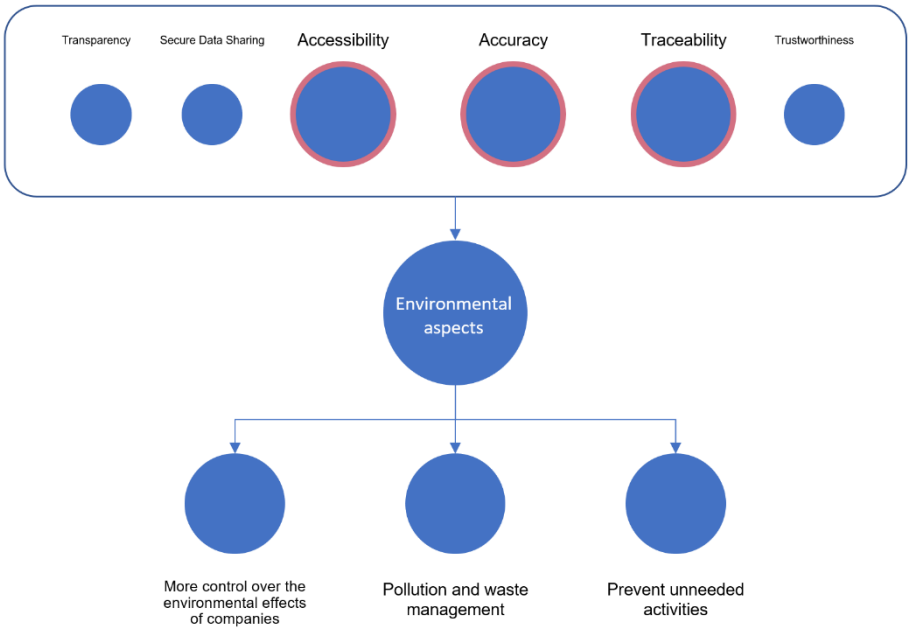

Figure 16. Blockchain technology impact on sustainability environmental aspects

Economic aspect

The results from analyzing the data gathered from interviews, showed that Blockchain characteristics impact the economic side of sustainability as well. From the experts´ point of view, Transparency, accessibility, and accuracy are the features that have the most effect on this aspect (Figure 17). The existence of transparency during all the processes of a supply chain, leads to more customer satisfaction because not only this feature can help producers identify various problems and issues in different operations, which results in better quality products, but also customers' access to accurate data about the products such as where they come from and how they were produced, would make customers happier. An increase in customers´ satisfaction would result in more economic benefits for companies and their supply chain. According to Expert 5 "accessing accurate data and statistics would help to improve supply processes and bring economic advantages".

