FACULTY OF SCIENCE AND TECHNOLOGY

MASTER THESIS

Study programme / specialisation:
Industrial Economics / Petroleum technology

The spring semester, 2022

Open / Confidential

Author: Nasim Malakooti

Nasim Malakooti
(signature author)

Course coordinator:

Supervisor(s): Professor Jan Frick

Thesis title:

Does blockchain technology have anything to say in the oil and gas industry: the study of opportunities, challenges, and future trends

Credits (ECTS):

Keywords:

Technology Adoption, Disruptive Technologies, Oil and Gas, Blockchain Technology, Qualitative Study

Pages: ……115……

+ appendix: ……

Stavanger, 15.06.2022
date/year

Acknowledgments

My deepest gratitude goes to my supervisor, Professor Jan Frick for his invaluable advice, continuous support, and positive attitude through all the stages of writing this thesis. I should state my extreme appreciation to all the participants of this research for accepting my invitation to participate in the interview, and for their willingness to share their insightful ideas and knowledge with me. They are all people with great minds and kind hearts who contributed so thoroughly through their further comments and emails. Their guidance enabled me to write and finish this master thesis. My thanks also go to all my family members and friends who provided me with moral support and encouragement during my studies.

Does blockchain technology have anything to say in the oil and gas industry: the study of opportunities, challenges, and future trends

Abstract

This research focuses on the utilization of blockchain as an emerging technology in the oil and gas industry with the aim to advance the understanding of blockchain technology adoption in this industry. Through conducting qualitative research based on semi-structured interviews with managers and decision makers in the oil and gas industry and by overviewing the literature, the current opportunities, challenges, and adoption barriers of this technology were investigated. Findings indicated that despite the rapid progress of digital technologies, the adoption of blockchain technology in the oil and gas industry is a slow process due to the conservative and inherently resistant nature of the industry. Although there is evidence proving that the technology is capable of increasing the efficiency and operational transparency in the industry, there are still challenges mainly due to lack of business and managerial support, awareness, and expertise about blockchain technology within the oil and gas industry or immaturity and complexity of the technology. Different categories of blockchain adoption barriers were detected together with the presentation of some solutions to overcoming these barriers. Additionally, the drivers and influential factors in the adoption of the technology were discussed. The future of blockchain technology in the oil and gas industry is considered to be promising based on the participants' opinions and the evidence from successful use cases.

Keywords: Digital Transformation, Technology Adoption, Disruptive Technologies, Oil and Gas, Blockchain Technology

Table of Contents

List of Figures

List of Tables

1. Introduction

1.1. The importance of the oil and gas industry

The oil and gas industry is considered as the core part of the global energy mix. The most recent BP Statistical Review of World Energy 70th Edition released in 2021, shows an overview of energy consumption in 2020 based on which the global primary energy consumption and carbon emissions declined by 4.5% and 6.3% respectively which is their fastest falling rates since the Second World War. The energy market was impacted by the Covid-19 Pandemic dramatically and consumption of all fuels decreased but almost three-quarters of this decline was driven by oil (-9.7%). Nevertheless, renewable energy such as solar power continued to grow with renewables (+9.7%) and hydro (+1.0%). but still, oil with 31.2% constitutes the largest share of the energy mix followed by coal as the second-largest fuel with 27.2 % of total primary energy consumption, and the share of both natural gas and renewables increased to 24.7% and 5.7% respectively. Nuclear energy only makes up 4.3 % of the energy mix and hydroelectricity constitutes 6.9%. The share of the global primary energy mix is shown in Figure 1. Therefore, despite the transition toward new energy, oil and gas would still constitute more than half of the world's energy by 2040 (BP Energy Outlook, 2022), and the dominance of oil and natural gas in the energy market will continue for the next 20-30 years (Lu, Huang, et al., 2019).

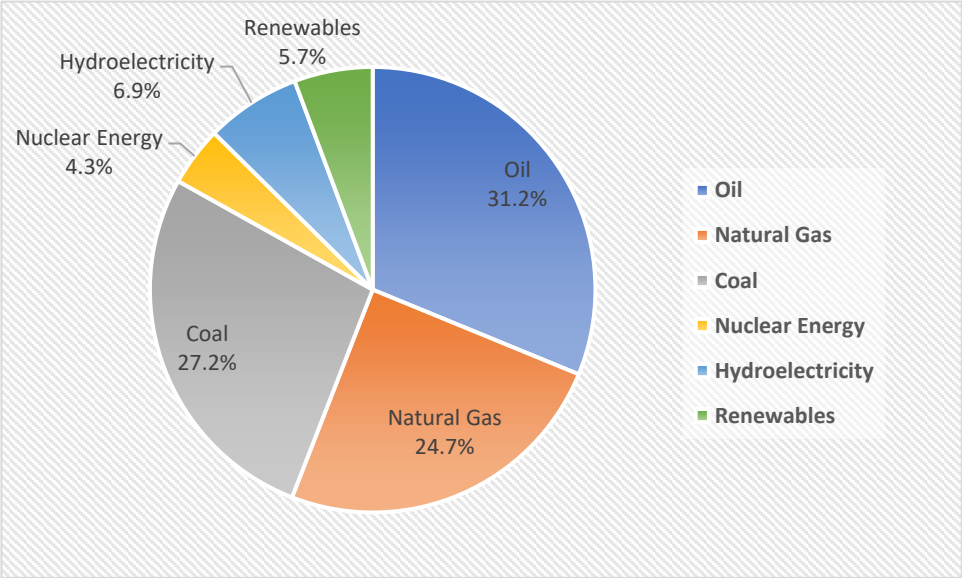

Figure 1. Shares of global primary energy in 2021

The importance of the oil and gas resources and the impact that this industry has on the global economy is increasing with the advancement of new technologies and accelerated digitalization which can improve the productivity and efficiency of the industry. Therefore, the oil and gas industry despite being very slow and conservative about the adoption of emerging and disruptive technologies is gradually shifting towards intelligence, digitalization, and automation (Lu, Huang, et al., 2019).

1.2 Digital transformation in the oil and gas industry

With the rise of "Industry 4.0" and the evolvement of emerging technologies on the daily basis, the technologies in the oil and gas industry have also been evolving very rapidly in recent years, intelligent drilling, intelligent oil and gas fields, intelligent pipeline, and marine digital platforms are some examples (Fraser et al., 2018). The concept of "Oil and Gas 4.0" emerged in 2019 with the core goal of achieving higher value in the O&G industry through the application of advanced digital technology and it is believed that it can change the status quo of the oil and gas industry (Lu, Guo, et al., 2019). It has been reported by Gazprom Neft, a Russian oil company that the productivity of the oil and gas industry can be increased by 10 to 15% using digital technologies (Antipova, 2020). There have been many technological innovations in the oil and gas industry such as 3D seismic, hydraulic fracturing, and geo-steering and the industry has transformed into a data-intensive industry by applying artificial intelligence, machine learning, cloud computing, and the internet of things (Lakhanpal & Samuel, 2018). However, there are still shortcomings in the administrative and managerial aspects of the industry since these aspects are done in a traditional manner and consequently there are problems such as low efficiency, high costs, high risk, and long period. To solve such problems technologies are needed which can help overcome this challenge by streamlining the traditional methodologies and various engineering and technical decisions (Lakhanpal & Samuel, 2018).

The oil and gas industry is a huge system that faces many challenges. According to market division, it can be divided into three sections: upstream (exploration, development, and production), midstream (transportation, distribution, and shipping), and downstream (refining and marketing). Therefore, multiple parties are involved in transactions, investments, and trading in the value chain of the oil and gas industry which may cause management issues like insufficient trade negotiation process, slow exchange of critical data, and high third-party management costs. Additionally, the large amount of paperwork and reconciliations are prone

to error and are very time consuming (Lu, Huang, et al., 2019). The value chain in the oil and gas industry is shown in Figure 2.

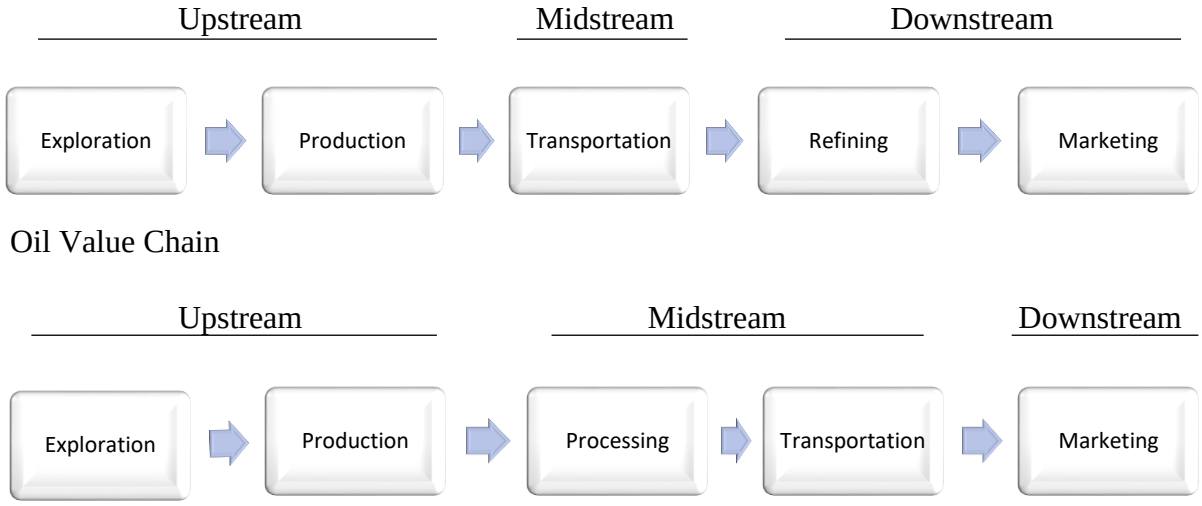

Figure 2. The value chain of the oil and gas industry

There are management problems associated with each market section in the oil and gas industry as presented in the following table. The information in Table 1. is taken from the white paper by Tata consultancy service in 2018. The focus here is mainly on the major information security issues existing in the oil and gas value chain. There are other problems related to the oil and gas industry which are going to be discussed later in the remaining chapters to investigate how digital technologies can solve the existing problems in the industry.

Market Section	***Issues***	***Causes***	***Consequences***
Upstream	Data Leakage	Loss of raw data and important information due to ineffective data storage and processing. Lack of data correlation due to Different locations where data is generated.	Wrong decision making due to wrong or incomplete data
	Equipment Tracking Difficulties	A huge number of devices Inefficient management of asset integrity	Human error Huge supervision fine
Midstream	Data handling and replication difficulties	Duplication of third-party transactions Replication of contracts between different parties	Increased operational costs Error-prone and non-verifiable transactions Delayed transactions
Downstream	Integrity & security	Vulnerability to internal and external attacks in close networks	Fraud, Loss of trust Cyberattacks & phishing The increased cost of authentication

Table 1. Major information management issues in the oil and gas value chain (retrieved from Tata consultancy service white paper, 2018)

The technologies and approaches for supply chain management in the oil and gas industry still suffer from problems such as lack of operational transparency, traceability, audit, security, and trusted data processing systems. The existing systems are very centralized, disintegrated, and manual therefore the systems are susceptible to fraud, manipulation, error, and the single point of failure problem (Ahmad et al., 2022). Therefore, it is time that the oil and gas industry change its management system using emerging technologies that have the potential to provide solutions to these problems.

1.3. Blockchain technology as a digital tool

Blockchain as a circular collaborative ecosystem improves collaboration among participants in the oil and gas ecosystem by using an integrated digital platform (Lu, Guo, et al., 2019). Blockchain technology or distributed ledger technology, has gained popularity in recent years as a disruptive technology that can provide innovative and value-adding digital solutions to address some of the problems that industries are facing. Blockchain's potential benefits provide the stimulation for some organizations to adopt this technology and it is becoming a widespread technology used by numerous companies. Through automation, decentralization, disintermediation, and remodeling of value chains, there will be improvements in operational efficiencies, data security, data processing, cost reduction, and industry growth.

Blockchain technology has promising capabilities which can help overcome the challenges that already exist in the oil and gas industry such as challenges in supply chain management and trading, data management, data security, and accounting. The reason large oil and gas companies are working on the application of blockchain technology in the few past years is that it can significantly improve the management level, operational efficiency, and data security in the oil and gas industry (Lu, Huang, et al., 2019). In a research study conducted by Shell, BP, and Equinor it has been estimated that blockchain technology adoption can reduce transaction execution time by 30% (Musienko, 2019). Therefore, Blockchain may play a vital role to solve some of the problems in this industry and can accelerate the digital transformation. The potential of this technology to create integrated platforms can increase transparency and reliability by streamlining the industry processes (Lakhanpal & Samuel, 2018).

The focus of this study is on how blockchain as a disruptive technology alters the oil and gas industry and transforms the way the industry is currently operating by understanding the idea behind this technology and investigating its potential benefits.

Blockchain applications in the oil and gas industry are still at the experimental stage with small investments in the technology, many companies still have very little or no knowledge at all about this technology and this study is an attempt in increasing awareness about the technology and the opportunities that this technology brings to the industry both now and in the future. The results from this study can benefit managers and decision makers in the oil and gas industry in decisions regarding the adoption of this technology in a way that it can add value to the industry.

There are still many questions to be answered and much research needs to be done on the adoption of blockchain technology in the oil and gas industry. By reviewing the related literature and interviewing the experts in the oil and gas industry who were completely familiar with this technology, potential benefits, and opportunities, challenges that are hindering the implementation of blockchain in the oil and gas industry, and risks brought about by blockchain technology are assessed. Moreover, the adoption barriers and some solutions to overcoming these barriers are discussed. Followed by a discussion of the future of blockchain technology in the oil and gas industry.

The interviews were designed and executed to find out the competitive advantage of the implementation of blockchain technology in the oil and gas industry. The results were analyzed to find out whether or not this technology can add any value to the industry. By assessing blockchain value proposition in the oil and gas business, companies may choose to adopt the technology anywhere it could be a good fit. The thesis is organized as follows:

1.4. Thesis Structure

Section 2 provides a brief background for the study. Section 3 presents the purpose of the study. In Section 4 a detailed review of the related literature about the foundational concept of blockchain and the implementation of blockchain technology in the oil and gas industry is presented followed by a theoretical framework used in this thesis. Section 5 describes the Methodological choices that are performed to investigate the research questions. Moreover, sampling, data collection, and data analysis methods are explained. In section 6 the main results from the study are analyzed and the chapter ends by presenting the answers to the research

questions. Section 7 is the validation chapter where the main findings of the research, sources, and methods are validated together with a discussion of the contribution of the study to previous literature. Section 8 summarizes the main conclusions drawn from this study. Section 9 presents the limitations of the study and the implications and suggestions for future research. Section 10 is the list of references.

2. Background

Digital technologies are utilized in the oil and gas industry with the goal of reshaping the industry and the industry's value chain that can subsequently increase the efficiency and productivity of the industry (Antipova, 2020). Digital transformation can have great advantages for the industry such as operational efficiency acceleration, safety increase, risk reduction, and production optimization (Ahmad et al., 2022). Emerging technologies like the Internet of things (IoT) and cloud computing are among the innovative technologies which can play a vital role in the oil and gas industry (Ahmad et al., 2022). Another technology that has become very widespread in many industries recently is blockchain technology. In 2020, Equinor software innovation introduced 12 disruptive technologies that would shape the future of energy companies, one of them was blockchain technology as a technology capable of creating distributed trust (Wesenberg, 2020). The applicability of this technology is being tested in different use cases and situations in many industries and its applications in the oil and gas industry are the focus of this study. So far, the technology has shown to have promising potential for this industry according to the latest studies in this area.

The development of blockchain technology date back to 2008 when Satoshi Nakamoto introduced the decentralized cryptocurrency called Bitcoin which is the most famous use of blockchain technology. There are three stages in the development of Blockchain technology in this decade. Blockchain 1.0 era which is represented by Bitcoin and comprises the virtual cryptocurrencies, blockchain 2.0 era which is represented by Ethereum and smart contracts, Smart contracts are digital contracts or protocols that execute predefined rules of transactions automatically and without the involvement of the intermediaries. Blockchain 3.0 era which is about applications in the social field (Mohsin et al., 2019). This developmental stage is still as a vision indicating that the concept of smart contracts develops further to creating decentralized autonomous organizational units that operate based on their own predefined laws (PwC, 2016).

Blockchain technology then found its way into many industries and the potential use cases of blockchain technology are growing rapidly across industries. Some of these applications can be applied in the oil and gas industry and can have significant implications. In the oil and gas industry, however, the technology was not adopted early since the industry is in general a slow adopter of new technologies and has more of a wait and see attitude, and rarely disrupts and leads new technologies. It was until 2017 that blockchain technology was applied by British Petroleum (BP) in the oil and gas industry (Lu, Huang, et al., 2019).

3. Purpose of the study

The novelty of blockchain technology and its scarce implementation in the oil and gas industry encouraged the author to explore about blockchain technology adoption in the oil and gas industry. Although many studies prove that blockchain technology is disrupting and reshaping energy industries, however, the rate of blockchain technology adoption in countries with high rates of industrial technology development such as Norway is still low. Especially in the oil and gas industry blockchain technology adoption is in its infancy. Therefore, there is great room for research about blockchain adoption in this industry. Blockchain usability in oil and gas is considered as a research gap. Although there are numerous predictions about the potential of this emerging technology in the oil and gas, there are still shortcomings in theory about the real applications and what value can this technology bring to the companies.

The goal of this study is to investigate the current state of blockchain technology and its applications in the oil and gas industry to find out where in the oil and gas industry blockchain technology as a disruptive technology is able to provide value-adding digital solutions to different challenges. The study aims to demonstrate the practicality and capabilities of this technology in the oil and gas industry and to highlight how specific characteristics of this disruptive technology can revolutionize the status quo. It is done by a systematic review of the most recent literature about the existing blockchain-based applications and case studies in the oil and gas industry as well as a thematic content analysis of the interviews with experts in the oil and gas field who are currently involved in implementing blockchain technology in oil and gas projects to overcome problems in the oil and gas industry. Perspectives from both academia and industry practitioners are gathered, analyzed, and evaluated to examine the benefits and challenges of blockchain technology adoption in the oil and gas industry and to understand which criteria should be met for overcoming barriers to blockchain adoption in oil & energy companies. Moreover, this study tries to elucidate the influential factors in the adoption of blockchain technology. The motivation of this study is to create awareness among managers, practitioners, and researchers in the oil and gas industry about blockchain technology and its applicability in order to offer a road map for the effective adoption and development of this technology in the oil and gas industry. Moreover, this research tries to remove the uncertainties that result from an insufficient understanding of how blockchain works. This research is an attempt to gain a better understanding of the technology and its effect on the functioning of oil and gas organizations.

There are three main research questions to be addressed in this study are as follows:

1. What are the key opportunities and applications of blockchain in the oil and gas industry?

2. What are the challenges and barriers to implementing blockchain technology in the oil and gas industry?

3. What are the influential factors in the adoption of blockchain technology in the oil and gas industry?

These research questions will be investigated through a review of prior literature and interviews with companies pioneering in providing blockchain solutions to the oil and gas industry. The purpose of this study does not cover the technical and programming aspects of the technology.

4. Theory

To understand what values blockchain technology can add to the oil and gas industry, it is necessary to understand what this technology is and how it functions to a certain degree. Therefore, the theory section is divided into three main parts. Firstly, it introduces the fundamental theories of blockchain and basic principles of the technology including the concept of blockchain and the core characteristics of the technology. Secondly, the chapter discusses blockchain technology applications in the oil and gas industry although a detailed presentation of the applications is presented in the analysis section of the study. The last part of the chapter introduces the theoretical framework that the researcher has applied to analyze the findings of this study.

4.1. Theories of blockchain and definitions

The following parts systematically explain what blockchain is and how it works. Moreover, definitions of major terms used in this study are provided.

4.1.1. Distributed ledger technology (DLT)

Distributed ledger also called a shared ledger is a public and decentralized digital database. DLT is a consensus of replicated, synchronized data that can be shared across multiple sites, institutions, and countries (Lakhanpal & Samuel, 2018). There is no centralized administrator or centralized data storage in distributed ledgers. (*Distributed ledger technology: beyond block chain*, 2016) & (Lakhanpal & Samuel, 2018). In other words, a distributed ledger is a shared database among several nodes or computing devices, and exactly the same copy of the ledger is saved and replicated by each node. A node is any entity that can connect to the blockchain, and those verifying all the rules of the blockchain are called full nodes (Casino et al., 2019). Each node records and constructs the updates to the ledger independently and there is no centralized server or authority. Each node has the same network power. To come to an agreement about the conclusion each node votes on the updates, this process of voting and coming to an agreement on one copy of the ledger is called consensus (Ray, 2018). A consensus algorithm conducts the consensus automatically. The distributed ledger updates itself once the consensus is reached and the latest updated version of the ledger is saved by each separate node. This updated version is the agreed-upon version. Since DLT removes the need for intermediaries like banks, lawyers, the government, etc., it can drastically reduce the cost of

trust. Distributed ledgers revolutionize the way transactions take place by changing the way data and information are collected and communicated (Ray, 2018).