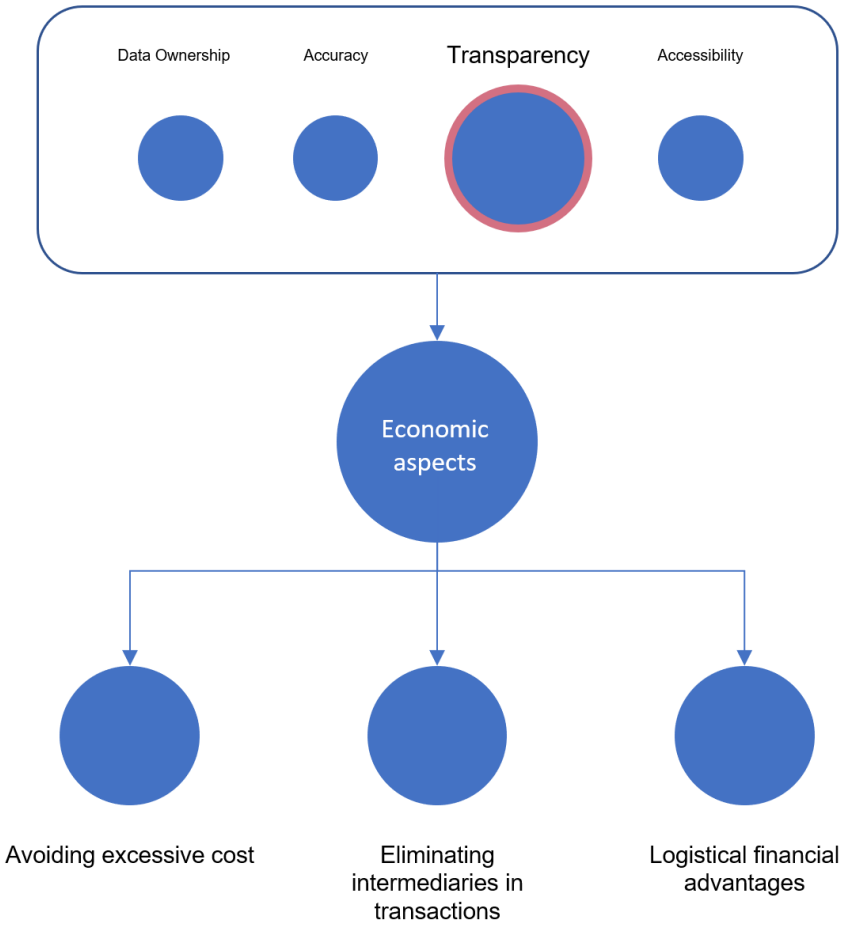

Figure 17. Blockchain technology impact on sustainability economic aspects

Drivers and Inhibitors/Challenges

The data analysis could reveal main drivers and those BC features that act as drivers for encouraging companies to benefit from this technology in their supply chain management in the future and what significant challenges might prevent them from implementing this technology in their processes (Figure 18).

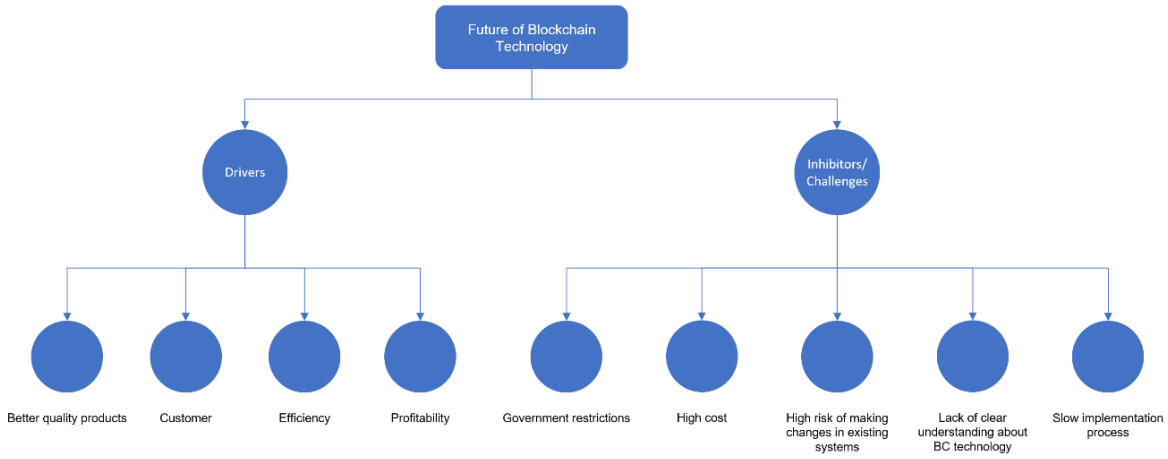

Figure 18. Drivers and inhibitors/challenges of employing Blockchain technology in SCM

Some main drivers could be extracted from experts´ sayings. These drivers are: more efficiency and profitability, customer, and better-quality products.

Blockchain technology can help get things done more accurately and quickly by digitalizing various supply chain processes. According to Expert 4, “Different supply chain participants can use this technology’s different capabilities to do all matters related to procurement and purchases in the best way and ensure that all these tasks and processes are getting done accurately.” Accuracy, speed, and lack of human error lead to higher productivity, resulting in better products, better customer service, and minimal supply chain costs. Also, automating processes mitigates the potential costs of doing things manually. Therefore, all these cases lead to customers’ and industry actors’ satisfaction and maximize the companies’ profits in this chain. “Achieving better products by having an error-free manufacturing process can motivate companies to use Blockchain" (Expert 4, Hedera).

Customers can also be considered a major driver, because through Blockchain, they can be aware of what processes have taken place in a supply chain and make more accurate decisions to buy better products. “When they are interested in Blockchain and are aware of its benefits, there is this possibility that they purchase those products that are backed up with Blockchain technology effectively. This could encourage companies to use this technology to attract more customers” (Expert 1, VTT).

Moreover, some features mentioned by experts that act as drivers for encouraging companies to use Blockchain technology in their supply chain processes in the future were: Accuracy, Integration, Secure Data Sharing, and Transparency (Table 17).

As making a profit is one of the main goals of any business, features that result in more economic advantages would be considered core drivers for implementing a new technology such as Blockchain. More accurate, secure, and transparent communication and data sharing without any error between supply chain actors leads to higher productivity and more economic advantages for companies.