4.1.2. Blockchain technology conceptual background

Blockchain is a subset of distributed ledger technologies (DLTs). A blockchain is a continuously growing chain of blocks where the data is recorded. The records on the blockchain are secured through the use of cryptography (Hughes, 2018). Each block contains the transaction data that are hashed and a cryptographic hash of the previous block that link the blocks to each other, and a timestamp. The blocks are linked and secured using cryptography to be used as a distributed ledger in a peer to peer network. Once the blocks are validated the data recorded in the blocks can not be altered. There is a chance of modification in the subsequent block but the consensus of the network is required.

Blockchain enables peer-to-peer transactions. This type of transaction creates the possibility of direct transaction among every participant in the network without any involvement of a third-party intermediary in an efficient and verifiable manner. There is no need for the traditional intermediaries such as banks, exchanges, or traders in peer to peer transactions because transactions are open to all participants and relevant information is stored identically and locally on the computers of all the participants so they can see each transaction and all the details about the transaction, therefore, the system is decentralized and highly transparent (PwC, 2016). The biggest innovation about blockchain is decentralization which means the data is no longer stored in the central database and is distributed to all participants (Lu, Huang, et al., 2019). Every member of the blockchain network has his own copy of the ledger or can access it in the open cloud (Andoni et al., 2019). This is contrary to the multi-tiered traditional transaction models in which providers and customers rely on a central authority as an intermediary platform that primarily stores the transaction data. Figure 3 is taken from Andoni et al., (2019) shows that a in centralized platform the ledger is managed by a single trusted authority while in a distributed transactional platform every member has a copy of the ledger (Andoni et al., 2019). Therefore, blockchain eliminates the influence of intermediaries.

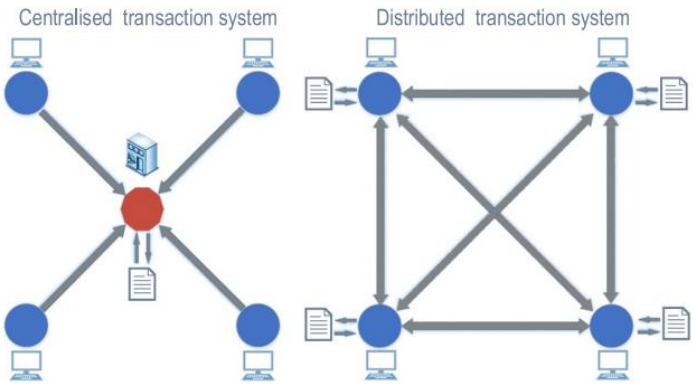

Figure 3. Centralized transaction system vs. Distributed transaction system (Retrieved from Andoni et al., (2019))

There are many definitions for blockchain all of which explain the same concept. According to Kshetri (2021), Blockchain is a decentralized ledger that keeps digital records of transactions simultaneously on multiple computers (Kshetri, 2021). Blockchain is a transaction mode that processes transactions through transparent and trustworthy rules to record data. Blockchain transaction data which are constructed in P2P network environments are traceable, non-forgeable, and non-tampering (Zheng et al., 2017).

Peer to peer network can be defined as a network in which every node has equal status or the same network power and all nodes share the same information. The information is stored in each node and not by the central authority. The challenge when there is no central authority is in the verification of the transaction and ensuring the integrity of the ledger. The verification process in blockchain is through a process called a consensus algorithm (Lu, Huang, et al., 2019). According to Zheng et al. (2017), consensus is the key mechanism to the proper functioning of the blockchain by determining the conditions which must be fulfilled so that a block can be validated for being added to the blockchain (Zheng et al., 2017).

There are many different specific blockchain systems, encryptions, and applications. There are various methods of cryptography that based on the strength of the techniques employed blockchain can be applied for different reasons. For example, it is increasingly used by military organizations (Hughes, 2018). A detailed description of cryptography is out of the scope of this thesis.

4.1.3. Functioning of blockchain

The following figure is an illustration of the way blockchain works in 5 steps. As can be seen, when two persons enter into a transaction, they first determine the variables of the transaction

such as the size of transaction, recipient, sender, etc., then all the information from this single transaction in combination with other transactions made during the same period of time make a new data block (PwC, 2016). After encryption, each transaction is distributed to multiple computers in a P2P manner which means that all these computers can store the data locally without any intermediary. Network members automatically confirm and validate transactions that are stored on each computer through algorithms. Each block is given a unique hash value by the algorithm (Lu, Huang, et al., 2019). The algorithm produces the correct hash code only for the right combination of data in the block otherwise the data in the block is not verified and the block is discarded.

The hash key is a series of numbers and letters that are created by the algorithm based on the information stored in the relevant data block. If the information related to the transactions in each block is mistakenly or intentionally changed due to error or tampering then the algorithm will no longer create the correct hash code and reports the error (PwC, 2016).

After the block is verified successfully, the new block is combined with other blocks which are already verified and will be added to the growing chain of blocks to form a blockchain. So, the blockchain is growing continuously. It is very difficult to tamper with the information stored on the blockchain due to the interlinking of the hash keys. The continuous process of verification is called mining and is done by the members of the blockchain. The last step is when both parties confirm the transaction which indicates that the transaction is completed successfully (Andoni et al., 2019). Therefore, blockchain provides the opportunity for peer-to-peer transactions directly between persons which can be legitimately recorded without the need for intermediaries such as banks.

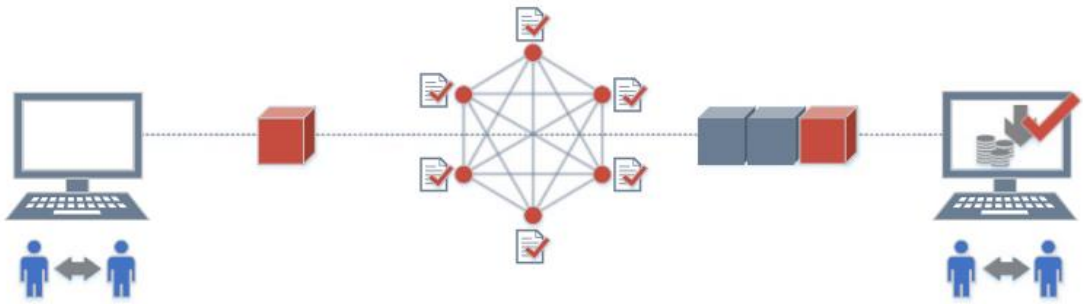

Figure 4. The blockchain transaction process retrieved from Andoni et al. (2019)

4.1.4. Classification of blockchain systems

There are different types and classifications of blockchain. The classification is based on the manner data is managed and become available and accessible as well as the actions that can be performed by the users on the blockchain (Lakhanpal & Samuel, 2018). Lakhanpal and Samuel (2018) classified blockchain based on authentication and authorization. Considering authentication or accessibility of blockchain by users there are public and private blockchains. By taking authorization into account and what users are allowed to do, permissioned and permissionless blockchains are defined. Permissioned blockchains include private and consortium blockchains and permissionless blockchains are public blockchains (Casino et al., 2019). The classification according to the scope of use is as follows:

Public blockchains are accessible to anyone without the need for approval from a third party. It means that public blockchains are permissionless and anyone in the world can join the blockchain, can send transactions, and participate in the consensus process (Lakhanpal & Samuel, 2018). The users do not need permission to perform a role and will anonymously contribute to the network. The most prominent feature of public blockchains is decentralization.

Private blockchains have an owner whether an individual or an organization who can restrict access to the network and joining the network must be permitted by the administrators or the central authority. Therefore, it is a closed system that is permissioned. Private blockchains can improve auditability but trust problems will still remain an issue in this type of blockchain (Zheng et al., 2017)

Consortium blockchains also known as federated blockchains are another type of permissioned blockchains. This type of blockchain is controlled by members of the consortium which can be a number of companies who have a node on this network. Permissions are determined based on the consortium rules. The data generated in this type of blockchain is only accessible by the authorized members of the network and only trusted nodes can execute a consensus protocol. Issues like data privacy and security are solved in this type of blockchain since it allows the owners of the blockchain to avoid exposing their sensitive data to the public and preserve their autonomy. It is a combination of public and private blockchains (Lu, Huang, et al., 2019). It acts like a semi-decentralized blockchain (Lakhanpal & Samuel, 2018). Table 2 shows the comparison of three kinds of blockchain.

Hybrid blockchain has an ecosystem that is a combination of both public and private blockchains meaning that it has the security and privacy of private blockchain as well as transparency of public blockchains. Therefore, hybrid blockchains provide more flexibility. They can be grouped as consortium blockchains.

Table 2. Comparison of three types of blockchain retrieved from Lu, Huang, et al. (2019)

Property	Private blockchain	Public blockchain	Consortium blockchain
Access	Public or restricted	Public	Public or restricted
Energy	Low	High	Low
Speed	Faster	Slower	Faster
Efficiency	High	Low	High
Security	Pre-approved participants and voting/multi-party consensus	Proof of work, proof of stake, and other consensus mechanisms	Pre-approved participants and voting/multi-party consensus
Immutability	Could be tampered	Nearly impossible to tamper	Could be tampered
Consensus process	Permissioned and known identities	Permissionless and anonymous	Permissioned and known identities
Consensus determination	Centralized organization	All miners	Leader node set
Network	Centralized	Decentralized	Semi-centralized
Asset	Any asset	Native asset	Any asset
Transaction approval	Order of milliseconds	Order of minutes	Order of milliseconds

Appropriate blockchain type for the oil and gas industry:

In the oil and gas industry, all types of blockchain can be used depending on the application needed. For digitalization of assets, tokenizing, incentivizing, and rewarding public blockchain is used. For decision making private blockchain is used. For supply chain consortium blockchain is used. It depends on what application you are using blockchain for.

The China Academy of Information and Communication Technology released a white paper in 2018 called blockchain white paper in which there is a flow chart showing different scenarios for different types of blockchain. The flow chart is shown in Figure 5.

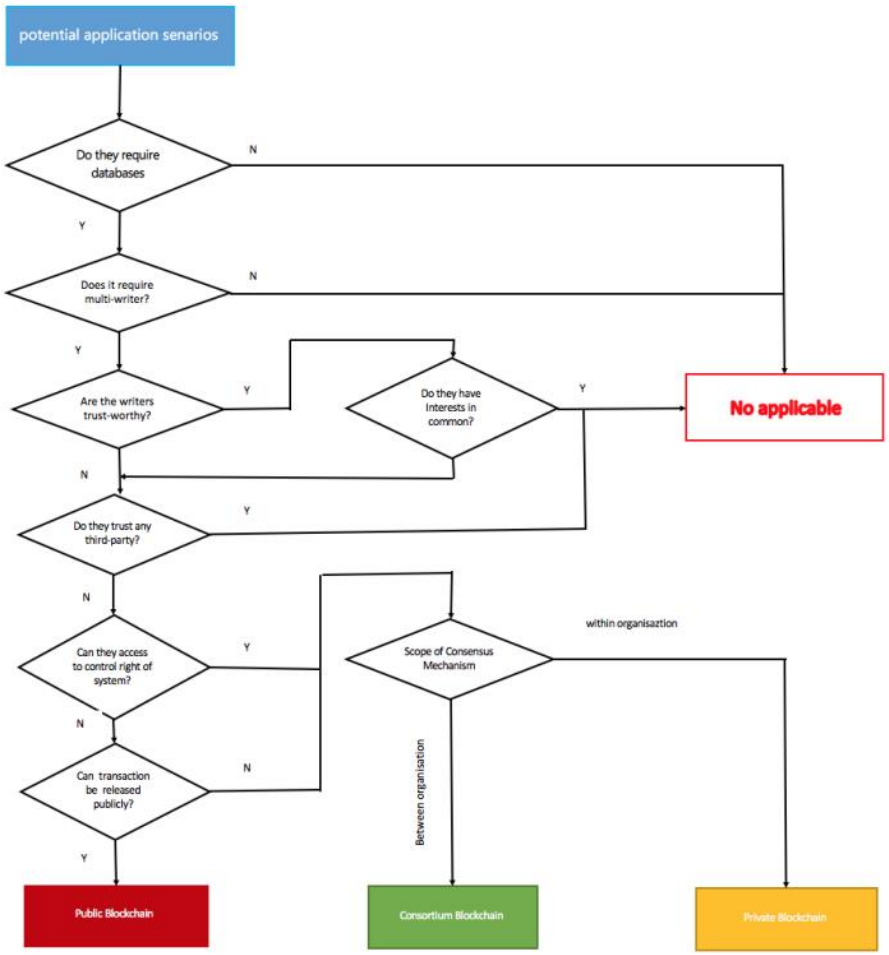

Figure 5. Flow chart for selecting blockchain type, Source: CAICT (2018)

4.1.5. Key Characteristics of blockchain

Literature shows that blockchain based systems have the potential to have an impact in numerous sectors, including finance, healthcare, supply chain management, and information systems, the characteristics of this technology are very promising and can benefit organisations and people using them (Boucher et al., 2017). In this section main characteristics of blockchain technology are discussed most of which make the technology attractive to the oil and gas industry as well. There are of course other characteristics of blockchain technology that will be considered later in other sections of the thesis.

1. **Decentralization:** the most prominent feature of blockchain based systems is that it is not governed by a central processing node and the status of each node in the network is equal. There is no authority.

2. **Transparency:** in blockchain, all the data is available to all the nodes of the network. Every peer has access to every transaction made making the system transparent. Data updates and data records must be transparent to make a trusted system. Therefore, transparency is the basis for and core characteristic of blockchain based systems.

3. **Traceability:** the data storage in blockchain is immutable which means transactions can not be altered or deleted once added to the blockchain and this makes the traceability characteristic possible.

4. **Security:** blockchain systems architecture allows to store the data in a tamper-proofed and immutable way. The decentralized nature of the systems makes it almost impossible and very challenging for ill-intentioned users to take advantage of the system. So, there will be data security and data integrity in blockchain. In contrast to the centralized networks if a node is attacked the security of the whole system is not destroyed. It can be stated that the security of the blockchain is a result of its other characteristics of immutability, decentralization, and transparency (Hughes, 2018).

5. **Immutability:** data stored in the blockchain can not be modified or deleted after verification and addition to the network. Therefore, there is high data stability and reliability in blockchain systems. Immutability leads to better traceability in the system.

6. **Efficiency:** Completing transactions in blockchain based systems is very fast and time saving. Transparency of the system and distribution of database records to all users make the system more efficient in terms of risk, cost, and time (Hughes, 2018).

7. **Auditability:** blockchain has features that make transactions auditable in real-time and it can be a game changer for audit processes.

8. **Pseudonymity:** in blockchain, there is no need for the parties in the transaction to know each other and they can make the transaction anonymously because of the preprogrammed set of rules which can automatically determine the validity of the exchanges between the nodes (Dorri et al., 2019).

9. **Automation:** Some applications of blockchain like smart contracts automate various activities.

10. **Distributed Trust:** blockchain systems are trust-free in the sense that no single authority is needed to be trusted and personal relationships are eliminated (Treiblmaier, 2019). Therefore, there is no need for intermediaries, and trust is provided by asymmetric cryptography. Validation and digital signature are proof that every node and user has done everything correctly (Lakhanpal & Samuel, 2018).

Knowing that blockchain can address these characteristics, more studies and research must now be conducted to explore whether these characteristics can solve problems in oil and gas and if

yes how. In what comes next blockchain use cases in the oil and gas industry are visited in more detail to guide us towards a better understanding of the technology and its application in the oil and gas industry.

4.2. Blockchain Applications

Despite the many advantages that blockchain technology can provide, the benefits of the technology should not be overestimated and inflated. Before applying blockchain in any industry such as the oil and gas industry, an objective evaluation of all the advantages and disadvantages related to the application of the technology must be considered as a guide toward the correct and appropriate implementation of the technology. Blockchain technology requires high power consumption moreover the expenses related to hardware setup are high hence it is very important to thoroughly evaluate whether blockchain can provide the best solution for specific projects before applying it. If the requirements of the project can be fulfilled by today's databases then applying blockchain is completely pointless. Blockchain should be used where it genuinely adds value to the project. There are many projects which use blockchain only because it is a hype technology where the project has nothing to do with blockchain at all. Therefore, certain conditions must be met and there must be a clear reason to choose blockchain for a project.

According to GreenSpand (2015), in order to determine whether a project is an appropriate use case for blockchain application five main questions must be answered.

1. Database- Since blockchain is a shared database the first question is to understand whether a shared database is needed at all or not?
2. Multiple writers- blockchain is a technology where multiple parties are involved so the question here will be is it necessary to have multiple parties writing data?
3. Trust absence- since blockchains are technologies for multiple non-trusting writers the question is whether writers should be prevented from modifying previous entities written by others.
4. Disintermediation- blockchain enables a database with multiple non-trusting participants or nodes where each node can independently modify or verify transactions without a need for a central authority. Now the question is whether it is necessary to remove trusted intermediaries? Is this disintermediation a necessity?

5. Transaction interaction- Is it necessary to check how transactions are correlated and linked to each other?

Therefore if certain conditions are not fulfilled then there is no need to use blockchain (GreenSpand, 2015). The goal is to use blockchain for problems that can not be solved by traditional databases.

4.2.1. Blockchain application in the oil and gas industry

Technologies began to transform the oil and gas industry in the early 21st century although the digitalization process of most oil and gas companies is still slow. The oil and gas industry is receptive to many innovative technologies in different parts of the industry's value chain. The reason is the volatility of the oil prices which impacts the stability of the industry greatly. In recent years from 2014 to the present time, the fall of oil prices resulted in exploration and production fall and consequently problems such as mass layoffs and increased unemployment rates. Under high pressure, oil and gas companies tried to rethink their operations and find ways to cut costs and maximize profits and improve transaction processing by applying innovative solutions in certain areas of the industry.

Blockchain technology can be used in the oil and gas industry for the purposes of increasing efficiency and reducing costs. According to the reports issued by Deloitte in 2017, blockchain technology has great potential in the oil and gas industry mainly in four main areas of supply chain and trading, management, and decision making, supervision, and cyber security (Lu, Huang, et al., 2019). Blockchain can help the industry by securing data, increasing transaction transparency, and tracking goods and equipment. (Deloitte, 2017).

The energy giants BP, Shell, and Equinor began to invest in blockchain technology in 2017 and they are the pioneers of blockchain application in the oil and gas industry. Then in 2017, China's first blockchain crude oil import trading pilot project was successfully conducted. The two major applications of blockchain based on this project were smart contracts and digital billing which could significantly improve crude oil trading and optimize transactions by 20% to 30% (Milano, 2017).

A systematic review of possible applications and scenarios of blockchain implementation in the oil and gas industry from these four perspectives is presented in the analysis section of the study.

In the case of oil field operations, Zuo and Qi (2021), stated that previous monitoring and controlling systems were centralized and prone to failure without acceptable efficiency. For automatic monitoring of the operations of the oil industry, blockchain can be used to reduce the centralization issues including a decentralized, immutable, and transparent control environment. They suggested a blockchain-based internet of things (IoT) framework for monitoring and control to enhance the operation of oil industries and property efficiency together with safety based on a real-time framework. They have presented important components consisting of algorithms, smart contracts, and system architecture. A smart contract was developed and verified on a blockchain framework as a proof-of-concept. Based on a comparative analysis, they proved many benefits of blockchain and smart contracts for providing reliable and automatic monitoring for different operations in the oil industry.

Miao et al. (2020), suggested a natural gas IoT system conducted on the basis of blockchain and AI to solve problems in natural gas transactions. The possible deficiencies in the existing natural gas energy supply system include unreliable transactions, variable prices, inaccurate gas data, and unsecured user information. Blockchain has been introduced to be used as distributed storage for trusted transactions and AI technology was utilized for natural gas data analysis to resolve the mentioned issues.

4.2.2. Blockchain application in supply chain management

Applications of blockchain in the supply chain attracted dramatic attention from industry and the scientific community. In the last decades, the blockchain as new technology has emerged and affected logistics and supply chain. In different private and public industries, this technology is in the early stages of development and testing (Dubey et al., 2020). In the USA, an open-source tool was suggested to develop and evaluate the services of blockchain technology in different sections of the government. The China Federation of Logistics and Purchasing (CFLP) has introduced a blockchain structure considering the basic aim of expanding standards for this technology. Similarly, the technology is also utilized in Russia Blockchain Consortium and Dutch National Blockchain Coalition, and also numerous developed countries (Liu et al., 2020).