Table 17. Number of times BC technology features mentioned as drivers by experts

	A: Drivers
1: Accessibility	1
2: Accuracy	3
3: Anonymity	0
4: Data Ownership	0
5: Decentralization	0
6: Integration	2
7: Real-time	0
8: Secure Data Sharing	2
9: Tamper-proof	0
10: Timestamp	0
11: Traceability	1
12: Transparency	2
13: Trustworthiness	1

Some possible use cases benefiting from Blockchain features that could encourage companies to use this technology in supply chain processes in the future, are shown in Figure 19. Data analysis showed that among all these use cases, digitalizing processes, tracking food supply processes and system integrations are the ones

that are mentioned more by experts and there is more potential of using Blockchain in these cases.

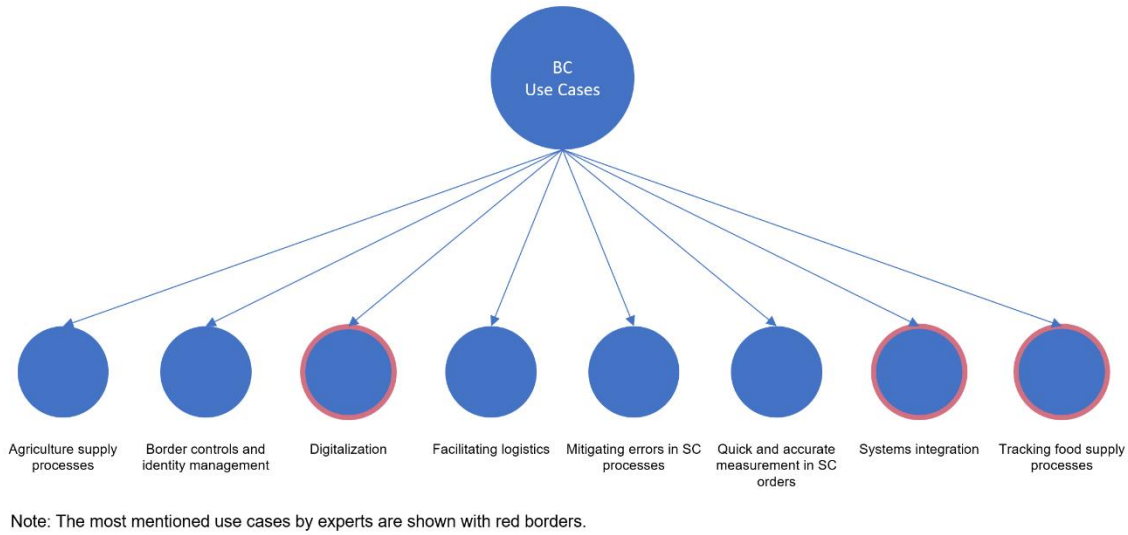

Figure 19. Use cases of Blockchain technology. Mentioned by the experts

Concerning the challenges and inhibitors that exist in the implementation of Blockchain technology in supply chains, the interviewees mentioned some main obstacles, which are the high cost of implementation, high risk of making changes in existing systems, lack of clear understanding about BC technology, government restrictions, and slow implementation process.

The high cost and the slow process of implementing Blockchain technology have always been obstacles to its implementation in different supply chains. “Various companies already have different ERP systems, for which they have spent lots of money to establish. Therefore, it would be difficult to convince the decision-makers to change all those systems” (Expert 2 - DBE Core). On the other hand, replacing costly existing systems with new technology and platforms is considered high risk. Also, “The incompatibility of companies’ current IT infrastructure to Blockchain technology’s infrastructure is recognized as an obstacle” (Expert 3, DBE Core).

Another significant obstacle specifically mentioned, is the lack of a clear understanding of the concept and capabilities of Blockchain technology. This is due to the nature of the Blockchain, which is difficult to explain, and this problem leads

to the fact that supply chain actors cannot understand what they can achieve with it and what problems they can solve via the technology. “When companies, including their employees and managers, are not familiar with Blockchain and how they can benefit from it, they will not be motivated enough to have it in their organization” (Expert 1, VTT).

Another inhibitor mentioned by the experts is government restrictions. Governments sometimes enact laws that prevent the proper and principled use of Blockchain technology in various industries and supply chains. These rules sometimes conflict with the interests of potential users of the Blockchain. “Governments should refrain from imposing restrictions and should not specify when Blockchain can be used or when it cannot be used. The imposition of such restrictions, which is not beneficial to companies, only leads to the fact that no one can do anything other than what is set by the government” (Expert 3, DBE Core).

7. Discussion

Considering the information obtained through literature and interviews, it can be seen that what is stated in theory is to a large extent consistent with what experts believe in practice.

7.1. Blockchain Characteristics

7.1.1. Decentralization

According to Lin and Liao (2017), decentralization of Blockchain guarantees that the data no longer has to depend on a centralized entity, this is what Expert 1 also believes. Likewise, Expert 5 sees decentralization as a factor that would provide the same access to all members and everybody may contribute to the ledger control. and experts 2, 3 and 4 have some practical views in this regard. Expert 2 elaborates that , where different businesses exist, many documents should usually be transferred to concerned parties and Blockchain technology allows to share data in real-time instead of exchanging data. Chang, Iakovou and Shi (2020) describe a decentralized system as a network where each participant holds a copy of the data that can be verified and refreshed at the same time. Likewise, Expert 3 is so excited about having all the necessary data and documents available and controllable due to decentralization of the network. He says that this leads to improving their businesses, because once they own the clear data timely, it makes them capable of making decisions in time and effectively. The fourth Expert refers to decentralization as a critical feature, which can help increase equal rights for all the actors involved in any transaction via mitigating monopolies. He says that the quality, sustainability, and credibility of the supply chain actors' processes, would diminish when there are inequalities.

It should be mentioned that none of the above Experts pointed that the transactions can be processed peer- to- peer in the network without a central body control.

7.1.2. Immutability, Transparency and Traceability

According to Batwa and Norrman (2020), consensus algorithms ensures, that the data in a block cannot be deleted nor edited easily. This is in line with Expert 5 saying that the consensus algorithm is the main reason for the reliability or

trustworthiness of transactions in Blockchain. Lin and Liao (2017)mention that the recorded data will be saved permanently and it is almost impossible to tamper with. This is the views of Expert 1 and Expert 2 too. Expert 1 believes that due to immutability, more trust is built over the records, therefore, it results in high accountability between different parties involved in all transactions. Similarly, Expert 2 considers Blockchain technology as a “trust technology.”

On the other hand, the Blockchain information is transparent, due to checking the validity as well as registering the timestamp for each transaction, which makes it simple to search and track previous records throughout the network via any node, which promotes the reliability and traceability of the data under process (Alahmadi and Lin, 2019). Expert 2 agrees that all the records are timestamped, and when transactions are stored in the Blockchain, there will be an international timestamp for each of them, and the exact time of any transaction is obvious to all the members of the database which helps traceability of the data. Expert 3 believes that transparency and tamper-resistance of Blockchain are derived from the ability of data control by everyone, and Expert 4 confirms that the traceability is a useful factor of this technology especially when there is a lot of data.

Experts referred to the accuracy feature of Blockchain technology several times. Although, this term was not mentioned specifically in the literature review as main features, but it could be concluded that accuracy is a result of Decentralization, Immutability, and Transparency.

7.2. Blockchain Impact on Sustainability

7.2.1. Social Field

According to Yigit *et al.* (2020), the end-user will have the chance of checking the authenticity of a product or service due to a better information traceability. In addition, Blockchains can keep the product provenance information which is accessible to all the participants in the supply chain (Chandan A., Potdar V., 2019). Expert 1 claims that Blockchain technology can provide an opportunity for consumers to check all the information over a product and its history, because all the information can be recorded from the beginning of the supply process on the Blockchain database. In this way, customers can check whether the food they want

to buy, for example, is produced in the factory where those products are healthier and more advantageous. He also mentions that the community can trace whether the employers care about the labor rights and doesn't have any child labor or such, with the help of the data obtained from the history of the products stored on the Blockchain.

Looking from another angle, the Blockchain involves digital signature-based peer-to-peer transactions which facilitates contact and trust between the parties involved. On the other hand, Blockchains provide easier communications by automation, and cause other means, such as digital spreadsheets, e-mails, and telephone contacts that are daily manual operations in working office, be reduced to a large extent. Additionally, many parties involved in logistics can benefit from openness and smart executions as the most exciting aspects of Blockchain in a social framework (Yigit *et al.*, 2020). The second Expert confirms, through an example, and describes the process of shipping Salmons from Norway to Japan in which a considerable number of documents are filled manually and transferred via email, but as the integration between different systems that these participants have is low, the social stress and the load of people will increase. Blockchains could provide a network for all the members of the supply chain process to insert and share data in real-time with all the supply chain participants, which lead to reduce human errors and stress.

Another ability which Blockchain provides, and may result in positive impact on social values are classified as high trust, and anti-counterfeiting characteristic (Yaga *et al.*, 2018). Expert 3 positively refers to the effect that establishing trustful relationships between supply chain partners has on the social aspect of sustainability via Blockchain. He also remarks that it can enable their business processes to operate reliably with a potentially larger pool of access. Therefore, it would help with improving networking with proper clients and suppliers.