Blockchain is used in logistics and supply chains, for securing, validating, and trustable exchange of data in real-time. It can lead to more accessibility and improved information exchange for all related members of the supply network together with other involved

individuals. Blockchain can also bring about the feasibility of automatic verification of agreed-upon transactions through using smart contracts.

Blockchain technology can help in reducing counterfeit and fraud risk, increasing trust, tracking product origin, demand forecasting, and tracking product flow via supply network as well as providing open access to information in the supply chain. therefore applying blockchain systems to logistics and supply chains will be more secure, authenticated, and trustless (Dujak & Sajter, 2019). There are more studies proving the benefits blockchain technology can have in the oil and gas value chain.

Ajao et al. (2019) have suggested an approach to evaluate and secure the distribution of petroleum product records considering a decentralized ledger database by utilizing the Blockchain method. This approach was used to secure the transaction of distributed ledgers as well as to protect records from many common problems such as fraudulent activity, tampering, and corruption from the chain of participants. They have stated that the blockchain approach provided a worthy security measure and many further benefits like the existence of transaction and distribution ledger management among the transporter, depot, and retailing filling station. Moreover, transparency, immunity to fraud, insusceptibility to tampering, and maintaining record order have been classified as the advantages of blockchain (Ajao et al., 2019).

Haque et al. (2021), believed that blockchain can be utilized for solving different issues of the traditional oil and gas supply chain by controlling the whole system. They introduced some benefits such as *data security* since blockchain can store the whole data which cannot be varied and is almost impossible to be tampered with. The second benefit introduced is real time data updating through using smart contracts. The adaptability of blockchain and smart contracts enables the system to update the information in real-time. Other benefits are customer access and removing third-party. Utilizing smart contracts can eliminate intermediates for controlling the price of oil providing the international market is volatile. Product Authenticity is another benefit since in the BT, the oil id, oil name, date, and time can be stored. Therefore, the final consumer evaluates the accuracy of the oil so the oil supply chain can be automatized by utilizing a blockchain based framework that can provide great help in the case of the oil industry. They then discussed some of the challenges in blockchain adoption in the supply chains in addition to its benefits. Blockchain can be used to reduce the traditional oil supply chain issues but there still remain some challenges. First, there can be a great data load from internet of things systems. In addition, there are many packages provided by distinct companies in the world. Monitoring any transactions and packages is hard work. However, the scalability

of blockchain is yet a problem, private blockchains are a little back from a fast update yet. In addition, the system sustainability was determined as a big issue that is hard to handle an IoT-based issue instantly in the case of a global supply chain. The process of updating smart contracts may be delayed (Haque et al., 2021).

Aslam et al. (2021) have provided research based on the blockchain for many industries with a focus on supply chains. They stated that the Radio-frequency identification (RFIDs) is obsoleted currently because blockchain can be used as a tool for this field due to existing unique attributes of that including transparency, cyber-security, reliability, real-time information sharing, visibility, and traceability that can be used to boost the performance of supply chain. In recent years, despite existing many efforts in the field of using blockchain, any clear framework is not introduced for a supply chain based on blockchain. Aslam et al. (2021), provided an effective framework based on a complex supply chain network. Firstly, they have introduced the practical supply chain fitted to the oil industry by considering a real case study, and then the impact of these practices was empirically analyzed and evaluated based on operational performance. They have found that the management of supply chain practices can affect the performance of the operation, positively. In addition, different Blockchain properties were detected and the related effects on many supply chain practices were suggested. For analyzing current supply chain practices as well as understanding the relationship between supply chain practices and Blockchain attributes, the results of this study were determined to be helpful for managers and decision-makers. More applications of blockchain in the oil and gas supply chain are discussed in the analysis section.

4.3. Theoretical framework

The choice of theoretical framework depends very much on the researcher's aims of exploration and on the best way to tackle the research questions. This study is a qualitative study done through semi-structured interviews so that the respondents can openly and freely provide their insights from different angles about the issues under investigation. Therefore, the researcher does not intend to obstruct the natural flow of the ideas by confining the respondents' ideas to a limited set of theories. At the same time, a theoretical framework can provide scientific proof for the project by showing that the existing theories in the literature can support the findings of this study. Another advantage is that the theoretical framework gives a clear and logical structure to the project and makes it more understandable for the reader. Therefore, the researcher decided to select a more comprehensive framework for

analysis of the results of this study. The integrated framework of technology adoption proposed by Zamani (2022) is applied in this study. This integrated framework encompasses all the theories that have previously been used for technology adoption in the literature from the past decade through the systematic literature review approach (SLR). A review of recent studies has shown that all these theories have been applied to blockchain adoption studies by other researchers.

The theories which were mostly applied are: technology, organization, and environment (TOE), diffusion of innovation (DOI), technology acceptance model (TAM), actor-network theory (ANT), unified theory of acceptance and use of technology (UTAUT), and theory of planned behaviour (TPB) (Zamani, 2022). These widely applied theories are briefly explained in what follows but

According to TOE which is the most popular framework, technological, organizational, and environmental contexts influence the technology adoption process in the organization (Baker, 2012). Another popular framework in technology adoption is DOI theory, developed by Rogers which explains how an idea or product diffuses through a specific population over time (Pathan et al., 2017). TAM or technology acceptance model discusses that attitudes and behavioural intentions toward the technology influence its acceptance by the user (Marangunić & Granić, 2015). TBA and TRA also focus on behavioural intention to be determinants of technology adoption. And in UTAUT four key constructs of Performance Expectancy, Effort Expectancy, Social Influence, and Facilitating Conditions, are influencing technology adoption (Ahmad, 2015). Based on these widely used theories used in 349 ISI papers Zamani (2022) proposed an integrated framework for technology adoption which is shown in figure 10. Based on this framework Zamani has identified 11 categories influencing technology adoption each containing several concepts. This integrated framework considers technology adoption as a dynamic process because of the dynamic nature of today's new technologies unlike many studies viewing it as a static process (Zamani, 2022). In this framework, influential concepts on the adoption of new technologies in the organizations are categorized and the barriers and supporting factors in technology adoption are considered through a comprehensive perspective. The framework is the best fit for the goals of this study in terms of an in-depth understanding and analysis of the issues being researched.

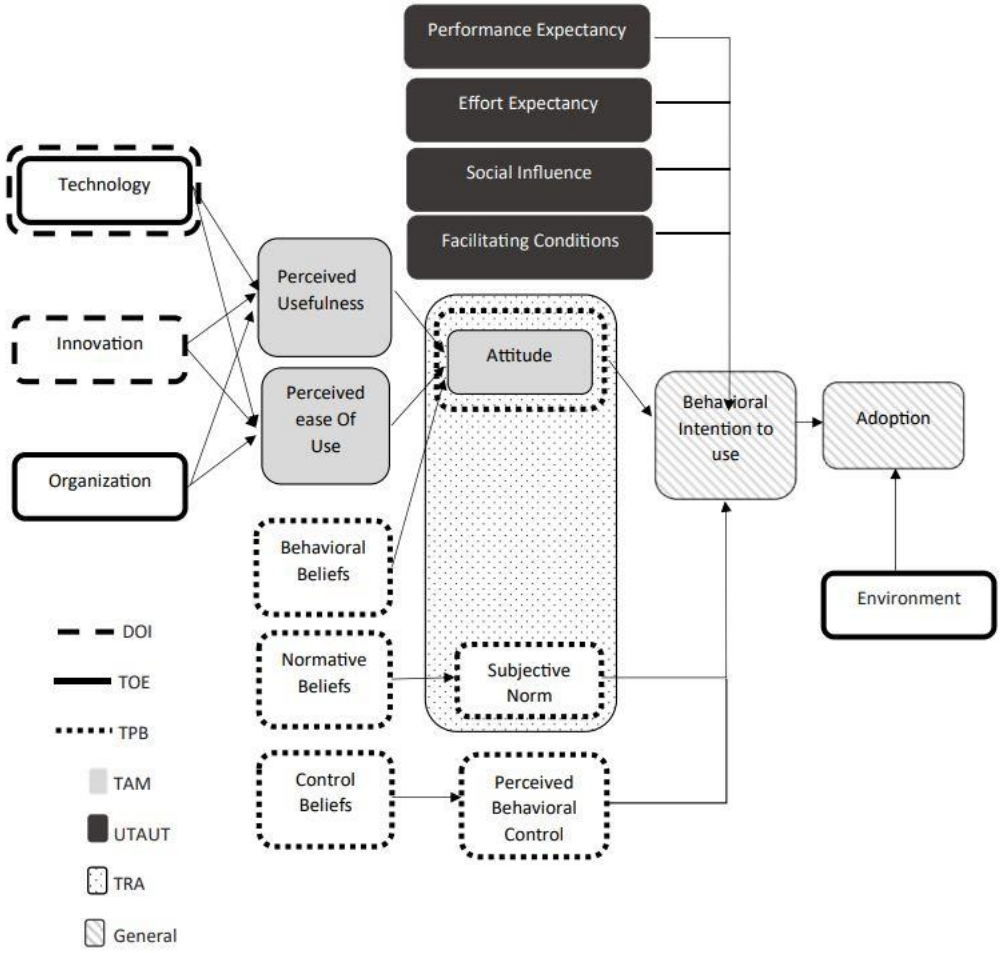

Figure 6. An integrated framework for technology adoption. Source: Zamani (2022)

The eleven categories extracted from a collection of 349 peer-reviewed articles by reviewing literature from the past decade and the most popular technology adoption influential factors with the mostly discussed determinant concepts in each category are listed in Table 3.

Category	*Definition of the category*	*Important concepts in each category*
Technological	Any concept related to the technical characteristics of a particular technology	Compatibility, complexity, relative advantage, perceived benefit, ease of use
Environmental	The surrounding and context of the organization such as geographical location, market, industry	Competitor's pressure, customers' pressure, external support
Management	Characteristics of the top managers e.g., skills, knowledge, experience	Top management support, top management commitment, top management knowledge
Organizational	Organization characteristics	Size, organizational readiness, innovativeness, culture
Knowledge	Characteristics of all stakeholders excluding managers pertaining to knowledge, experience, education, and skills	Employees' technical knowledge, knowledge constraints, prior IT experiment
People	Any attribute other than feature related to knowledge	Openness to change, perceived trust, intention of adoption, individual attitude
Financial	Financial issues such as measurements of profitability	Cost, Return of investment (ROI), financial supports
Resource	Any source of supply, aid especially readily available ones	Financial resources, human resources with skill, technology access, time,
Strategy	Setting goals and priorities, determining actions to achieve adoption goals	Strategic orientation, perceived risk, communication
Regulation	Rules made by the government or other authorities to control the way of technology adoption	Government regulations, government support, government awareness
Infrastructure	Any basic systems or services needed for technology adoption	IT infrastructure, infrastructure limitations, organisational infrastructure

Table 3. 11 identified categories and influencing factors in technology adoption. Source: Zamani (2022)

The researcher makes use of these influential categories and concepts in the analysis of the results. This integrated framework of all most used theories about technology adoption can help as a guiding path to compare and to contrast the obtained results from the participants of this study with the previous studies in the literature about technology adoption.

Zamani (2022) has designed a mapped version of this integrated framework for these 11 identified influencing categories as can be seen in Figure 7. In this mapped version the categories that are taken into consideration in theoretical frameworks are represented in solid lines and dashed categories refer to categories in the literature that are used alone and not as a framework. This is an indication that even in the studies that use integrated frameworks of the top six theories of technology adoption, only a limited number of influential categories are taken into consideration (Zamani, 2022). Therefore, there is a need for more comprehensive studies of technology adoption.

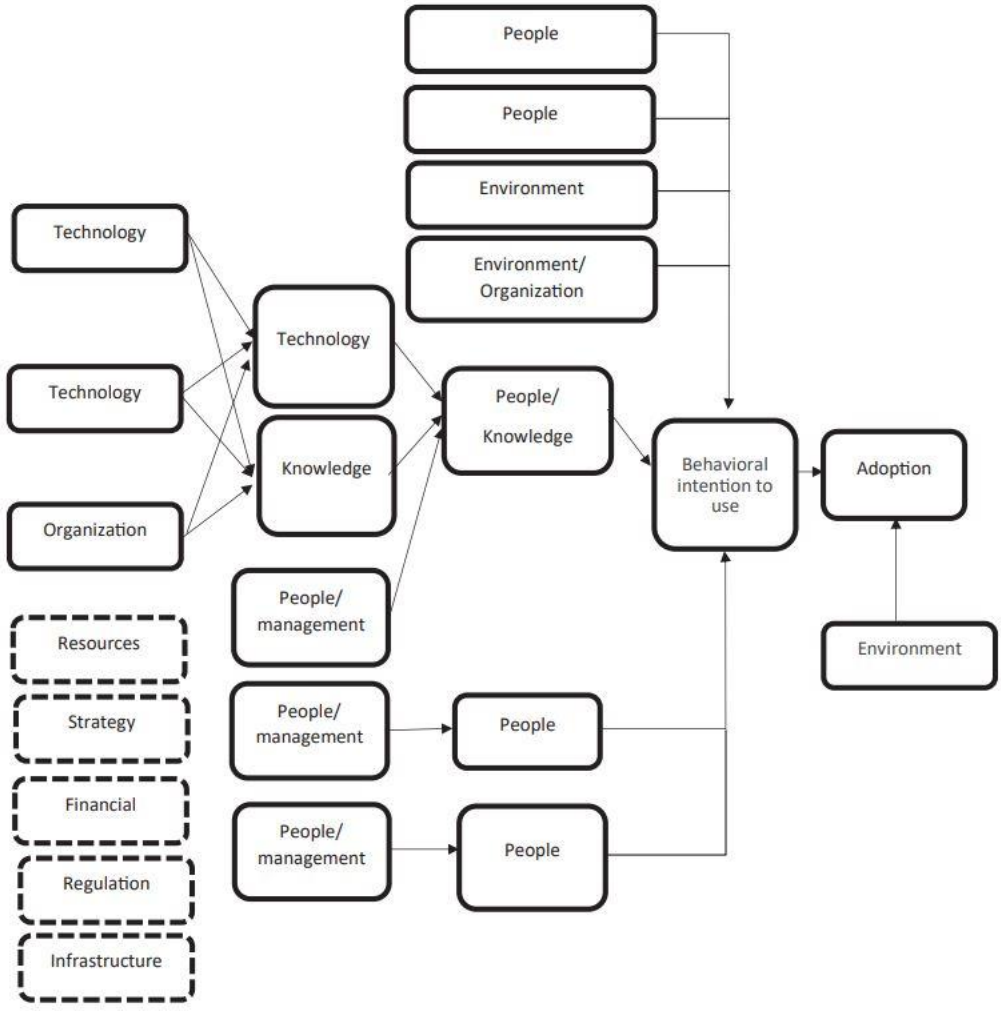

Figure 7. Categories mapped on the integrated framework. Source: Zamani (2022)

This integrated framework is considered for the blockchain adoption in the oil and gas industry in this study since it provides a comprehensive and in-depth knowledge of influencing factors on the adoption of technology.

5. Methodology

As mentioned earlier the novelty of blockchain technology and its scarce implementation in the oil and gas industry encouraged the author to explore about blockchain technology adoption in the oil and gas industry. The goal of the research is to explore the benefits and challenges related to the adoption of blockchain technology in the oil and gas industry, blockchain implementation barriers, and future trends. This chapter presents a detailed explanation of the appropriate methodology applied towards finding reliable answers to the research questions. The research onion model proposed by Saunders et al. (2012) is used to explain every stage involved in designing the research methodology for this study. As can be seen in the following illustration each layer indicates a stage in the research process. Developing the research methodology is analogous to peeling the research onion backwards from the outer layer to the inner layer one layer at a time (Saunders et al., 2012).

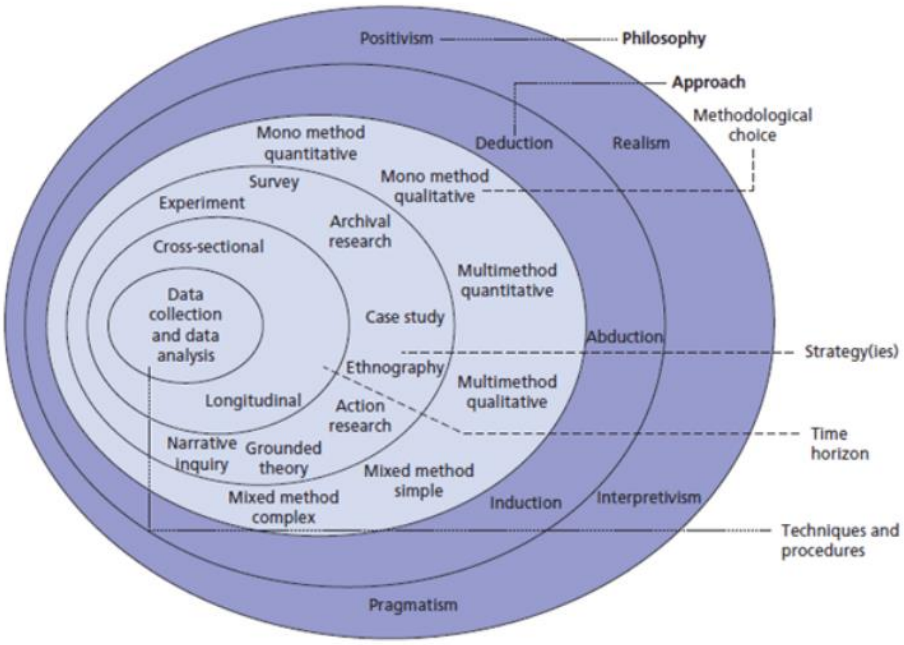

Figure 8. Research Onion. Source: Saunders et al. (2012)

5.1. Research Design

5.1.1. Research Philosophy

This is the outermost layer of the research onion framework. Research philosophy is the foundation of any study. It is about building up beliefs and assumptions about how to collect and analyse the data. The philosophical approach that is adopted for this research is

interpretivism where reality is explored subjectively. this choice is based on the nature of this research and research questions. The interpretivist paradigm is appropriate in studies where there is little prior research and theoretical development. It is most appropriate for doing an in-depth investigation in qualitative studies with small samples. The focus is on the thoughts and ideas of the participants and the researcher plays a very active role in the research. Data is interpreted to let the knowledge and theory emerge.

5.1.2. Research Approach

This study is exploratory in nature where the researcher reaches out for understanding the issue under study through exploration and interpretation. The research starts from the data collected through interviews and by organizing and interpreting the data from the bottom up, patterns, categories, and themes are built. Therefore, this research has an **inductive** process of moving from the database to more meaningful units of information and more comprehensive themes. This type of research is subjective since the data is recorded and interpreted by the researcher. Although in this research a deductive way of thinking was also involved while moving backwards from the main themes to the database for gaining a more comprehensive understanding of the themes. (Creswell, 2017).

5.1.3. Methodological Approach

This research is broad and general in nature and there is still little literature about blockchain technology in the context of the oil and gas industry since the technology is novel by itself. To answer the research questions the researcher strives to establish a holistic picture of the main themes and variables under investigation by considering multiple aspects of the central topic. Therefore, the most appropriate strategy for reaching an in-depth understanding of *how* blockchain technology can reshape the oil and gas industry is a **qualitative approach**. Qualitative research allows the researcher to report multiple perspectives and identify many factors relevant to the study from different faucets of a central phenomenon (Creswell, 2017). The focus of qualitative research is on textual, visual, and audio based data rather than numerical data. Qualitative research is preferred when the researcher aims to capture accurate, in-depth insights and factual data which represent the current dynamics in the field.

5.1.4. Research Strategy

In this stage of research design, there is a shift from more conceptual and intangible aspects of the research to more practical aspects. In this study, the research starts from the data from the information grounded on the views of the participants. Results are drawn from analysis of that data and the commonalities in the data without any attempt to fit the findings to pre-existing theories. The research is a typical qualitative study based on one-to-one interviews with experts with the goal of gaining in-depth information about the issues under study.

5.1.5. Time Horizon

In this study data is collected in a certain time span, spring semester 2022, so the data collection has a **cross-sectional** time horizon. The research onion for this study is illustrated in Figure 8.