Besides, according to Rejeb and Rejeb (2020a), it can promote support equality in society (Rejeb and Rejeb, 2020a) which is in line with Expert 4 opinion. He says that equality between the buyer, shipping company, and the customer has been improved due to Blockchain's use in supply chain management, which would result in more equality in social rights and social situations. Similarly, Expert 5 believes

that Blockchain could bring more equality for all supply chain members due to transparency existing in the processes of a supply chain. Those partners who didn't have enough power in the supply process, could now benefit from Blockchain transparency to observe what exactly the powerful partners are doing.

7.2.2. Environmental Field

Expert 1 believes that, as long as supply chain actors know that their work process is monitored, and their audience is sensitive to issues related to the environment and green products, they eventually are pushed to produce the least harm or no harm products to the environment. His opinion is in line with the view of Romare (2017) that using a Blockchain is a straightforward way to explain what happens in the network of suppliers and discloses environmental deception, deceptive exchange of information and quality violations, and in line with da Cruz and Cruz (2020) that say there is a need for clarity of what happens at each point of the supply chain, and this knowledge must be accessible to the customer. Thus, the entire supply chain must be transparent, from the supply of raw materials till the delivery of the final goods to the end user. It is crucial to store information on each step to make the traceability of goods clearer, and this approach will make the producers to move in the right direction.

Expert 2 raises the issue of pollution and waste management and says, for example, that in the process of shipping a product from one country to another by a vessel using Blockchain technology and transportation manifest, makes it possible to determine the best route a vessel can voyage to produce the least pollution. In other words, from a logistical point of view, Blockchain technology can help prevent unnecessary activities in delivery processes which lead to reduction in traffic, carbon dioxide emissions and ultimately waste generation level. In this respect, Mao *et al.* (2018) point out that Blockchain has the potential to increase accountability and traceability in the supply chain which leads to enhancing the environmental issues.

Expert 5 explains that increased transparency in supply processes using Blockchain technology would result in access to exact data and statistics that enable the members to make proper decisions concerning sustainability and ecological issues.

In addition, by implementing Blockchain in supply chain management, the environmental footprint of each step could be monitored and improved if needed.

Similarly, Expert 3 states that Blockchain can have the ecological impact, which can be accurately measured in a standard way and shared with other partners in the supply chain. For example, it is possible to accurately measure how much CO2 for a certain route in a certain time frame is emitted. This can help arrange carrying, for instance, a certain container with a minimized emission through a certain track. This leads to encouraging concerned parties to make environmental decisions responsibly and take required actions in advance.

Regarding controlling harmful environmental elements, Esmaeilian *et al.* (2020) say that, Blockchain helps with monitoring goods over their entire life cycle, and the information required to determine their proportional shares of environmental impacts. Likewise, Saberi *et al.* (2019) mention that the information traceability and transparency in Blockchain can specify whether the presumed green goods are actually environmentally sustainable or not. For example, the carbon dioxide emissions can be better measured, and increasing the transparency will decrease data manipulation which consequently yields to emission reduction.

Considering the Blockchain role in misinformation reduction, Expert 4 points out that in the absence of Blockchain technology, companies have the opportunity to hide information about issues that may lead to environmental damage during their operations. However, using Blockchain, there is the ability to have complete and accurate access to true information about the activities for everyone, which leads to close monitoring of various stages of the supply chain and preventing any data from getting hidden. This issue has been highlighted by Chandan A., Potdar V. (2019). They say that in the supply chain, waste management is crucial, and waste management is much more important in the case of toxic waste. Blockchain network can assist in monitoring the toxic waste disposal and control misinformation and cheating by the manufacturers.

7.2.3. Economic Field

Batwa and Norrman (2020) mention that, the transactions between nodes are done peer-to-peer without any intermediary, and every user can check the records of the transactions individually which will result in cost reduction. This is what has been pointed out by Expert 1 too. He argues that by using Blockchain, intermediaries can be avoided during supply chain processes, so that producers and businesses can benefit the most. Because in this case, the money goes directly from the buyer or consumer to the manufacturer or service provider.

According to Grech, A., & Camilleri (2017), Blockchain accelerates the removal of a paper-based system, and the digital processes are easier and less complex. Similarly, Yigit *et al.* (2020) say that the use of well-established Blockchain within the supply chain, can have a significant effect on using paperless services and removal of manual processes. In line with this advantage of Blockchains, Expert 2 emphasizes that reducing costs and increasing profits during a supply chain process have always been the main challenge of companies, and digitization is one of the most effective factors in this respect. Presently, only about 5% of transactions of businesses in the world are done digitally and the rest are manually. Therefore, a considerable amount of time is wasted during information exchange in papers, so if the Blockchain implementation is taken seriously, this exorbitant cost can be avoided remarkably.