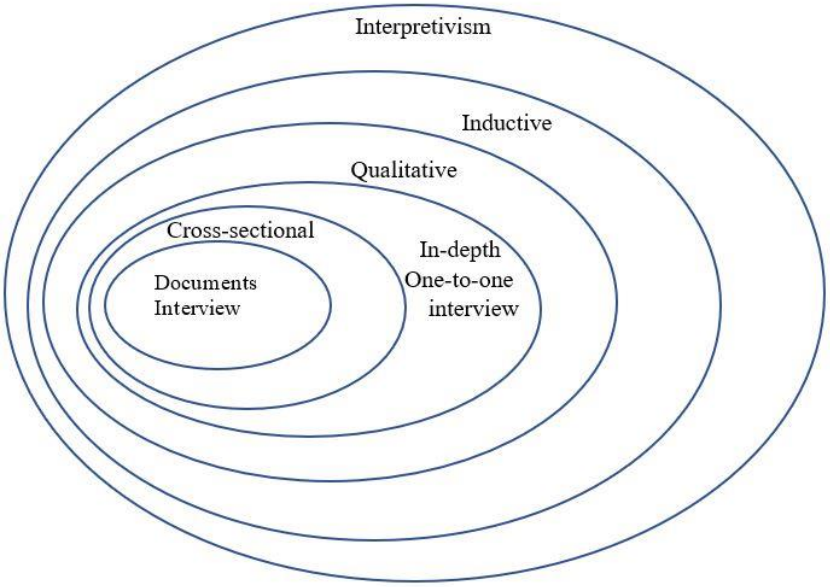

Figure 9. Research onion of this study

5.2. Data Collection Methods

To collect the essential and appropriate data for finding the best and most updated answers to the research questions in this study, both primary and secondary sources of data were considered. Since studies about blockchain adoption and implementation in the oil and gas industry are limited, the researcher aimed at gathering the most relevant and updated information from knowledgeable experts in the field who are currently working on projects with hands-on implementation of blockchain technology to solve problems in the oil and gas industry and supply chain management. In addition to the data collected through interviews,

secondary data was gathered from many different sources such as the most recent scientific articles published in scientific journals, from online reports, and the company's websites. Using more than one method of data collection which is called *triangulation* can increase the validity of the research and decrease the bias. The data for this study is divided into three main categories and more details are provided for each category in the following sections.

5.2.1. Documents and Audio-visual Materials

A thorough review of the literature was done on the research topic using different sources of authentic information such as scientific journals, books, online reports and surveys, and News articles from authentic sources such as Deloitte, IBM, PwC, Accenture, EY, and Bp energy outlook. Websites of the companies that are directly involved in implementing blockchain in oil and gas projects were another important source of data collection. Equinor, Data gumbo, and Blockchain for Energy websites are the three most visited websites. *Blockchain for Energy Consortium* and *Data Gumbo* are doing interesting projects in the oil and gas industry. Another very useful source of information was Podcasts about innovation in the oil and gas industry. The most useful and relevant podcasts to the goal of this research were those from Geffrey Cann available on his website together with many other sources of information such as his blog series interviews and public presentations. TED talks on YouTube about blockchain and available university seminars on blockchain were reviewed. ChainTalk channel was the best source of finding relevant data and most importantly finding the right participants for this study. Zara Zamani the host of ChainTalk conducted interviews with experts and carried out discussions on blockchain and provided the researcher with a great opportunity to get to know experts active in blockchain society. Another useful source of information about recent advancements in blockchain technology was LinkedIn. This networking media was a great help for the researcher to get to know and communicate with the experts. Last but not the least taking an online course in Basics of Blockchain Technology provided the researcher with a basic understanding of the technical aspects of blockchain technology. Although technical information about blockchain is out of the scope of this research, it is useful to have some background knowledge about the technology to better understand its applications in different use cases. It is also worth mentioning that to learn about qualitative research free online lessons by Dr. Kriukow on his website were the best online tutorial source besides reading books from Creswell.

5.2.2. Interview

The main data collection process in this study was through conducting **interviews**. Based on the aim of this research and the nature of research questions which include a broad range of topics, it was decided to collect primary data by directly interviewing the target population. Another reason for choosing interviews as a data collection tool in this study was that interviews provide a great opportunity to gather precise and unadulterated data from the most relevant sources. Moreover, the interview process generates a large amount of relevant data which can be broken down into meaningful inferences to solve different problems. The purpose of doing expert interviews was to approach the issue under investigation from different perspectives and to compensate for the lack of sufficient up to date information in the literature. Detailed information about participants of the study and the selection criteria is provided in section 5.2.4.

5.2.3. Participants and Selection Criteria

The sampling of participants in this study was non-probability and purposive sampling. Experts in blockchain technology and the oil and gas industry from Europe and U.S. were invited to participate in this study. They were from both academia and the industry. Practitioners were in leadership positions. All participants had an acceptable level of knowledge about applications of blockchain technology in different industries and had professional experience in oil and gas or supply chain management. Two of the participants were experts in supply chain management without working experience in the oil and gas industry but had extensive knowledge about blockchain applications in different industries including oil and gas. One is a university professor and active researcher in blockchain and sustainable supply chain management and the other is a blockchain architect providing this technology for other industries. Detailed information about the participants of the study is presented in the Analysis chapter.

5.2.4. Interview Procedure

The questions designed for interviews were based on the main research questions and were designed by breaking down the research questions into about 20 preliminary questions which were shortlisted to about 10 questions. The questions were identified while doing a review of the literature with the goal to address issues under investigation as accurately as possible. The

researcher designed a semi-structured interview which was a list of pre-determined open questions with a primary focus on the main themes of the study such as the benefits and challenges of blockchain adoption in the oil and gas industry. The use of pre-determined questions provides uniformity to the data. The questions were designed in a way to prompt discussion and provide the opportunity for the interviewer to explore themes or responses in more detail. This type of interview unlike structured ones does not limit the respondents to a set of predetermined answers. It can create an opportunity for the researcher to make inferences and to compare and contrast the responses among the participants of the study. Additionally, this type of interview allows the interviewee to raise issues that the researcher may not have considered previously. This increases the chances of learning and gaining new information for the researcher. For all these reasons semi-structured interviews were regarded as the best option considering the purpose of this research. Semi-structured interviews provide flexibility for both the interviewer and interviewee but at the same time, it is not a purely objective process. The interviewer could change the order of questions or ask some additional questions depending on different responses received in the course of the interview and different people talking to. However, all the questions were covered in each interview since the researcher had prepared an *interview guide* (see Appendix. A).

All interviews began with an introduction and presentation of the research goals. Practical information about the interview process and participants' rights were explained in advance and for the sake of confidentially recording started after asking for permission. 11 interviews were video recorded and only one was audio recorded. Video recordings were preferred since nonverbal behaviour and interactions can be helpful in data analysis. 13 participants took part in the interviews. 12 Interviews were conducted remotely via Teams in addition to one in-person interview. The reason most of the interviews were conducted online was the distance due to the geographical diversity of the participants. Although there were complexities in scheduling due to different time zones, however, the participants were very cooperative in overcoming this challenge. Each Interview took on average 40 minutes, with the longest one taking about 1:20 mins and the shortest about 25 minutes. One of the biggest challenges after conducting interviews is the transcribing process since it is a very time-consuming process. I could take advantage of Teams' automated and live transcription feature, so the process of recording and transcribing was done simultaneously with acceptable levels of accuracy, only minor editions were needed.

5.3. Data Analysis

After collecting the raw data through interviews and transcribing them, the researcher started organising the data and preparing them for analysis. The goal of data management was to identify, interpret and classify common, recurrent, and emergent themes. Since the data in a qualitative study is voluminous it is important to find themes directly related to the main research questions and discard redundant parts from the data. To this end, the researcher utilized both *content analysis* and *thematic analysis* methods to analyse the data. The researcher started by coding the data since coding is the very first important step in analysing qualitative data. Coding helps summarize the data into meaningful segments and then combine them into categories and finally concepts or themes. According to Creswell and Poth (2016), these steps are the core elements of qualitative data analysis (Creswell & Poth, 2016, p. 148). The same process is called " the three C's" approach by Lichtman (2009) where the three C's stand for codes, categories, and concepts. In the analysis chapter, all these steps are discussed and presented separately.

5.4. Ethical Considerations

In research, there are set of ethical principles that must be considered for the sake of human rights and scientific integrity and quality. These principles are to ensure that participation in this study is voluntary, anonymous, and confidential. The participant became well informed about the purpose of the study and how the data will be used, the researcher's identity, and their rights prior to their participation in the interview.

In this research permission to conduct the audio-video recordings of the interviews was gained before recording and each participant was asked whether they want to check transcriptions before their application in the analysis. They had the opportunity to correct and comment on their own statements. The researchers received the participant's consent on mentioning their names in the thesis. At the same time, the researchers provided confidentiality in that the recorded interviews will be stored in safely by the researcher.

The researcher remained neutral and unbiased in the course of conducting the research and minimised the occurrence of bias in the results and analysis sections. The researcher did not have any prior knowledge about blockchain and did not have any affiliation with any of the companies and consortiums related to the participants.

5.5. Methodological limitations

The development and changes regarding the application of blockchain are very rapid. Therefore, it was not enough to rely only on prior research found in the literature. To obtain updated information experts in the heart of the technology application were invited to take part in the study. Although their contribution had a great positive impact on the results, however, bias in their perspectives can be counted as one of the limitations of the interviews. The researcher tried to remain as neutral as possible in the analysis of data.

6. Analysis

In this chapter, the results obtained from the interviews are presented and analysed in different sections.

6.1. A snapshot of Participants

As mentioned earlier the sampling of participants in this study was non-probability and purposive sampling. Due to the need of the research for experts in both blockchain technology and the oil and gas industry and the scarcity of eligible participants in the researcher's immediate setting a multi-regional approach to the selection of participants was preferred. Participants from different regions in Europe and U.S. were invited for interviews in this study. They were from both academia and the industry. Practitioners were in leadership positions. Participants from academia were university professors having publications in blockchain technology adoption in supply chain management and blockchain in oil and gas. Diversity of participants with regard to region, areas of expertise, and experience could result in teasing out more information at multiple levels. Table 4 provides a snapshot of the participants in this study.

Potential respondents were identified by searching for professionals on LinkedIn, the Society of Petroleum Engineers (SPE), blockchain architects who had experience in the oil and gas industry and were actively involved in relevant projects, and university professors who had recent publications about the topic under study.

By checking the public profiles of the potential respondents, they were contacted by the researcher on LinkedIn or through their business email and were invited for the interview on Teams. They were given detailed information about the goal of the study and the researcher.

The *Snowball sampling* method was also applied. Since the participant who could meet the selection criteria for this study were not easily available, the researcher asked each participant for assistance in referring her to other suitable candidates. 77% of the participants are living and working outside of Norway. Figure 8 shows the breakdown of participants by the location of their business units.

Name	Position	Place of work	Roles and experiences	Location
1. Zara Zamani	Chief Blockchain Solution Architect & Former Field & Wireline Engineer Entrepreneur	ChromaWay Schlumberger	Diverse tech experience in oil and gas and blockchain, Ph.D. in Innovation Sciences, Master in Petroleum Engineering. Business management &business law 10th most influential woman in technology in 2021 by Analytics insight 21st woman in blockchain in 2021 by Fintech Review, etc.	Sweden
2. Geoffrey Cann	Director,Author, Speaker, trainer in digital innovations	Adappcity Inc., Deloitte Canada	Providing management advice to companies in oil and gas, including producers, shippers, and key suppliers on a broad range of management issues. 20+ years of experience	Canada
3. Rebecca Hofmann	President and Executive Director Founder	Blockchain for Energy Consortium Equinor	Over 20 years of experience in the energy and oil and gas industry & variety of leadership roles. Finance and Compliance leader Blockchain CEO, Global Supply chain Leader 2018 GRIT Award winner for Creativity and Innovation, etc.	U.S.
4. Raquel Clement	Director Digital Product Manager, Mechanical Engineer	Blockchain for Energy Consortium Chevron	Variety of leadership roles in the oil and gas industry. LNG commercialization analyst, On-shore Production Operations Engineering, Process Safety Management, Performance Improvement/Lean Sigma Management, etc.	U.S.
5. Ove Sandve	Country Manager Co-Founder	Data Gumbo Aker companies	Entrepreneur, Software developer, Various managerial roles, R&D roles in the Aker family of companies. 20+ years of experience in software development, blockchain & smart contracts developer	Norway
6. Maxine Aitkenhead	Director of Business Development	Data Gumbo National Oilwell Varco Schlumberger	Diverse roles and years of experience as Project Manager, Market Analyst	U.S.
7. Alastair Caithness	CEO & Founder	Energy Tokens & Ziyen Energy	Entrepreneur, Business advisor, Strategic advisor	U.S.
8. William Pete	CEO & Founder	Energy Ledger Inc.	Entrepreneur, Software developer Solving oil and gas problems using blockchain technology	U.S.
9. Astrid Schober	CIO	Wien Energie GmbH OMV Accenture	Specialized in Change management, Blockchain, IT manager, Project Manager, IT strategy, Risk management, Manager energy Trading	Vienna
10. Kenneth Titlestad	Senior Manager, Solution Architect, Cyber Security & IT/OT Specialist	Sopra Steria Aibel Aker BP Equinor	Demonstrated history of working in the oil & energy industry. Skilled in Industrial Control Systems, Asset & Vulnerability Management, Operations Management, Windows Infrastructure, Virtualization, IT Service Management	Norway
11. Stephan Nilsson	CEO, Founder Enterprise blockchain Implementer	UNISOT AS SeafoodChain Venture AS	30+ years of international IT experience 20+ years of SAP experience 5 years of Mechanical/ Automation Engineer	Norway
12. Sara Saberi	University Professor Ph.D. in Industrial Engineering & Ph.D. in Business Administration	Worcester Polytechnic Institute	decision-making on network systems, especially in supply chain networks, communication networks, blockchain researcher	U.S.
13. Robello Samuel	University Professor Drilling Engineer	University of Houston & Southern California Halliburton	30+ years of multi-disciplinary experience in domestic and international oil and gas drilling operations. Significant expertise in consulting and teaching. Onshore and offshore well engineering, design, cost estimate	U.S.

Table 4. Information about Participants

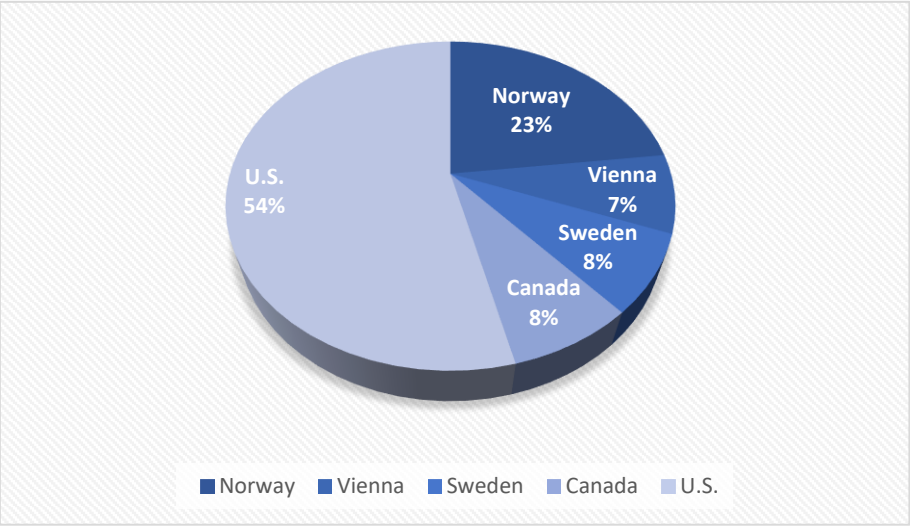

Figure 10. Breakdown of participants by location of their business unit

6.2. Data analysis steps

As mentioned in the methodology chapter the analysis of raw data from interviews is conducted by choosing the content/ thematic analysis method. In this chapter, the process of data analysis is discussed in more detail and all the steps covered in moving from data to results are explained and clarified.

Audio or video recorded interviews were transcribed by Teams software and the researcher edited the transcription after each recording. The analysis started by coding the data.

- **Initial coding of the transcripts:**
  Important parts of the transcriptions were labeled with codes and the initial coding list was generated. The list was quite long to avoid bias. Identification and selection of keywords and phrases for coding was

- **Evaluation and adjustments of the coded labels:**
  each time a new interview was conducted, it was coded separately. The coded labels were reevaluated by comparing the labels with the previous interviews. The labels were edited by removing duplications and keeping a record of the most important and relevant ones for further analysis.

- **Categorizing the coded labels and finding sub-themes:**
  The main categories were identified based on the interview questions for which the researcher was looking for the relevant answers. Categorization was done by clustering similar coded labels under the same group.

- **Evaluation and adjustments of the categories/ sub-themes:**
  Categories were evaluated and adjusted continuously each time an interview was conducted, and a new range of labels were appearing. Categorization helped the researcher focus more on the necessary data for answering the research questions and putting aside the redundant parts of the data.

- **Setting the initial themes:**
  The main themes of the research were based on the main research questions. Themes provide patterns in the data set and guide the researcher toward answering the research questions. After putting together all the interviews that had received an acceptable level of saturation and finding the sub-themes, themes of the research were naturally appearing.

- **Evaluation of themes:**
  Themes were evaluated and reorganized with a focus on research questions and the redundant ones were eliminated. This was the last step in preparing a coherent list out of the raw data.

At this stage, the researcher tried to analyse the patterns amongst themes by finding similar traits among the respondents who presented the same themes. For example, finding the pattern by checking pre-existing knowledge, attitude, gender, or any other trait that has led to a recurring theme. This is the process of moving from description to analysis. After finding and evaluating these patterns, the results were tabulated and presented. in the next chapter, the contribution of the obtained results from the project to the previous studies and the development of the industry was explained. A simple illustration of the process of data analysis is shown in Figure 11.

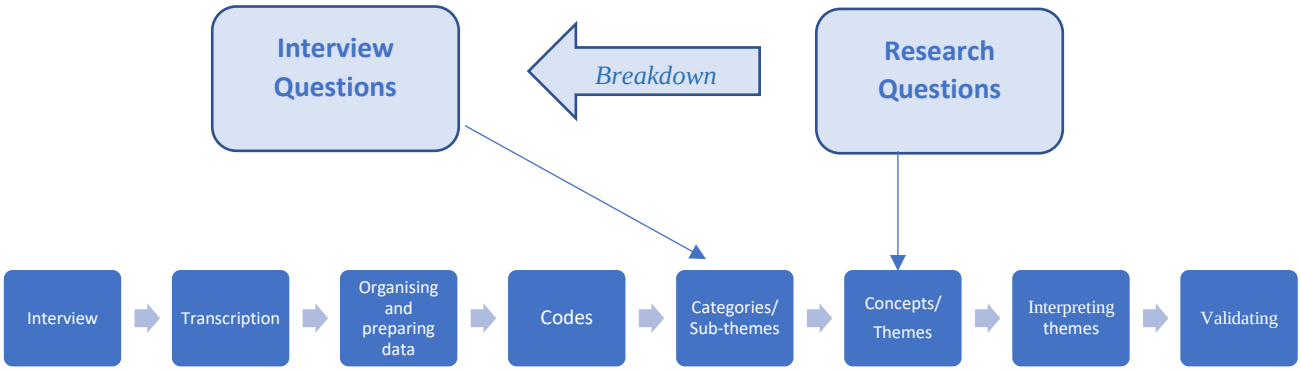

Figure 11. The process of data analysis

The processes of analysis and preparing results in the qualitative study are not distinct steps but they are interrelated and occur simultaneously. Therefore, both presentation of the results and the process of coming to these results are presented together in the following sections.

6.3. Presentation and Analysis of Categories/ Sub-themes

In this chapter, the empirical findings from the collected data are presented in tables and graphs and are explained by the researcher. Extracts from the interview transcriptions are presented in each category to illustrate the participants' thoughts and opinions. It is of course not possible to quote all the participants' opinions in this section, the complete transcriptions are provided as an extra pamphlet. Many of the participants had similar perspectives on some specific areas so the researcher tried not to bring similar ideas repeatedly and they are only illustrated by an asterisk in the tables. Results are analysed by focusing on the categories or sub-themes that subsequently guided the researcher towards detecting and analysing the main themes of the study. The main research themes emerged naturally while analysing the sub-themes. As mentioned earlier, sub-themes are based on the interview questions and are illustrated in separate tables to better represent the respondents' answers which were labelled as codes. The researcher did not include all the codes in the tables. The codes were collected, analysed, and grouped, and selected codes most relevant to the research questions are represented in each category in the tables. The focus of the researcher was on the most frequent ideas in other words frequent codes. Respondents sometimes provided the same answer for different questions since some of the questions were somehow overlapping. This did not cause any problem because in the end all similar categories were grouped under the same main theme. The themes are based on the main research questions and are discussed in section 6.4 of this chapter.

6.3.1. Category 1. Underlying reasons for blockchain adoption in the industry

There are a table and a frequency chart under each category to illustrate the results. They are designed based on the participants' responses to the interview questions. The tables present the results from the respondents' direct responses to the interview questions and are not based on the researcher's inferences of the data. The researcher's opinions are not reflected in the data to avoid bias.

The tables present the responses each participant provided for interview questions and the bar charts indicate the frequency of each response. The frequencies are an indication of the prominence and importance of the answers from the participant's point of view (see Figure 12).

The first category discusses the underlying reasons that companies adopt or apply blockchain technology. Most of the participants answered this question by focusing on the main principles and functionalities of blockchain technology (see Table 5). They counted distinct functionalities of blockchain technology as the underlying reasons for blockchain adoption in different industries and companies. They focused on the role each of these features plays in the oil and gas value chain.

Participants / ***Reasons***	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**P11**	**P12**	**P13**
Decentralization	*	*	*	*	*	*	*	*	*	*	*	*	*
Transparency (One source of truth)	*	*	*	*	*	*	*	*	*	*	*	*	*
Efficiency (Minimize cost and save time)	*	*	*	*	*	*	*	*	*	*	*	*	*
Auditability	*	*	*		*	*	*	*	*	*	*		
Immutability	*	*	*	*	*	*			*	*	*	*	*
Data integrity	*	*	*	*	*	*	*	*	*	*	*		*
disintermediation	*	*	*	*	*	*	*	*	*	*	*	*	*
Security	*	*	*	*	*	*	*	*	*	*	*		*
Facilitation of Trust	*	*	*		*	*			*	*	*	*	*
Traceability	*	*	*	*	*	*	*	*	*	*	*	*	*
Sustainable supply chains	*	*		*		*	*	*	*		*	*	*
Creating digital assets	*	*	*				*		*		*		*
Reshaping business models		*	*		*		*				*		*
Proactive working style	*	*	*	*					*				
Removing disputes and renegotiations	*	*	*	*	*	*			*			*	*

Table 5. Category 1. Reasons for blockchain implementation

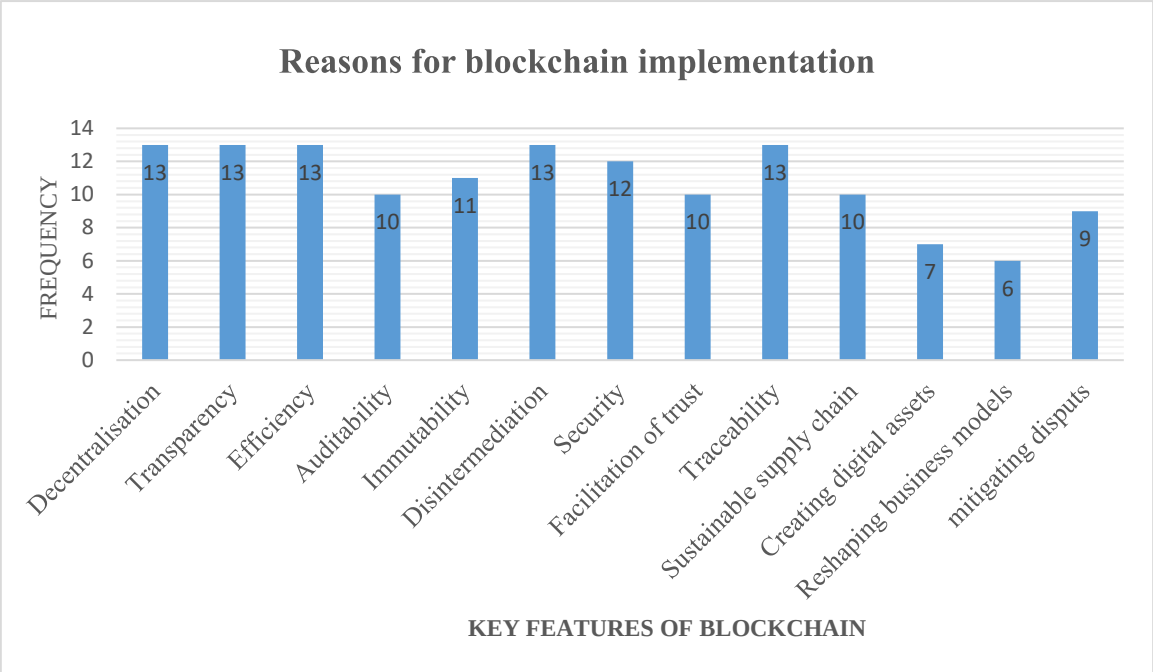

Figure 12. Frequency chart representing reasons for blockchain implementation by companies

The frequency chart shows the frequency of the main characteristics of blockchain technology which constitute the main reasons for applying blockchain technology. Decentralization, transparency, disintermediation, traceability, and efficiency were mentioned by all the participants. They mentioned these features lead to a reduction in cost, and administrative time and increase efficiency significantly.

In what follows the answers provided by the participants are discussed and extracts from the transcription are quoted as evidence for the explanations given by the researcher. Another reason is that these extracts contain insightful information about the updated use cases and applications of blockchain in the oil and gas industry, in addition to the explanations of the main features of the blockchain technology, and the role they play in the oil and gas industry. Therefore, the researcher decided to include the quotations in this section. Not all the responses are mentioned in this section since they were repeated information discussed by most of the participants. Only those extracts containing some kind of new information before reaching a level of saturation in the responses are represented in this section. All the participants confirmed during the interviews that their opinions can be quoted in the thesis non-anonymously. Therefore, the extracts indicate the source of the quotation. In what follows the underlying reasons for using blockchain technology are discussed.

Participant 1 is an expert in blockchain technology and chief solution architect. She started the interview by giving a thorough definition of blockchain technology which included almost all the important features of the technology which is worth mentioning here.

> *"Blockchain is a decentralized distributed digital Ledger that is irreversible, is a peer to peer network and eliminates intermediaries. It is a technology that comes with time stamping and chronological cryptography. It is a technology that makes processes transparent and irreversible. That means in the blockchain you cannot change the past, you can only make the future and that brings a lot of security but also sometimes vulnerability to it. and then Decentralisation eliminates the central house of control. And it's a P2P network. That means it's a direct connection between the members of the network. So, there are no intermediaries. And when there are fewer intermediaries, that means you save time, and you save cost".*

In response to the first interview question, Participant 1 discussed the main reasons that companies adopt blockchain as such:

- Transparency and decentralisation:

  > *"Companies adopt blockchain for multiple reasons. The main and most reasonable application is when they want to apply it for transparency. A lot of times they want to apply for transparency and that means in the hard core of their operation they have a problem with centralization. So, they want to fight against centralization, they want to decentralize things, to make it transparent".*

- Auditability and Immutability:

  > *"Different industries want to have proof that something has happened. In auditability, with regulators, with audits, etc. they want to make sure that they have a ledger that cannot be manipulated and that's why auditability, especially in finance industries or in sensitive industries is a big reason for adopting blockchain".*

Participant 2. is an expert in digital innovation in oil and gas. In 2013, and 2014 while working in the natural gas industry in Australia he got to know about the possibilities of blockchain technology and he wrote his first article on blockchain technology on tax related issues. And starting in 2016, he began writing articles about blockchain-based business models and the impact that they would have on industrial sectors that were sensitive to trust issues. He believes the technology has great potential in the oil and gas industry like many other industries. He believes the industry needs to become transparent to increase trust among the stakeholders: "*Oil and gas industry is a classic. No one trusts anybody".* Then he explained how he found

out that blockchain technology can make a big difference in reshaping business models and supply chains through transparency and traceability and immutability functionalities.

He explained because the product of this industry is fungible which means a barrel of crude oil is largely indistinguishable from another barrel of crude oil to a large extent, there is a high chance of fraud, and blockchain based business models can help the industry overcome this problem.

> "*If someone were to steal a barrel of crude oil or mislabel it etc, you would never know that it's been mislabelled or stored or has been tampered with at all, particularly after it's been refined, it's even more extreme. So, this means that anybody who's working in this supply chain has to have very elaborate mechanisms to maintain confidence in the supply chain that the product hasn't been stolen, substituted, defrauded, paid for correctly, taxed correctly, is from the right source not corrupted, etc. And that is a place where blockchain-based business models could make a big difference. So that was where my interest came about. The oil and gas industry looks very well suited to blockchain based business models. And so that's what I've put into both of my books on oil and gas industry dynamics and how the industry can evolve."*

Participant 2 is now working with one business in Calgary, whose model is to take a low productivity oil well, then shot in the well, and although the production has stopped because there is oil underground, it can be produced otherwise, therefore it is converted to carbon credit. And the carbon credit becomes a new asset. So, basically, the value of the oil underground is exchanged for a high-value credit, which can be traded and sold, and a carbon credit only exists if it is recorded in a database of some kind. Then it is not sold twice, it's owned by one and only one person at a time. This is another business model, a blockchain business model.

Participant 3. CEO of Blockchain for energy started by explaining how they come up with the idea of consortium. A consortium for evaluating blockchain adoption and scaling and to check whether the technology can bring choices together with other companies. She believes blockchain technology adds the most benefit when companies are interacting in business with parties external to their own company. Since companies affect each other and a lot of times, they are having a reactive approach to that so they're building their processes, compliance, or governance in a reaction to what's coming at them from external factors. She mentioned blockchain technology is now allowing all of these parties to interact in *one source of truth* where everyone gets to see the *transparency* and it can happen in real time. So as the activity happens in the field, it is possible with blockchain to record that and see that in real time

between the parties that need to see it. And therefore, it's creating a whole new way of working. And blockchain makes it possible to run the business much more effectively.

Participant 4. possess long years of experience in different sectors of the oil and gas industry and comprehensive knowledge about both blockchain and its implementation in the oil and gas industry. She said she has always been curious about how blockchain technology can benefit the oil and gas industry. She shared her first encounter with blockchain technology and what triggered her curiosity. She has been trying to find a solution for increasing efficiency by reducing the time spent on information sharing. The solution she thought about was to transmit the data directly from the wellhead to any authorized party that needs this information in a safe way. Immutability is one of the main functionalities of blockchain technology that interests her.

> *"As an engineer, I used too much of my time in transcribing information from the wells to government form to explain to the government how much we were producing, which day, how long? So that inefficient process was taking a lot of our engineers' time and energy me included. I was one of the production engineers in California. And I was thinking if there could be a way that we can transmit that data, my dream is that it comes directly from the wellhead to anybody that needs it, the government, ourselves, other entities. If we could have that information directly from them in a safe way that is not questionable because immutability is one of the things that I appreciate a lot from blockchain. And when I was thinking of that in California in our fields, we had 17,000 wells. If we could connect all of them in a way that we can present the data to the government, I was thinking, OK this is it. This is an inefficiency that we can take out of our industry and make it more productive for us more productive time."*

Participant 5. CTO of Data Gumbo gave a brief explanation of how they help the industry by the implementation of blockchain technology. Data Gumbo is a Blockchain as a Service Company. They provide GumboNet, an industrial network of smart contracts for industry. Their main task is to turn legal contracts into digital Smart Contracts and automate the execution of those using IoT data to validate when events occur and execute payments based on the terms defined. Their customers save manual work and time by automating their contracts, and sub-contractors improve cash flow by being paid quicker for services delivered. For Data Gumbo, being able to provide one version of the truth, between counterparties in sometimes an untrusting eco-system, has allowed them to generate revenue in their implementations.

The underlying reasons for using smart contracts according to Participant 5 are as follows:

- *"Security on sensitive data (such as exploration well drilling) and sharing it between counterparties of a contract, to create an immutable audit-trail of events that occurred, supported by IoT data as evidence.*

- *Binary execution of contracts, and enforcing complex contracts by well-defined Smart Contracts, take disputes and renegotiations out of the processes and drive savings.*

- *Improving cash flow by paying faster services delivered according to specification."*

Participant 6. explained how blockchain and smart contracts can help the oil and gas industry increase efficiency and trust among stakeholders.

> *"In Data Gumbo, experts are trying to solve problems in the oil and gas industry using blockchain technology. By performance contracts between drilling contractors and operators based on day rates and performance. Contract was in an effort to improve their process in that partners can drill the well quicker and that's the goal for these oil companies to do things a lot quicker and easier and cheaper."*

They are building smart contracts for other industries as well as the oil and gas industry.

Participant 7. CEO of Ziyen coin focused more on *tokenising energy assets*. Stating that in the oil and gas industry digitalisation and technology adoption in operational sectors are taking place rapidly but the way energy assets have been acquired, held, and transferred has not changed for over 100 years. They have tried to find solutions to some of the financial problems in the industry using blockchain technology and tokenizing assets to reshape the financial structure. They have tried to solve some of the existing problems for example one existing problem is that non-industry investors have limited access to energy investments. It is difficult to sell or buy fractional interests. There are limited liquidity opportunities by holders of non-controlling interests prior to the sale of entire interest and their solution is that they provide liquidity for illiquid energy investments through tokenizing oil. It is a lot easier to transfer assets in this way. They are using permissioned blockchain for their financial infrastructure.

Participant 8. The founder of Energy Ledger has been granted patents by the United States Patent and Trademark Office (USPTO). The idea came to his mind when he decided to apply blockchain technology to the commodities market, and he saw oil as the biggest commodities market in the world. Therefore, he has brought the functionalities of blockchain and the encryption algorithm behind cryptocurrencies to the oil and gas commodity market. He explained about his patent:

"It's decentralized distribution systems substantiated by crude oil reserves on a blockchain network. And the idea was to use the encryption algorithm, which is the very basic encryption algorithm behind Bitcoin. And actually every other cryptocurrency. It's called ECDSA. That's elliptical curve digital signature algorithm to basically Serialize containers of oil with public private key pairs which denote a token. So, in a blockchain network as one token. We filed for this patent in 2019. It's a pretty simple concept. We are just looking to serialize containers and manage them through a computer network. A human being can manage how many barrels of oil are in a different size container digitally."

Participant 9. is the CIO of the largest utility company in Austria, Wien Energie which provides energy and heating to the citizens of the city of Vienna. They have about 2,000,000 customers within the city of Vienna and the surrounding area there, so they are based on customer volume the largest utility in Austria, Wien Energie has a long history of about 75 years of experience. They are running five combined cycle gas turbine energy and create energy production facilities within the boundaries of the city of Vienna. They are highly dependent on natural gas and the current crisis is hitting them hard in the production area at the moment. However, they are also relying on recycling waste for production of heat. So, this is their second main source of primary energy for production, but it is mainly used for the generation of heating power. Before that, she was working for Austria's largest oil and gas company OMV in an IT role and she was responsible for new technologies and IT strategy in the architecture, looking into the development of exciting new technologies that may be useful for a company, not in the very immediate time frame, but in the mid to long term. She discovered DLT and blockchain back in 2015. Her experience with the technology is presented in the following sections.

Participant 10. is a senior manager in Sopra Steria in Norway. He has worked as an expert in cybersecurity and IT in the oil and gas business in Equinor. His vast areas of specialisation include industrial control systems automation and highly critical systems to assist and assess cybersecurity. He is also sitting as a chairman in the Norwegian Electrotechnical Committee where they are responsible for the development of the international standard on industrial cybersecurity, IEC602443. They discuss new possible technologies, resilience, and robustness of existing technologies by taking into account organizational measures and the people's perspectives. As he mentioned they consider the whole domain of industrial cybersecurity from the perspectives of people, process, and technology.

Considering blockchain he believes that blockchain technology and especially the principles behind blockchain is something that they really need to get a grasp of and try to implement in

their solutions because there are really good principles. But he added the technology is still at the level of talks and discussions and he has not been involved in any project where they've tried to use it or to do testing or piloting on it. Participant 10 approached the question from very technical aspects of the technology with a focus on cyber security and provided loads of useful information that are used throughout this thesis.

Participant 11. CEO of Unisot, an enterprise supply chain sustainability platform. He has over 20 years of experience as SAP consultant or SAP integration Architect. He believes in the supply chain it is very important to set up one big central database where everybody connects to so that everybody would have the same universal source of truth, and this is where their company name Unisot comes from. His focus was mainly on the decentralised public blockchain which is permissionless and everybody can become a part of it. He believes private blockchains are only replicated databases controlled by one company or consortium of companies and can not be counted as blockchain. Because it is no longer decentralised.

He argues that an enterprise blockchain must have certain criteria first scalability which means it has to do minimum hundreds of transactions per second. In this manner, the energy cost per transaction is almost 0. All systems have a cost, so what should be considered is the return on energy investment. Secondly, it has to be very secure and stable. It has to be very cost efficient and energy efficient. It has to be legally compliant since there are many blockchains that are not legally compliant.

He pointed to the integrity of data and the possibility to exchange information very securely by applying blockchain and mentioned that the internet today doesn't really provide that integrity. By monetization of information, it is possible to start buying and selling information in a very secure and a very cost-efficient way. Blockchain can provide better information sharing among more actors in the supply chain.

> *"There is a problem today in all industries that companies only have information one tier up and one tier down. They only get information from immediate suppliers and give information to their immediate customers. Blockchain develops the communication channel and makes it possible to get information from the whole supply chain network".*

This reduces costs, increases efficiency, and makes supply chains more sustainable.

Participant 12. She is an assistant professor at a business school at Worcester Polytechnic Institute. From 4 years ago she is researching about the barriers and obstacles of blockchain for

implementation in the supply chain and sustainability of the supply chain. Moreover, about the governance of sustainability practices and how the blockchain can help for governing these practices in a supply chain. She starts by saying that blockchain is not going to be a panacea for everything, but it has some functionalities that can solve many problems, especially in the supply chain. She then gives an overview of these useful principles by saying that blockchain provides one common poll of information that everyone can have access to the similar information and there will be symmetry of information between the participants. Therefore, information put on blockchain are traceable. She mentioned that the most important part of the blockchain that can be used for oil and gas is Smart contracts. Then it is possible to set up the contracts automatically instead of relying on words and negotiations and there would be a better synchronization between the information and between the parties involved in transaction. Smart contracts eliminate the need for many intermediate people. She added that:

> *"Blockchain is just a database. It's an advanced database, so we need to use other technologies such as those like FrID or something that can read the data from the goods and put it into the database. So as long as we can have a good connection between the IoT and blockchain for getting the right data into the right database. Then it would decrease these difficulties that we have in the oil and gas supply chain, I think."*

She also mentioned that blockchain can reduce costs by eliminating intermediaries, which means decreasing the double marginalization for every step of the supply chain. Therefore, efficiency increases.

Participant 13. is a university professor in the University of Houston and Southern California. He has long years of experience working in the oil and gas industry. He has some publications about the implementation of blockchain technology in the oil and gas industry that were used as useful sources of information for this thesis.

6.3.2. Category 2. Key features of blockchain that can benefit oil and gas

Blockchain features \ Participants	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
Transparency: In supply chain & in contracting	*	*	*	*	*	*	*	*	*	*	*	*	*
Decentralization	*	*	*	*	*	*	*	*	*	*	*	*	*
Auditability	*	*	*	*	*	*		*	*		*		*
Efficiency (Cost saving, Time saving)	*	*	*	*	*	*	*	*	*	*	*	*	*
Immutability	*	*	*	*	*	*			*	*	*	*	*
Traceability	*	*	*	*		*	*	*	*	*	*	*	*
Automation (e.g., Smart contracts)	*	*	*	*	*	*	*	*	*	*	*	*	*
Disintermediation	*	*	*	*	*	*	*		*	*	*	*	*
Security (data protection)	*	*	*	*	*	*	*		*	*	*		*
Facilitation of Trust (Trustless system)	*	*	*	*	*	*			*	*	*	*	*
Safer & quicker Data transmission				*	*	*	*	*		*	*		*
Self-monitoring (Self-healing)			*	*									
Monetizing data (Digitalizing assets)	*	*	*				*		*		*		*
Tokenizing assets Tracing ownership of assets	*	*	*	*			*						*
Removing disputes	*	*	*	*	*	*	*				*	*	*

Table 6. Category 2. Key features of blockchain that can benefit the oil and gas industry

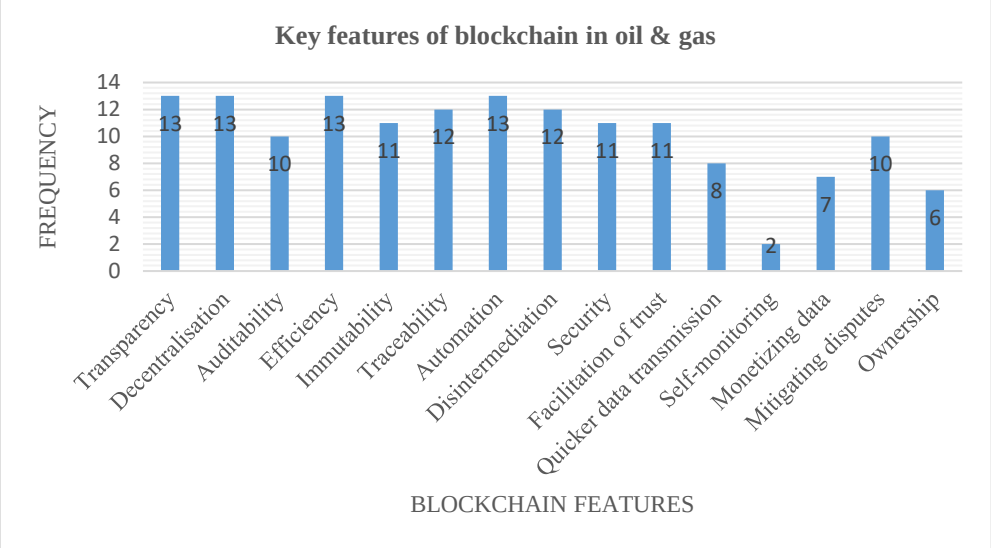

Figure 13. Frequency Chart for key features of blockchain technology in the oil & gas industry

Participant 1 describes the oil and gas industry as a very sensitive industry that is very strong in technology adoption in operational sectors but weak in technology adoption at the managerial levels. She added that this industry is not very open to decentralisation and transparency because centralization brings power and wealth to certain people.