With regard to data sharing between companies, on the one hand, Blockchain technology promotes exchange of information between supply chain partners with transparency and verifiability, but on the other hand, some companies are reluctant to share their essential information due to their willingness to keep them confidential (Sayogo *et al.*, 2015). As a result, the reluctance of some partners to disclose information could impede having the complete advantage of Blockchain technology. According to Block and Marcussen (2019), Strategic data exchange often poses a risk of losing economic profit, therefore it is a very strategic and selective process. On the contrary, Expert 4 is somewhat opposed to the mentioned drawbacks of information transparency and data sharing. Expert 4 believes that, although absolute transparency may sometimes be undesirable for some partners, and cause, for example, a unique innovation be exposed to the competitors, but the

consumer will benefit from it in the end, because the producers will be pushed to offer a better product in the competition cycle with transparency and the least possible problems. This will lead to consumer satisfaction which implies more economic growth for the industry.

7.3. Future of Blockchain

7.3.1. Drivers

It is interesting to point out that Blockchain features which were discussed in different studies, were considered as drivers by experts. In other words, any feature of Blockchain that could increase Trustworthiness, Accuracy, Integration, Secure Data Sharing, and Transparency in addition to economic benefits would encourage the companies to use this technology it in their processes.

In addition, there are some other elements that could be seen as motivation. For instance, customers have always had a significant impact on the decisions that companies make. Da Cruz and Cruz (2020) explained that there is always this need to clarify what happens during each step of the product's supply chain and the information related to that should be accessible by the customers as well. That is what exactly expert 1 mentioned. According to him, Blockchain provides this possibility for customers to access all the data for the products that they want to buy. This is something that customers would like to have; Besides, in the literature, it was admitted that quality has been always a main principle in supply chains (Golicic and Smith, 2013); thus, the ability of Blockchain that reduces human errors can result in better quality products, according to expert 4. Another important driver is efficiency, Tan *et al.* (2020) elaborate that by using the Blockchain technology in supply and logistics processes, the ability to trace and track products would increase, and this leads to a notable effect on performance. In line with this view, Expert 4 pointed out that using Blockchain would make processes faster which results in more efficiency. Therefore, since having a better performance in the processes is important for all companies, it could be an important driver for them to use this technology.

7.3.2. Inhibitors/ Challenges

As a problem, According to Mougayar (2016), running Blockchain technology needs an investment in new IT systems which is normally expensive for companies and network participants. Similarly, Expert 1 believes that spending money and changing the system is usually risky for any company, and the organizations are usually reluctant to make any significant change. More or less, the Expert 2 has the same view and argues that the biggest challenge for implementing Blockchain in different operations is the legacy systems. He explains that various companies already have different systems, for which they have spent lots of money to establish, therefore, it would be difficult to convince the decision makers to allocate another fund to change all those previous systems.

According to the first Expert, when companies, including their employees and managers are not familiar with Blockchain and how they can benefit from it, they will not be motivated enough to have it in their organization. This is, to some extent, in line with Angelis and Ribeiro da Silva (2019) that say it is important to achieve higher knowledge and technical expertise so that participants can be familiar with different perspectives of the use of Blockchain. Likewise, Expert 3 has the same opinion. He explains that, one of the problems that always arises, is to clarify the concept and function of a Blockchain to the general public or to those who are not already familiar with. He also points out that one of the main obstacles to applying Blockchain technology in different companies is the incompatibility of their current IT infrastructure with respect to Blockchain technology's infrastructure.

Expert 5 sees eye to eye with the literature views concerning all the challenges mentioned above, and explains that one of the main challenges could be the lack of interest of big companies and suppliers who use the traditional supply chains and they might not want transparency in all of their processes. Because this would result in more monitoring from other parties, which could put them under pressure for lowering the prices or acting differently. The lack of interest could also be a result of the absence of a clear understanding of Blockchain technology and its benefits. Besides, companies already have their own systems for doing different processes which changing them to new ones would require lots of extra investment.

8. Conclusion

In this section, the results of the research over the subject and the contribution that has been made through this thesis are discussed. Finally, the limitations are mentioned and some topics are suggested for the future research.

This thesis sought how the basic functions of Blockchain could improve the supply chain performance and how its characteristics would enhance the sustainability of supply chain management.

The questions that this research seeks to answer can be listed as follows:

RQ1: How can employing Blockchain technology improve supply chain management and its sustainability?