> *"Oil and gas industry is a very sensitive and political industry. Because it's an industry like the financial industry, it's very political because it accumulates wealth. And that means there is amazing room for technology in this industry. Because the more you're advanced in technology and the more your digitalized, the more wealth you can bring to this industry. So, there is amazing technology within the operation of oil and gas industry, however, because it's a sensitive industry, there is very little technology in the management of the industry. And the reason why is because it's an industry that benefits a lot from centralization. Centralization brings a lot of power and minimizes transparency".*

To answer the second question, Participant 1 referred to the current problems in the oil and gas industry and explained how DLTs or blockchains can be applied to solve current problems in this industry. She stated:

There is a lack of transparency in the oil and gas industry in the supply chain and in contracting. Centralization and auditability are two other big problems. Participant 1 mentioned centralization brings power and minimizes transparency.

Counterfeiting is another big problem in oil and gas since there is a big market of counterfeiting products which are very dangerous. Counterfeited products in vehicles can cause damage and death. Using blockchain these products can be traced. Then she explained blockchain has features that can provide solutions to these problems. These features are shown in table 6.

Participant 2. Believes that the principal value of blockchain databases is there they serve as an *immutable record*. And it gives you a single version of truth at a point in time. This feature is quite valuable for a fragmented industry like oil and gas since from the time oil is produced until it gets to the refinery there are easily hundreds of transactions that might have occurred. And what blockchain does is it creates transparency, it can be seen precisely where the oil is and who's touched it and when, whenever the product is handled. That's an important feature.

As another key feature of the blockchain which is very valuable for the oil and gas industry, he referred to smart contracts. "*Blockchain database structures to now auto execute as the oil moves from the tank to the truck and then from the truck to the new tank."* He by giving simple calculations explained how blockchain technology can take out costs and he stated that a key feature of blockchain is that it helps eliminate many costs related to keeping track of oil

products. And he added, "*blockchain is a cost takeout machine".*it eliminates all the intermediaries.

Participant 3. talked about different features of blockchain technology that can benefit the oil and gas industry as presented in the table. She focused on the facilitation of trust between the parties and increased reliability since the parties upfront are agreeing. She also discussed how blockchain makes monetizing data and assets possible such as seismic entitlement and land.
She explained about smart contracts and how automation facilitates transactions.

> *"Smart contracts do self-executing tasks in terms of what you agreed upon and it executes that for you. And then we're seeing a huge reduction in inefficiencies. It makes it possible to eliminate disputes and constant reconciliations and audits and it just calms all of that down significantly."*

Therefore. Smart contracts are among the most important applications of blockchain technology in the oil and gas industry and improve efficiency considerably in terms of saving cost and time. She focused on the traceability feature where the origin of products such as valves can immediately be found, as all the information is recorded on the database if a failure occurs, it can be traced so easily which sites are using these valves to check them for the failure and this results in a proactive working style.
In their seismic entitlement use case, they focused on the ownership meaning who's entitled to that seismic. So, in a joint operating agreement between multiple operators, they get a right to that seismic and it's all stated in that operating agreement between each other. Tracking and managing seismic that can last for 60 years can happen by blockchain application.

> *"Once that management and tracking can happen, that opens the doors to be able to create a new marketplace to buy, sell, lease, seismic as an asset and companies can then get some monetization for that seismic that they couldn't because there wasn't the visibility that was needed to even know that that company owned it. And you can keep things private as they need to be kept private. And you can make them public as you need to make them public. So, there is control that the blockchain lets you do over that."*

She pointed out the self-monitoring capability of blockchain by which she meant there's no central point of failure and the system can almost be self-healing because it is decentralised. She pointed this out as one of the most important differences between blockchain with other databases.

> *"The difference between a database and a blockchain platform is that there are nodes, and every party can get a node and so in decentralization, all of them have copies so*

you have a central source of truth with everyone having the same copy, and those copies have to stay the same. So, if there is somebody who comes in and tries to hack up. There are copies so that it can then self-heal and copy over. And you always have the same information whereas if you have a database there is only a centralized database. If it gets hacked, you are down. So, we love that about the blockchain. It is much more secure."

Concerning the type of blockchain which is appropriate for oil and gas companies, she suggested *hybrid blockchains*. The blockchain that is more suited for business adoption is the private. But the information that needs to be public can be on public blockchains. There is no need to have everybody on blockchain except those whom you are doing business with and have interaction must be part of the agreements and are permissioned to be on the blockchain. Governing the blockchain and validation process varies depending on the type of blockchain. Mining is a validation mechanism that due to ESG concerns many people are moving away from that type of validation to other types of validation mechanisms. Depending on what they are trying to accomplish they choose the right validation mechanism.

Participant 4. Believes that blockchain in the oil and gas industry provides an ecosystem that supports ESG goals, a green ecosystem since net zero goals require that all industries talk together and exchange data both within the industry and outside the industry. It is not going to be an exchange of data just between operator to operator, it is going to be the operator with the world and the world with operators. Here blockchains offer unlimited possibilities for exchange of the data in a safer manner. And blockchain not only provides engineering problems with a solution but also is evolving to deal with social and economic problems.
She counted transparency and immutability as the two main features that she sees beneficial in addition to decentralisation. She said:

"Right now, if everything goes to a central point, we have a single point of failure, decentralisation can protect and preserve the data. It's another big advantage of blockchain that we shouldn't dismiss because the more we keep making faster processors, including getting through the quantum computer. The more we need to have different ways to protect data and establish governance of that data and ownership of the data. And that's another piece that blockchain can help us with."

Participant 5. explained the most important features of blockchain in the oil and gas industry as follows:

- *Security by encryption and distributed consensus.*
- *Smart Contracts that provide transparency and trust between counterparties.*
- *Immutable ledgers for audit purposes.*

A brief explanation of the history of Data Gumbo in the oil and gas industry provided by the CTO of the company can explain the important aspects of blockchain adoption in the oil and gas industry. One of the main issues in the oil and gas industry is Trust between different partners.

> *"Data Gumbo started as a Data Platform company (2016), and its founders came from companies such as Aker Solutions, MHWirth, National Oilwell Varco, and Schlumberger. We wanted to pull data out of information/department silos in the Oil & Gas sector and make it easy to build smart applications on top. Quickly discovered that with the maturity of cloud offerings (MS Azure, Google, Amazone, etc.) that most Operators in O&G were already investing in Data Platforms to collect valuable information. Data Gumbo was presented with a use-case where an operator wanted to improve drill pipe connection speed by an average of 1 minute across their fleet of drilling rigs. This would be worth approx. 250MUSD per year to them if it could be achieved. This was technically possible to do, but the sub-contractors were not willing to make the technology and personnel change for it to happen. The operator offered a share of the savings as bonus if they would be willing, but the answer was still no. Data Gumbo spoke to the counterparties and found that the core issue wasn't money or technology, but trust. The sub-contractors didn't trust the operator to correctly execute the bonus agreement. The companies would pull out different reports on what was performed and how things were measured, and they would be stuck in disputes about KPIs, incentives, what really happened, who's to blame, etc. Data Gumbo introduced the concept of using blockchain principles, to agree up-front on terms and KPIs, collect real-time data from multiple sources and sides, and then have a digital smart contract automate the validation of the bonus/penalty agreement and execute the payments. No discussions. The parties agreed."*

Participant 6. Believes in the oil and gas industry, the job is done with lots of documentation and paperwork that goes back and forth, then reconciling that paperwork, then generating invoices, then reconciling those invoices, and then going through the disputes between the invoices regarding what one person, one company's opinion versus another company's opinion is of what has actually happened. These are not just very time consuming, but they're very emotional types of behaviours so the way of doing business is very emotional. There are lots of people involved. There are lots of processes involved.

So what data gumbo is bringing to the table is a way to do business by reducing all those processes and reducing the number of people who have contact with these processes. That reduces the payment by trying to take these processes and people out and by automating the process using data. Everyone is then doing business based on data.

As another goal of using blockchain, she mentioned blockchain provides an immutable record of all the transactions and assets in a way that is easy to track and trace assets and everything pertaining to those assets.

Participant 9. Told about her experience with blockchain in the area of oil and gas that at the beginning they were really struggling to see applicable use cases. There were use cases in terms of the supply chain which were not only related to the oil and gas industry. She gave examples about crude oil origination and the marine scheduling of crude oil. She mentioned there is a lot of paperwork attached to that and that's quite an administrative effort.
In the area of oil and gas, crude oil transportation was of interest to them, and the second application was oil and gas trading. As very early use cases, there were several attempts to build a European wide, common oil, gas, and power trading platform. But she added all of these big consortium efforts actually just ended at some point because it was not supported by big players in the oil and gas industry in 2016, and 2017.

She said the board of directors in Wien Energie was extremely interested in applicable areas for blockchain. They really did believe in this technology and started exploring use cases applicable to them as a utility company. Microtransactions are very interesting for them since they have very high costs for generating the billings for their customers.
So, this was one of the first areas they looked into, how to utilize distributed ledger technology to make microtransactions economically feasible.
They also considered energy trading and power trading, but it was too difficult since there were no standardized protocols, and no standardized energy related blockchain technologies available. So, they saw a lot of those early adopters were breaking away. They had their innovation budgets, but they didn't come up with groundbreaking solutions or use cases. And then obviously those innovation budgets were cut or redirected towards other technologies.
Later they applied blockchain for use cases around energy production for example from wind power plants where they implemented those hardware elements within the asset of the windmill so that every kilowatt that was produced by the windmill was actually registered via this hardware token and actually saved into a very specific blockchain. She continued this method is very lean and cost effective and bridges the gap between the physical and the digital world.

They are addressing the market of energy communities. They are working on their nonfungible energy token, but the goal is really to provide those energy communities that are very heavily supported by the European Union with a platform that they can rely on and they can securely

and safely do their business by utilizing technologies that they don't necessarily need to understand, but it provides them really the basis to make all these energy community effort economically feasible as well for the benefit of everyone involved in the energy community.

They have another application of distributed ledger and call it fuel capital equipment, which means that Austrian citizens used this model and buy shares. They can basically be part of a big photovoltaic plant without having to install the panels on their own rooftop. But Wien energy offers them this photovoltaic plant. It has the capacity of 500 kilowatt hours people can buy shares for 4-5 kilowatt hours and then all the energy produced by this power plant is deducted from people's energy bills by the end of the year. This can be done using standard IT technology, but they make this use case using distributed ledger and created their own energy token. She emphasized on decentralization, decarbonization, and democratisation after production using blockchain in the oil and gas industry.

> "(…) *by using blockchain in the oil and gas and energy as a whole, it will be possible to have decentralisation, decarbonization, and democratisation after production. This means becoming a big network of producers, consumers, and prosumers, and this is actually what blockchains have been built for or distributed ledgers have been built for a lot of participants, not necessarily trusting each other. but there is also no need to really trust each other because you have this technology, it enables participants to do safe and secure transactions with other participants you don't know, you don't have a relationship with, but you can assure that this interaction, this transaction is safe and secure".*

Participant 10 believes that blockchain has many principles and functionalities in the oil and gas industry depending on the specific area of application and the specific goals of using the technology. He discussed where the technology can bring advantages to the oil and gas while focusing on the specific features of the technology from different aspects. For example, his discussion about the transparency feature is quoted here, according to him transparency and decentralisation are the biggest principles of blockchain however he argued that these principles are not useful everywhere and it totally depends on where and why blockchain should be applied which requires careful thoughts before using the technology.

About transparency he mentioned:

> *"Transparency is not very important when it comes to industrial control systems and resilience in instrumented systems, because there are no secrets in kind of the industrial control systems and instrumentation on the factory. So, we don't need to consider whether we hide it or not. So, the transparency is not very relevant, but when it comes to supply chain and commercials and contracts then I would think that transparency*

would be really interesting but could also be something that you absolutely in some cases you absolutely don't want. It's really sensitive and confidential and then you don't want that transparency, but you would of course in contracts and commercials. You definitely need traceability."

About decentralization he believed:

"Decentralized Principles really help when it comes to sort of the IoT or industrial IoT Internet of everything, there's a lot of sensors out there that are really good and functional, but they could also be vulnerable. So, when considering as sort of a decentralized approach, you can have lots of vulnerable sensors instead of trying to build that big one that is always functioning. You also have 1000 of them instead. So, then you can trust the data due to the very decentralized amount of them, sort of mesh or fog computing. And then you have the end to end or security or the chain of trust, by using blockchain or hashing functionality you can really trust the data quality."

In his opinion anywhere data quality, resilience, and data integrity are needed blockchain can help but there are hinders and barriers also against it in every area which must be carefully considered before application of the technology. He thinks:

"If we can sort of break up blockchain and look at the functionality and the principles that lie underneath it, there are lots of interesting features that we can build into our existing technology, but I'm not sure if we could call it blockchain anymore"

The researcher is also interested to find the answer to this question in her future investigations.

Participant 13. believes that blockchain can be used in lots of areas in the oil and gas industry. He argued that blockchain can provide an option to securely store the data. He pointed to the security and the trust and mentioned that it provides a more comprehensive way of starting the database on tokens and smart contracts. He believes that blockchain can be used in drilling for digital twins in connecting the virtual world to the real world, and in the production of royalty payments, smart contracts, etc. in his recent publication he proposed that the entire royalty management can be hosted on permissioned blockchain. Blockchain can streamline the royalty distribution process. Moreover, he stated that blockchain can be used to secure the safety of the system or the data that are being transmitted through IoT devices and sensors. These are the areas that participant 13 concentrated on in his research and publications. He mentioned:

"Blockchain will provide a comprehensive umbrella protection between different vendors, different operators, different service companies so that there is some smooth flow of information on the digital side."

Blockchain adds value by securing the data and disseminating the data in the whole value chain. Therefore, it is easy to see the workflow. It also gives the possibility to expose or hide a certain amount of data to certain users and this is an advantage of blockchain technology.

6.3.3. Category 3. Value proposition through blockchain implementation in the oil and gas value chain.

Based on the review of previous literature and respondents' answers, the value added from the application of blockchain in the oil and gas industry is divided into some main areas. These areas were discussed with the respondents and their opinions were analyzed as can be seen in table 7.

Participants / ***Value proposition***	***P1***	***P2***	***P3***	***P4***	***P5***	***P6***	***P7***	***P8***	***P9***	***P10***	***P11***	***P12***	***P13***
Improve Supply chain & Trading	*	*	*	*	*	*	*	*	*	*	*	*	*
Contracting (Smart contract)	*	*	*	*	*	*	*	*	*	*		*	*
Improved Decision making & Management	*	*	*	*	*	*	*		*		*	*	*
Cyber Security	*	*	*	*	*	*			*	*	*		*
In business Reshaping business models		*			*	*	*		*		*		
Removing Fraud, corruption	*	*		*			*					*	
Increasing efficiency	*	*	*	*	*	*	*	*	*	*	*	*	*
In politics governmental decisions	*	*							*				
Monetize assets/ Digital assets	*	*	*	*		*	*		*		*		*

Table 7. Category 3. value adding by blockchain adoption in the oil and gas industry

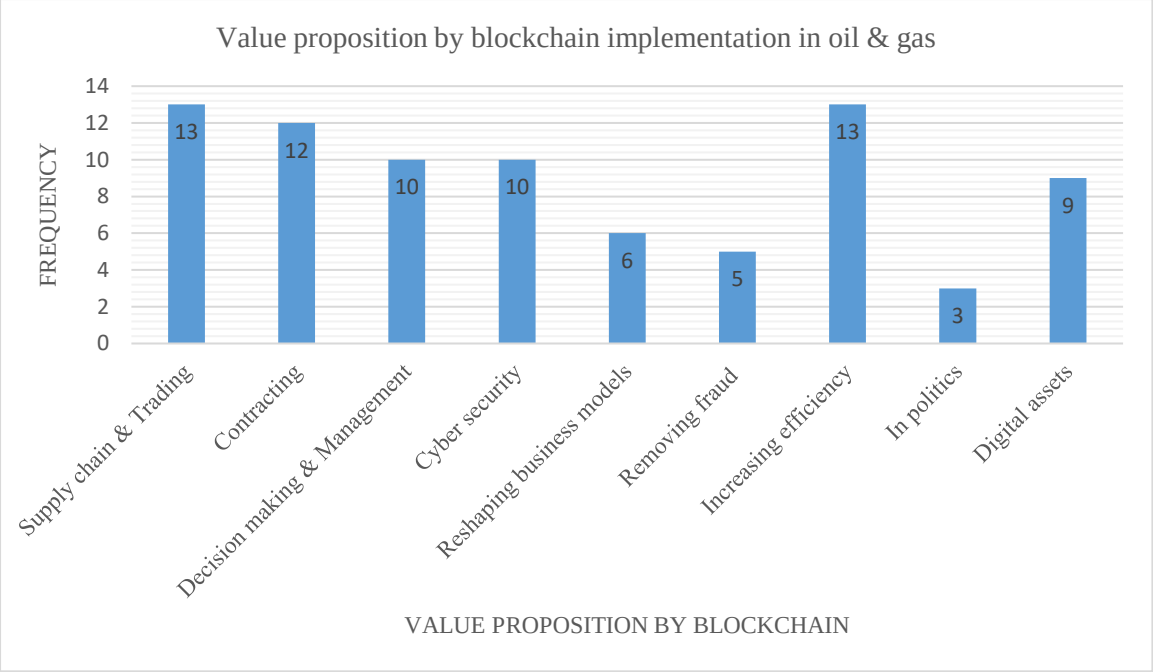

Figure 14. Value proposition by blockchain application in oil & gas industry

Participant 1 believes that blockchain can add value to the industry in many respects some of which are as follows:

- Blockchain can add value to the oil and gas supply chain by providing transparency.
- Blockchain can improve contracting by providing *automation* and *transparency* which help remove corruption in the oil and gas industry everywhere in the world.
- Contracting can be automated by using smart contracts on the blockchain which improves efficiency.
- Blockchain can help in keeping a record of the ownership of oil and gas as assets.
- Blockchain can help in tracing the ownership of oil and gas.
- Blockchain can remove corruption and fraud.
- Tokenizing the asset and keeping a record of the asset on the blockchain.
- In cyber security blockchain can help a lot but it very much depends on the type of blockchain.

> *"The choice of blockchain and the technical choices says a lot in cybersecurity, but for sure cyber security is one of the big applications of blockchain in general, and that is the reason why, for example, Maersk the biggest logistic company in the world started using blockchain for the purpose of cyber security".*

Transparency in the oil and gas is very important to lessen and ideally remove corruption, as participant 1 states:

> *"Transparency in oil and gas is something I think the world needs to demand and it will eventually because we have countries like Russia, Saudi Arabia, Iran, the U.S., and many other countries that are always a big question mark to the world. They are the owners of oil and gas. But what do they do with it? How do they sell it, like in the sanctions, people say that, the whole world says that we're not going to buy oil and gas from a specific country, however, behind the scenes they do it at a much cheaper price."*

Data from Participant 2 indicates blockchain creates the possibility to unlock quite different business models that our industry has not yet seen. So new business models, cost takeout, end of fraud, corruption, and other sorts of things are examples of the value propositions by blockchain technology. Moreover, blockchain can do the tracing of oil through the facility, the wells, etc. There's lots and lots of where this technology can fit the industry he stated.

Participant 2 referred to politics and sanction rules that can be improved by blockchain implementation so that blockchain can solve sanction problems by tracing the origin of oil therefore, bad actors in the industry can be detected and their oil can be banned or purchased at a lower price. Like today's critical war between Russia and Ukraine.

> "*Blockchain could create value almost immediately in the sanctions world*."

Using blockchain database can eliminate a lot of paperwork and reduce costs.

> *"(…) in the United States, the Department of Homeland Security is running experiments and trials right now to put oil production from Canada to the United States, on a blockchain database, using a technology called Mavennet company out of Toronto. And the idea behind this is to save cost. In the United States when oil is imported because there's an awful lot of paperwork, they have to go through to follow. And what blockchain does is it actually eliminates a lot of the paperwork."*

A detailed description of the opportunities blockchain provides in transaction processing and minimizing disputes was elaborated by participant 2 which can be referred to by reading the transcription pamphlet.

Participant 3 explained Blockchain for Energy Consortium aims to find out where blockchain technology can add value to the industry. They aim to "*learn lead and leverage*" by bringing in subject matter experts from 10 major oil and gas companies and energy companies who again bring in their subject matter experts. real people who work in that job today are coming

together to find how blockchain technology can benefit their companies based on the need of their own companies. They're learning to adapt and create their own change management within their companies.

Participant 4. believed that blockchain can help in the supply chain, management and decision making, cyber security, and contracting. Considering the projects that she is involved in, she mentioned blockchain can be beneficial in tracing and tracking products in the whole value chain. It can also help to trace and track carbon emissions. To achieve net zero, transparency is what is needed mostly and blockchain can help in reaching transparency. Blockchain can benefit many case projects such as seismic entitlement and asset ownership for example ownership of land. Asset ownership can be stamped in the blockchain. Regarding fungible and nonfungible goods blockchain can help industries in better exchanging goods.

Participant 5. believes that blockchain adds value:

> *"Wherever counterparties have legal contracts with many transactions that need to be validated to approve invoices. In other words, improves processes for large parts of the entire value chain and logistics. Also allows for secure data sharing where necessary to drive mutual business incentives."*

Participant 6. Believes that the biggest benefit of blockchain to the industry is in supply chain management. And security is the other added bonus by using hash encryption to code the data information can be kept safely. By reducing the number of people and processes in the supply chain human error will be eliminated and efficiency increases. the data for the supply chain is something that is agreed upon ahead of time between the two parties or the three parties. So, there is agreement on the data source.

Participant 7. Focused more on tokenizing energy assets. Moreover, he stated that blockchain can help in carbon emission tracking on the granular level. The transparency feature of blockchain and track and traceability capabilities of blockchain makes this possible.

Participant 9. In her opinion blockchain can add the most value in trading because there are a lot of participants involved that by using blockchain, there is no longer the need to trust each participant. She added:

> *"The trading business at the moment is a lot about securities, margins that need to build up, a lot of credit risk that needs to be administered. A lot of that can be completely ruled out using blockchain technology. So, a lot of administrative and actually back-*

office effort in trading can be completely automated, especially when knowing how much effort is in the confirmation of trades and also in the logistics in the scheduling of power, of gas even of oil. This can be completely automated using distributed Ledger technology and also in the supply chain in transportation, etc there's a lot of paper and administrative effort involved that can be completely automated at a very low cost. The cost aspect is also always very important, but an argument from those that are sceptical around blockchain is always the topic around the energy efforts that are being put into the validation of the blockchain, but there with the involvement of different proofing concepts. Also, this argument is not valid anymore from my point of view. in the bitcoin world you have the proof of work which is obviously very energy consuming, but it was built in order to reach this extremely high secure level, you also have proof of stake, proof of authority now, which is much more applicable to real life applications. It's especially in the administrative part."

Participant 10 believes blockchain can add value to the supply chain and contracting due to its functionalities. blockchain can be applied to enforce data transport and ensure that the necessary integrity of the data and authentication mechanisms are in place. There is more need for technologies like blockchain in the future where everything is connected to everything.

6.3.4. Category 4. Barriers and obstacles to blockchain adoption

Participants / ***Adoption Barriers***	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**P11**	**P12**	**P13**
Lack of awareness	*	*	*	*	*	*	*	*	*	*	*	*	*
Resistance to decentralize	*	*		*	*	*	*			*	*		*
Top management resistance	*	*	*	*		*	*					*	*
Conservativity of the industry (Traditional system)	*	*	*	*	*	*	*			*			*
Traditional business views	*	*	*	*	*	*	*	*		*	*		*
Extreme centralization of the oil industry	*			*	*		*			*			*
Political barriers	*	*					*		*				
Lack of regulations (Legal constraints)	*	*					*		*				*
Lack of expertise	*	*	*		*	*	*	*		*	*	*	*
Mindset & attitude		*	*	*	*	*		*					
Short-sightedness Expecting immediate results			*						*				
Fear of change, Resistance to change				*		*	*	*	*				*
Technological: Immaturity and complexity										*		*	*
Absence of standardization									*	*		*	*

Table 8. Category 4. Main obstacles and barriers to blockchain implementation in oil and gas industry

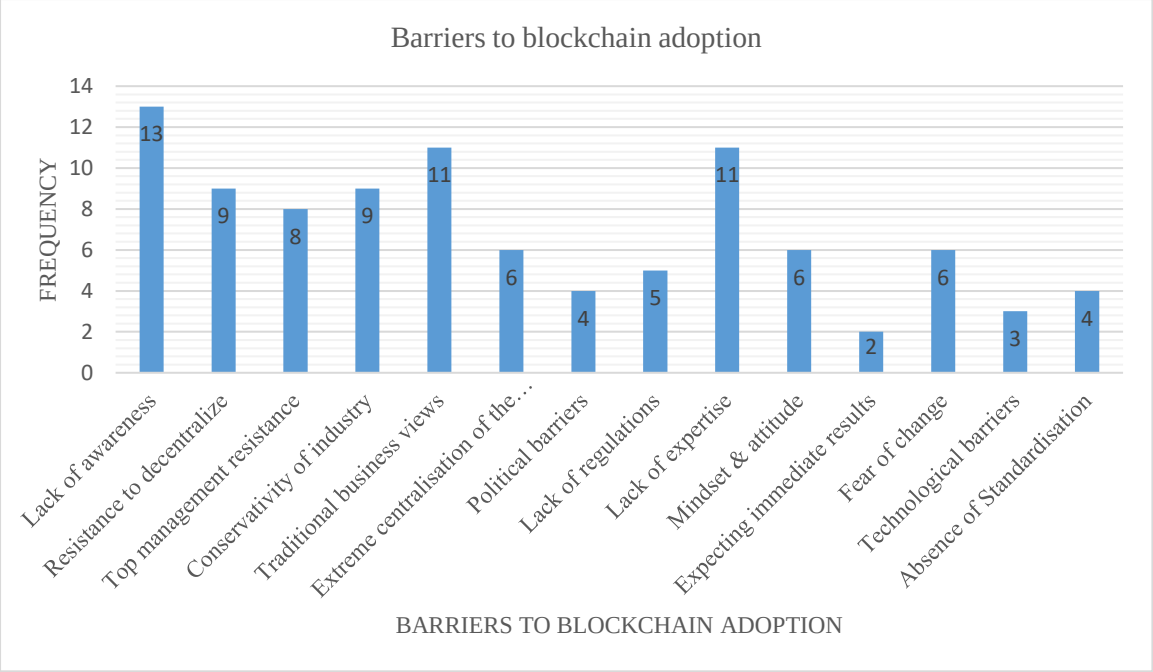

Figure 15. Frequency chart for barriers to blockchain technology adoption in oil & gas industry

Lack of awareness, lack of expertise, and traditional business views constitute the main barriers to blockchain adoption according to participants of the study. Conservativity of the industry is the next important barrier because as was mentioned earlier the oil and gas industry is not very open to disruptive technologies and change. As the data also shows oil and gas industry shows resistance to decentralisation. Other barriers that emerged in the data are explained by reference to each respondent.

Participant 2 states the single biggest barrier to blockchain adoption is people's mindset and attitudes and claimed there are no technical and technology-based reasons why blockchain could not be used in this industry. He added that the issue regarding being hacked is something that happens with all systems and concerns that quantum computing may be able to break encryptions are false. Too much concern about energy usage is false.

> *"(…) because it's very easy to say it's too much energy consumption. But compared to what, if you want to actually compare the energy consumption of blockchain, a blockchain based solution to the status quo, you actually have to look at the energy that goes into the status quo, to establish whether or not blockchains are going to be too energy intensive."*

So, there is false resistance to blockchain applications he believes.

Participant 3 according to the data collected from participant 3 people's awareness and understanding of the technology are the biggest barrier. She believes the true potential of blockchain is undermined.

> *"All of the noise with Bitcoin and cryptocurrency has overshadowed the true potential of blockchain technology and for us. But the reality is Bitcoin and cryptocurrency are just an application run on a blockchain."*

She also mentioned companies know they should become digital and find new solutions, but they are very short-sighted, and they look for immediate results. Real change management needs to occur in the companies by moving from a reactive to a proactive approach she mentioned. She mentioned the top management's awareness of the technology is very important as well as knowing where the technology really fits. Resistance to technology adoption is another barrier.

> *"A lot of people are fighting that within their companies because they can control and they can understand the landscape today, so it makes them nervous about having new technology, having new ways of working, and having to do change management on top of their already busy days and that is too much for like mid management and below. So, they're just going to go get a short-term fix for problems, make an incremental change, and move on, they're just not thinking long term right now."*

Participant 6**.** argues that resistance to change is an obstacle. Lack of awareness comes from the fact that the technology is not mature in the industry yet. It is widely misunderstood and feared. The actual value of the technology is misunderstood.

Participant 9. Believes the biggest barrier is legal constraints.

> *"Even though in Austria the regulative authorities are very open to discuss and open to understand. It will take quite a while until the legislation and although authorities wrap their head around what is actually behind this technology. And to figure out if it is secure and can be really built on it."*

Participant 10. Referred to technological barriers of blockchain as the main obstacle and said: the biggest obstacle is the immaturity of technology itself because in the case of industrial control systems the technologies that are qualified, robust, and proven for almost 10 to 20 years are now being applied and blockchain is still not mature enough and well-proven. In many parts, isolated networks are preferred to distributed networks. Therefore, there are still limited use cases in specific areas. The complexity of blockchain also hinders its application. There is a lot that experts do not understand about blockchain even those computer scientists who very well understand blockchain, when talking about other functionalities of the technology have

different perspectives. Therefore, there are many aspects to the technology that are still unknown like the physical consequences of the technology if it is not under control. The complexity and immaturity of blockchain hinder its early and easy adoption and are counted as big obstacles. Getting access to people who really know the technology well is very challenging.

Participant 12. Referred to the technological barriers by saying that scalability, a little bit of security, and privacy are the key challenges in the current blockchain area. Challenges of information disclosure policy between the partners in the supply chain since different partners might have different privacy needs and different policies related to data sharing. Regarding security, she argued that there are still concerns about sensitive data which might be hacked. Although other participants mentioned this as a common problem for all databases and did not count this as a barrier or disadvantage for blockchain technology. She had a different opinion.

Participant 13. mentions some of the barriers as having no legal or regulatory framework. Then he pointed to governance and mentioned there is no regulatory governance so that if something goes wrong in the value chain it is not very clear who is going to be liable for that. He also counted lack of expertise in obtaining the complete solution as another barrier.

6.3.5. Category 5. Solutions to overcoming adoption barriers

Participants / ***Solutions for Barriers***	***P1***	***P2***	***P3***	***P4***	***P5***	***P6***	***P7***	***P8***	***P9***	***P10***	***P11***	***P12***	***P13***
Collaboration and partnership	*	*	*	*	*	*	*	*	*	*	*	*	*
Creating awareness	*	*	*	*	*	*	*		*		*	*	*
Educating top management	*	*	*	*		*			*		*	*	*
Strategic shift towards decentralization	*		*	*			*	*	*	*			*
Changing the mindset and attitude		*	*	*		*	*	*	*				
New leadership	*	*	*	*	*	*							
Change management			*	*	*	*							
Easy deployment and use of the technology					*				*	*		*	
Promotion of success stories as evidence	*	*	*	*	*	*	*	*	*		*	*	*

Table 9. Category 5. Solutions to overcoming adoption barriers

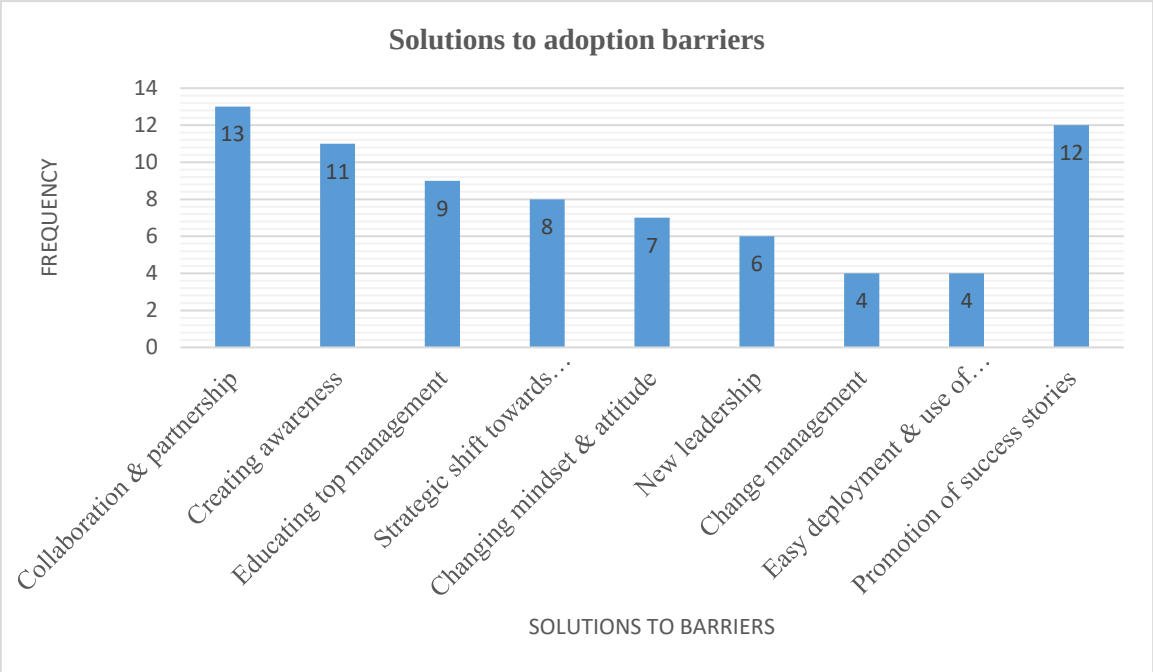

Figure 16. Frequency chart of solutions to adoption barriers

All participants believed that collaboration and partnership would solve adoption challenges. The oil and gas industry should break free from the traditional management style in order to survive and this can be possible by being ready to the adoption of innovative technologies and solutions such as blockchain. This requires collaboration and partnership with start-ups and blockchain companies to provide the best solution for the industry's current problems.

Participant 1 believes:

> "*Collaboration and Partnership is a big empty hole in the oil and gas industry. Oil and gas industry is all in-house industry. The typical industry that says I want to do it all myself which is impossible in today's world.*
> *I mean, an oil and gas company should focus on what they are good at and let others do what they are good at. And that means having partnerships with different blockchain companies, or start-ups that are working on that or that are experts. inquire them and bring them on board. Oil and gas industry cannot continue in traditional manner. Conservative oil and gas industry is going to die soon. one biggest sign is the war in Ukraine today (…)."*

All the rapid changes happening in the world will force the oil and gas industry to move from a traditional and conservative manner to a more decentralised industry in which there is no central authority. Participants believe the decentralization will benefit the industry and the world. An example that was given by most of the participants was the war in Ukraine and the

global reaction to that which indicates centralisation is no longer favoured. According to participant 1:

> *"Right now, what we see is immediately a shift because the whole world got involved in this situation, the whole world is having a say, the whole world is having an opinion, then the oil and gas industry finds the courage to decide beyond that centralization, So, Italy immediately shifted to Morocco. And I'm sure other countries are going to find their own solution around it as well. But that shows how the world is not in favour of centralization anymore. Definitely. I mean, and how dangerous centralization is in oil and gas industry. How can you centralize the whole consumption, the whole supply of Europe on a country with a psychopath leader?"*

More than half of the participants believe that changing the mindset is the biggest solution to remove barriers and the reasons why blockchain struggles are because the individuals who are running oil and gas companies today, the decision makers who must agree to execute and use these solutions, lack the necessary experience with the technology. So, the technology represents a significant unknown to them. They have no personal and practical experience with it. Therefore, in the oil and gas industry, there is a workforce whose experience doesn't include embracing this kind of technology and one of the solutions is new leadership.

As another solution participant 2 suggested what is being done in the United States, several oil companies have formed a consortium called blockchain for energy where they figure out solutions as a group. No one company has to figure out all this stuff on their own, they do it collectively. And that's a big plus. He also mentioned that oil and gas companies that wish to develop a blockchain solution do not need to concern themselves with precisely how blockchain works and do not need to know the technical aspects of the technology. Blockchain companies have manufactured the software that insulates the people who want to use blockchain for some business model.

> "*(...) it removes a technical objection that people have. Or we should be using Ripple or we should be using a hyper ledger? Those are the wrong decision to even talk about, what oil and gas companies need to decide is whether or not they can create value with their business solution. They should not worry about the technology."*

Change management was suggested as another solution, Participant3 believes that building change management tools with all other companies and collaboration are the key to removing adoption barriers. She mentioned companies that resist to change are putting all their trust on one vendor instead of coming and being collaborative with the whole industry and creating a

standard. Consortiums have a significant role in finding the best solution for the industry. Participant 4 believes that:

> *"One of the biggest solutions is blockchain for energy consortium because the world is starting to form that ecosystem and we are discussing things we're talking about that technology and doing business cases and from those business cases, we're learning what the behaviours are, what are the good things, what are the bad things? But we're doing in it a safe environment. We're doing it and we are sharing the cost. And we're also learning with mock data, and mock cases and we start building that language on how we communicate in this new world using blockchain, be more transparent, and still keep our business and keep each company independent and separate business on how we use that data. So, to overcome barriers we should start the ecosystem and conversation."*

Negotiation with the authorities was considered as a solution to adoption barriers. Participant 9 believes:

> *"At this point we need to work very closely with the authorities so that they don't block out certain technologies, not knowing what's actually behind when they are trying to implement the regulations within the countries, so this is really the turning point where we need to work closely."*

She emphasized the importance of research on the adoption of blockchain since it takes time because the technology is new not only to the companies but also to the authorities. But from the research point of view, she mentioned that research enables people to prove that the technology is actually working and then it can be discussed with the authorities to show them it is working in this very specific area.

> *"When it is a research project usually the very strict regulations are loosened a little bit because we are able to do the research there and that enables us to prove that things are actually working and then we can move it to the next level and get it into the next round when the regulations are being relieved."*

6.3.6. Category 6. Influential factors or drivers of blockchain adoption

Supporting Factors \ *Participants*	***P1***	***P2***	***P3***	***P4***	***P5***	***P6***	***P7***	***P8***	***P9***	***P10***	***P11***	***P12***	***P13***
Fear of missing out	*	*											
Push from other industries	*	*						*	*			*	*
Sustainability goals	*		*	*		*	*	*	*		*	*	*
Regulations & policy i.e., Governments & regulators	*	*	*	*		*	*		*				*
Academia & education			*	*		*	*		*	*	*	*	*
Technology Maturity Technological readiness level (TRL)	*				*		*		*	*	*	*	*

Table 10. Category 6. Influential factors in blockchain adoption

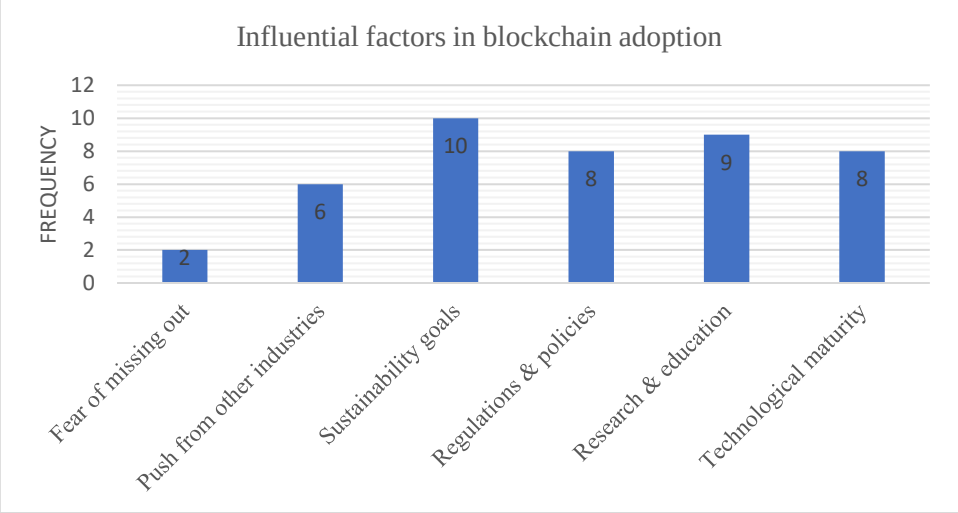

Figure 17. Frequency chart for the influential factors in the adoption of blockchain technology

According to participant 1, The move toward digitalization in general and applying blockchain as a sub part of this transition provides the oil and gas companies with an opportunity to achieve their sustainability goals by trying to become transparent, auditable, and decentralized. Regulations play an important role since the role of regulations can be twofold, it can serve both as a barrier and as a driver or influential supporting factor.