RQ2: What is the future of Blockchain application in supply chain management?

A. What would be the major drivers of applying Blockchain in SCM in the future?
B. What would be the major challenges of applying Blockchain in SCM in the future?

To answer the above questions, a research framework was developed, based on which the studies conducted by various researchers in scientific articles were reviewed and then, for reaching to a robust outcome, an interview arranged with five selected experts from companies involved in some form of Blockchain-based projects towards supply chains to draw on their experience in this area.

From the interviewees' comments about the benefits and features of Blockchain, it can be seen that from their point of view, access to the same, accurate and reliable information for all concerned members of the network are the main advantages of the Blockchain technology. According to the experts, the most important advantages of using Blockchain as a database are: data accuracy, accessibility, transparency, traceability, trust, sharing and decentralization.

They emphasize in particular the features of decentralization, transparency and traceability, which play an important role in building trust and security in the network.

In any case, it seems there is a unanimous agreement that these features have created a unique and powerful database for use in various fields.

Further, about how these features can improve sustainability in SCM, sustainability was divided into three main aspects and then each aspect was explored separately. *In case of social side, Blockchain capabilities can be used to trace whether the employers care about the labor rights and doesn't have any child labor or such, with the help of the data obtained from the immutable history of the products stored on the Blockchain. It can also protect the rights of consumers, especially regarding the products important information required to be exposed to the public.* For example, a consumer can be informed of all the specifications of a product such as production date, producer, place of production and such. *Blockchain also reduces the problems and stress of the people in charge of doing business by providing the possibility of easy and secure exchange of information and documents in various fields.* A clear example is the use of smart contracts in fulfilling bilateral or multilateral commitments. Additionally, due to transparency of information and disclosed processes of the supply chain, this technology enhances the equality among the stakeholders.

Next, the environmental side was studied. Thanks to Blockchain potentials, the processes across the entire supply chain, from the supply of raw materials till the delivery of the final goods to the end customer can be under the microscope of environmentalists. *The Blockchain features, such as information transparency and other trust-building attributes make it possible to monitor the compliance of relevant activities with the environmental standards, and make the stakeholders not to do anything in conflict with environmental values. In the other words, due to characteristics of Blockchain, the relevant actors will not have the opportunity to hide information about issues that may lead to environmental damage during their operations, because everyone can have complete and accurate access to true information about their activities.* Consequently, Blockchain technology can help prevent inappropriate activities, for example, in processes which lead to increasing carbon dioxide emissions or other environmental pollutants and wastes.

It was mentioned that sustainability could work when it also brings some financial benefits to the companies. Therefore, after the social and environmental aspect, the economic side was discussed. *All indications show that the decentralization of the Blockchain will eliminate intermediaries such as banks and other third-party entities, which results in cost reduction.* For instance, the transactions between the participants in a supply chain can be done peer-to-peer without any intermediary, and every user can check the records of the transactions individually. Another economic impact of the use of a well-established Blockchain within the supply chain is that *it can have a significant effect on using paperless services and removal of manual processes which leads to reducing costs and increasing profits. It is worth mentioning that a considerable amount of time is wasted during information exchange in papers, so if the Blockchain implementation is taken seriously, this exorbitant cost can be avoided remarkably.*

To answer what would be the future of Blockchain technology, the researcher studied the possible drivers and inhibitors of employing this technology in different processes of companies that might exist in the future. Based on her findings, it seems that Blockchain will continue to be used in cryptocurrencies application, but major changes will not take place in the future unless central banks and governments provide adequate protection for the cryptocurrencies. In terms of use in other sectors, *Blockchain technology would be the key solution for digitalization and automation at many industry levels in the future. Besides, there wouldn't be any differences, whether it is healthcare, manufacturing, maritime, logistics, or any other industries.*

As already mentioned, *there are some obstacles in the way of implementing Blockchain technology which can be divided into three categories: technological, organizational and inter-organizational*. Considering the high level of IT network requirements, it is understood that many nations are not yet prepared to adopt Blockchain technology, and supply chain partners who are in developing countries are not technologically ready to utilize Blockchain-based solutions. As another barrier to mention, organizational, running a Blockchain needs an investment in new IT systems which is normally expensive for companies and network participants. In the other words companies have already spent much money for building their IT

infrastructure, and deploying a new system practically means ignoring previous spending. This acts as a demotivating factor for companies, and that is why the organizations are reluctant to execute such transitions. In addition, lack of knowledge is another organizational barrier. For example, when companies including their employees and managers are not familiar with Blockchain technology capabilities and its benefits, they will not have enough motivation to adopt such an unknown new system in their organization. Besides, there are also some inter-organizational barriers. For instance, the companies and suppliers who use the traditional supply chains, might not be interested in transparency in their processes. Because, the transparency may result in more monitoring from other organizations, which could push them to decrease their prices or act differently.

Despite all the current barriers, due to its unique features discussed in this study, it is tempting for many organizations to employ it as a secure and trustworthy tool for improving their business processes. Many supply chains companies have already concluded that they will definitely fail with the methods they have been using over the past years. So today, they are slowly starting to use Blockchain technology in their work processes. However, in order to put it into practice, it is necessary to explain its capabilities effectively so as to convince the target community to adopt it practically. In addition, sufficient trained specialists are required to perform the relevant projects in this field. And lastly, governments should support the utilization of Blockchain technology through enacting appropriate laws. It is worth mentioning that the future of Blockchain depends on providing prerequisites mentioned above and without those, its development will not be easily done.

8.1. Theoretical Contribution

This research has contributed to scrutinize how Blockchain technology can serve the sustainable supply chain management and how it can help the various aspects of sustainability. It also clarifies existing barriers towards its deployment, and the prospects for its future.

8.2. Managerial Implications

The results of this study will encourage the companies and the decision makers to take the Blockchain technology into account for their business and specially for

supply chain processes. They can see how their internal and external interactions and processes can be improved and executed in a more trustworthy, transparent and reliable platform which leads to a higher productivity as well as better contribution to different aspects of sustainability. They also become familiar with the challenges and inhibitors against Blockchain technology implementation, which enables them to take right measures in the right time.

8.3. Limitations and future research

Blockchain technology is a new concept in areas which are not related to cryptocurrencies. Due to this fact, implementation of this technology for SSCM has not been established yet in many companies. As a result, the method used for collecting data was exploratory-qualitative approach. Therefore, it was not possible for the researcher to explore the exact process of using Blockchain in SSCM through real case studies and data was collected from experts based on their experience in Blockchain and SCM. Moreover, as this technology has not been applied widely in SCM processes, it was essential to select those who were experts in Blockchain in the first place, and the SCM in the next. This fact limited the options for interviews. Considering the limitations mentioned and the type of research method selected, it is not possible to generalize the results of this study till there are more cases of using Blockchain in SCM, and further research can test the results via other research approaches

Due to the widespread variety of Blockchain technology and its applications, and because of the novelty of these topics and the scarcity of study in these areas, many cases can be suggested for further research. This thesis does not address the deceptive deeds that can effectively weaken the position of the Blockchain as a powerful system.

For further research, fraudulent actions and Blockchain's points of weakness which can affect the efficient use of a Blockchain in supply chain management can be proposed. Moreover, since this technology is not established on a large scale in supply chain processes yet, this study is based on qualitative exploratory approach and mostly addresses only some processes of the supply chain. Therefore, Future

research can also explore how a complete Blockchain-based supply chain is designed, from A to Z and as an integrated package.

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Appendix A: Interview Guide

Theme	Questions
Warm-up Questions	1. Do you mind if I record this interview to evaluate and transcribe our conversation?
	2. Should your personal information be mentioned in the related thesis, or would you prefer to be anonymous?
	3. What earlier experience have you had with Blockchain technology and supply chain management?
	4. What is the role of digitalization in sustainability and visibility development (in SCM), in your opinion?
Blockchain Technology	1. What do you think are the most important Blockchain features in order of priority? Why?
Application of Blockchain technology in SCM	1. What are the Blockchain use cases towards the supply chain management in your company?
	2. How Blockchain's main features and capabilities, i.e., Decentralization, Tamper-resistance, Transparency, Traceability, and Smart Contracts may influence the social aspects of the supply chain such as corruption, public health, workers' rights, organizational issues, and such.
	3. How Blockchain's main features and capabilities, i.e., Decentralization, Tamper-resistance, Transparency, Traceability, and Smart Contracts may influence the environmental aspects of the supply chain such as waste management, pollution control, energy-saving, and such.
	4. How Blockchain main features and capabilities, i.e., Decentralization, Tamper-resistance, Transparency, Traceability, and Smart Contracts may influence the economic aspects of supply chain such as cost reduction, profit increase, and such.
Future of Blockchain Technology Application in SCM	1. What do you think about the prospects of using Blockchain in different industries in the future?
	2. What do you think are the major drivers of applying Blockchain in SCM in the future?
	3. What do you think are the major challenges to deploy and implement the Blockchain in general and particularly in your company, in the context of technology-based issues, organizational issues, partners issues, and such?
	4. What are the actions from the ecosystem needed to boost the development of Blockchain technology in SCM?