> *"Regulations can act both way basically. In one way, the lack of existence or proper regulation can be an obstacle. In the other way, the existence of pushing regulations can be influential factors in adoption of blockchain."*

Sustainability goals were the concern of almost all of the participants. Blockchain experts from blockchain for energy explained their sustainability goal as they have started in ESG program because they believe everyone needs to help in ESG and this technology is perfect for several segments of ESG.

They also emphasized the role of governments. They believe governments have an important and key role since they have seen when governments start talking about blockchain, everybody reacts faster. And because at the end of the day, governments are there to be referees and they need to be at the centre of helping them, making sure that all these data benefit the countries that they are operating in and the business.

They mentioned that academia is another driver.

> *"The universities can help if they talk about blockchain and its benefits and use cases, they have a profound effect in nurturing the new generation and helping people in the industry go beyond their walls. Governments and companies, and academia if they connect and create networks, will overcome a lot of the challenges and fraud and situations that exist right now."*

Participant 2 states that in many industries there are dominant players that have the most influence in the industry. Dominant players like Walmart in the US retail sector which is 40% of all retail sales of the whole country play a crucial role. If Walmart uses blockchain to track and trace the supply chain, then those companies who want to work with Walmart should get on board with Walmart's blockchain solution. If they fight against Walmart they are going to be shut out. But in the oil and gas industry, there is no dominant player in the industry.

> *"(…) the industry relies on governments and regulators to create rules of play or compliance requirements. And then they count on all the players in the industry having to comply with these rules. And that's one of the ways that they get around the fact that the mindset of people has to change, the easiest way to make the change happen is to force it."*

He concluded the way to get the oil and gas industry to change is to put a rule in place that says you have to comply with this rule.

6.3.7. Category 7. Risks and disadvantages related to blockchain adoption

Risks Disadvantages \ *Participants*	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
Wrong applications Wrong implementation	*			*				*	*	*	*		*
Wasting money	*			*									
Complexity (Bringing more complications to a simple problem)	*			*				*		*			*
Bringing disappointment & distrust to technology when used wrongly	*			*					*		*	*	
Commercial risks		*								*			
No technological risk		*	*		*	*					*		
Technological risk: Immaturity, security issues, scalability											*	*	
Huge energy consumption is only when there is mining	*	*	*	*	*	*	*		*		*	*	
Lack of control/ Susceptibility to exposure					*	*	*		*	*		*	*
People losing manual jobs as a result of automation							*						

Table 11. Category 7. Risks & disadvantages related to blockchain implementation

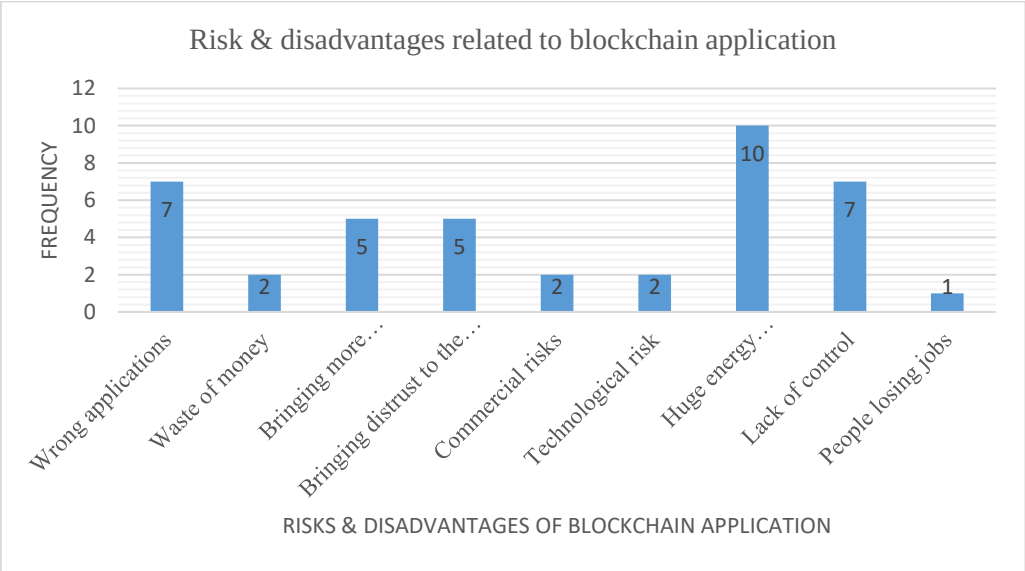

Figure 18. Frequency chart for the risks & disadvantages of blockchain implementation

The biggest risk detected in respondents' opinions was adopting blockchain for the wrong application, in other words, to fix a simple problem with a complicated solution is the biggest disadvantage and it is a waste of money. Participant 1 explained this issue very precisely. There are many companies that are using blockchain for the applications that can perfectly be done by a centralized solution and there is no need for DLTs or blockchain. Before investing a lot of money in fixing a problem multiple things need to be checked to investigate the reason why there is a need for blockchain.

> *"The goal is to fix complicated problems with simple solutions. Because blockchain is hype everybody wants to use it to say they are transparent."*

According to Participant 1, in the oil and gas industry, real applications of blockchain are big and complicated which require:

> "*collaboration, and partnership, years of implementation, proper implementation, a lot of knowledge, a lot of resources, and those are quite big projects and of course, it's very difficult strategically to get them on board."*

Participant 2. believes that there is not any risk related to blockchain adoption. There's no risk in the sense of safety risk such as catastrophe risk of an oil spill, those sorts of risks. So, there are pretty minor risks, more commercial risk than anything else. And he believed even those are manageable. The risks of blockchain adoption, are tiny compared to the risk that they already have to deal with in the oil and gas industry.

Regarding energy consumption participants state that for oil and gas industry applications there is no need for mining. Mining is a process that draws a lot of energy. In a public blockchain, you need the mining. That's one of the misconceptions that is not helpful for blockchain adoption.

Participant 5. Argues the risk associated with blockchain by considering the type of blockchain with the focus on the privacy issues. He believed lack of control brings vulnerability for some people.

> *"Public vs Private blockchains have different risks associated with them, depending on the use-cases. Sharing sensitive information on public networks carries more risk. Also, the feeling of "lack of control" in a distributed network, over time, is perceived as risk."*

Participant 9. She focused on immutability feature which can be regarded as both a benefit and disadvantage. Therefore, there must be a lot of thought before blockchain is applied to sensitive information.

> *"Immutability of data recorded on blockchain, data that can not be erased can sometimes be regarded as a thread if they fall in the wrong hands. If politically unforeseeable things happened, that can be really a threat to the people".*

Participant 10. considered the wrong application of the technology when it is not needed at all as a disadvantage. There are some use cases where there is no need for a blockchain at all. In other words, one single company doesn't need a blockchain. There are many other much better systems if companies want to store information just for themselves. But as soon as they add more than one company and want to exchange information with someone else applying blockchain makes sense. Therefore, the risk is using blockchain when it is not needed at all.

Participant 12. believes that there is no strong structure or framework behind blockchain research, so it is hard for companies to make a correct decision. She also mentioned there are technological disadvantages about blockchain. In line with the viewpoint of other participants, she mentioned that energy consumption depends on the consensus algorithms so it can not be always counted as a disadvantage.

6.3.8. Category 8. Future of blockchain technology

Blockchain or distributed ledger technologies can clearly benefit the industries, markets, and consumers to a certain degree since they offer novel solutions to the current problems in the industries. Therefore, the technology will continue to grow rapidly, and more use cases and applications are expected in the energy, oil, and gas industry. Based on the information collected from the participants of the study the future of blockchain is illustrated in the following figure.

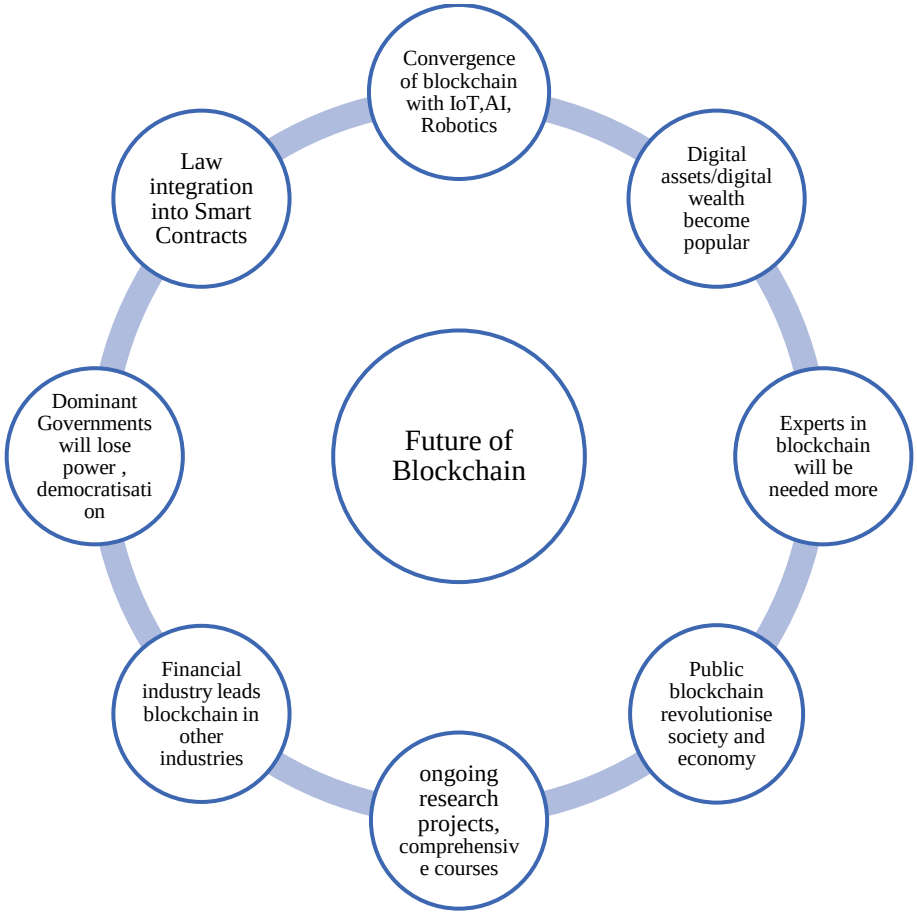

Figure 19. Future of Blockchain

Participant 1 believes that the oil and gas industry might be a late adopter of the technology but there is no other choice for the industry but to adopt the technology.

> "*The future of blockchain in oil and gas industry is like any other industry. There is no future without blockchain in any industry."*

She further comments that as the oil and gas industry is very much intertwined with financial industries and the financial industry is very receptive to blockchain technology then this shift will soon happen in the oil and gas industry too. In oil and gas blockchain can be adopted first with safer applications like supply chain because providing transparency in the supply chain is easiest and does not involve power conflict. Blockchain application will go toward market application first because it is safe and easy and has no conflict.

As an example of the great advantage of using blockchain technology in the financial sector, participant one referred to the use of cryptocurrency by Ukrainians during the crucial time of war. It was a big solution for them while the whole country and banking systems were down. It provided people with financial freedom, and they were free from the Ukrainian centralized

financial system with no dependency on a centralized authority such as the government. They have the ownership of their own assets and had the freedom and power to decide for themselves.

> *"People have started buying stuff with Bitcoin. You can see Ukrainians buy cars with Bitcoin and travel. or a lot of donations were done by crypto from around the world that under the traditional financial system would take weeks."*

She added

> "*as the governments become more decentralized then the decision making in the oil and gas industry is also affected and becomes more decentralized and transparent."*

The digital transition has changed many aspects of the industries and in today's world wealth is no longer oil and gas or even energy and it is moving towards digital wealth. Therefore, blockchain is playing a role in the future of wealth. Participant1 believes that:

> *"Oil and gas industries should be very careful about the definition of wealth and asset because today there is a shift in what wealth is. Wealth in today's world is no longer oil and gas and energy it has changed to digital assets. Although energy is still needed for digital assets but today there are more than 13 blockchains for which minimal energy is needed. With that minimal energy, it is possible to create assets than bring wealth more than oil and gas. So, I think if oil and gas companies are smart, they need to have this transition. I think that is something that oil and gas industry really needs to be proactive, not reactive in."*

Now the question is how it is possible to translate oil and gas into a digital asset and how it is possible to tokenize it and make it a digital wealth? Blockchain technology can provide the answers. The researcher may find answers to these questions in her future research.

Participant 2. Focused on blockchain technology from the cryptocurrency dimension and the shift towards cryptocurrency as a digital asset. He referred to the Ukraine crisis, and also Venezuela and other countries that got under sanction and stated that the populace quickly moves away from relying on a sovereign currency and are putting their assets into a cryptocurrency. Then he brought the cryptocurrency concept into oil and gas industry by saying that oil and gas companies will eventually be able to transact in some kind of cryptocurrency, which means that they will be outside the US banking system. And once they get outside the global banking system, then the sanctions that are applied might not work. So, the oil companies, particularly the ones who are coming from nations that wish to sidestep or avoid the dominance of the US dollar on pricing, oil assets, and oil products, go on to cryptocurrency

and transact using cryptocurrency using blockchain technology to get away from the American dominated banking system.

About the future of blockchain participant 2 explained the *convergence effect* where blockchain technology converges with artificial intelligence and robots and the Internet of Things to create new and more creative business solutions that we currently can't achieve. Blockchain creates an immutable record of robots' actions as they execute. There is also the possibility to go back and trace the activities that they actually did. The data on the blockchain shows all the information such as time, location, date, etc.

> *"(…) the robot arrived at this GPS location on this date in this time and did this function for example the oil was removed, and everything is recorded by automated sensors."*

As another example of implementing blockchain, he referred to Spotify and the solution they have applied by blockchain which can be beneficial for solving other problems.

> *"Spotify purchased a blockchain company a few years ago because they were sued by the musicians, the people who make music, because Spotify couldn't prove that they paid all their royalties correctly. And what Spotify did was they said, Fine, here's a solution. Every time somebody plays the music, we'll record a little transaction on blockchain. And now we have an immutable record that the music was played. And that's how they'll pay the royalties. And they let the musician see exactly how much how many times the music has been played on Spotify."*

Participant 3. CEO of blockchain for energy talked about the convergence of technologies such as IoT and AI with blockchain. By emphasizing that blockchain is already being used in other industries, she believed it is an urgent need for oil and gas industry to take this technology seriously into consideration.

"even if we did nothing about blockchain it would still come at us, as it is already in many other industries such as the insurance, the banking, and real estate, all of these other industries are 2-3 years ahead of the energy industry in this space and
It is coming very soon and blockchain is happening at such a rapid pace, more rapid than we've ever seen technology being developed. blockchain is a normal and needed component to all the other technology. many AI companies now realized they have to have a blockchain component to what they are doing digital twin, passing the data they want it cryptographically locked and be able to have it. They're using blockchain for cyber security purposes. and IoT. It's a natural fit. We shouldn't even talk about IoT unless we put the word blockchain with it. I mean, they're just a natural marriage, so blockchain is never on its own. Blockchain is a back end technology that's actually helping to make all the other technology give greater ROI and give greater value than even anything on its own. (…) *this is our window of opportunity to shape and mold blockchain technology for our industry. So it is important to think ahead and apply the technology where it is needed".*

In blockchain for energy, there are 6 use cases in the energy industry they are recently working on, and one is *digital identity*. She said blockchain has some basic foundational pieces that go across all use cases and digital identity is one of them. Their main focus is on how their wallets are going to be handled now and in the future. Another focus is on the governance. Who will govern the blockchain? Do they want one vendor governing the blockchain for them? Or do they want a Council that governs the blockchain for the industry? Because a lot of times a vendor is not just for the energy industry they are from multiple industries and so they are pulled by their stakeholders on how they govern and it's all monetary based and maybe it's in alignment with what the energy industry wants, and maybe it's not. And blockchain for energy is already talking about those things and they're creating their first product council over commodity transport, and they would like to go into regulatory reporting and start working with their regulatory agencies she mentioned.

Participant 4. Believes that the future of blockchain is rising fast, especially in ESG area, governmental and social sectors.

> "(…) *the biggest area where we see growing at faster is this ESG area, not only in the carbon emission but the government portion and their social portion, especially in the tracking of the legality of the products. Those things are going to move faster, and it's because right now the industries are no longer isolated. The world is opening and we need to exchange some of the data. So going with blockchain is going to help us to accelerate that in a safe way, exchanging data outside without those intermediate priorities that we traditionally use. So, I see a future or blockchain growing in certain areas faster than others."*

She also emphasized the role of academia in the future of blockchain where there must be education about blockchain applications other than cryptocurrency which is sometimes used for negative purposes such as money laundering and hiding money. The benefits of blockchain can be harnessed by educating and learning more about the technology and successful use cases. And this will mitigate the fear of change and traditional systems will feel more comfortable with this technology.

Participant 5. talks about the future of blockchain in the oil and gas industry by considering smart contracts and believes that there will be great opportunities.

> "*We in Data Gumbo believe that many legal contracts today will exist side-by-side with blockchain Smart Contracts, to drive transactional certainty."*

Participant 6. believes that ultimately, over a period of time, there will be full transition into blockchain. However, it starts piece by piece. Like for example using smart contracts. It is initially kind of frightening and can be started with one operation at a time and continues. She believes in the future 100% of the supply chain will be on the blockchain.

Participant 9. Emphasized the importance of research for understanding the technology more.

> *"So much has happened in the last five years that wasn't on the horizon then. A lot of research and a lot of testing on our side must be done but Time will tell."*

Participant 10. believes in the future the blockchain is broken up into its principles and functionalities. Blockchain going to be applied based on its best functionalities. He believed there are already technologies close to blockchain like OPCUA that are more environmentally friendly, and lean compared to blockchain. So, the future of blockchain very much depends on the market and other emerging technologies.

In oil and gas also, there are the technology qualification regulations which means the technologies must be qualified and become proven within safety systems.

In the world today, there are always new interesting technologies coming up, and blockchain is one of them. However, few of them are adopted due to the conservative nature of the oil and gas industry and also because technologies must move through the gates of the technology qualification framework before adoption. Participant 10 was wondering if anyone has started to try to do a technology qualification of blockchain.

Participant 11. Talked mostly about the benefits of public blockchains and he called it one of the world's most important inventions which can revolutionize both society and economy and the financial situation for everybody, much more than the internet has done. This decentralized internet can provide equal opportunities for everybody to sell their talents and knowledge and make money out of it. He believes *"the world economy will just explode with all of these people being able to do that."*

6.4. Presentation and Analysis of Main Themes

The main themes of the study emerged during the analysis of the sub-themes or categories, although from the beginning of conducting the research the main themes of the study were reflected in the research questions. Sub-themes were decided while designing the interview questions in the quest to elicit the best responses from the interviewees for the main research questions. Analysis of the sub-themes was based on respondents' opinions and perspectives as presented in the previous section 6.3. Since the sample of participants was a homogenous purposive sampling, in other words, expert sampling, they shared a set of characteristics in line with the objectives of the study. Therefore, no major variation was observed in the respondent's viewpoints on most of the topics of discussion and the frequency of most responses was high which could indicate similar opinions. The main themes and sub-themes of the study are illustrated in Figure 12. In this section, the researcher is seeking to elaborate on the main research themes at hand to provide answers to the research questions. Section 6.4.1 discusses theme 1 which is about the opportunities and applications of blockchain technology in the oil and gas industry. Section 6.4.2. provides a discussion on the challenges and blockchain adoption barriers together with presenting some solutions to overcome these barriers. Section 6.4.3 deals with the influential factors in the adoption of blockchain technology in the oil and gas industry.

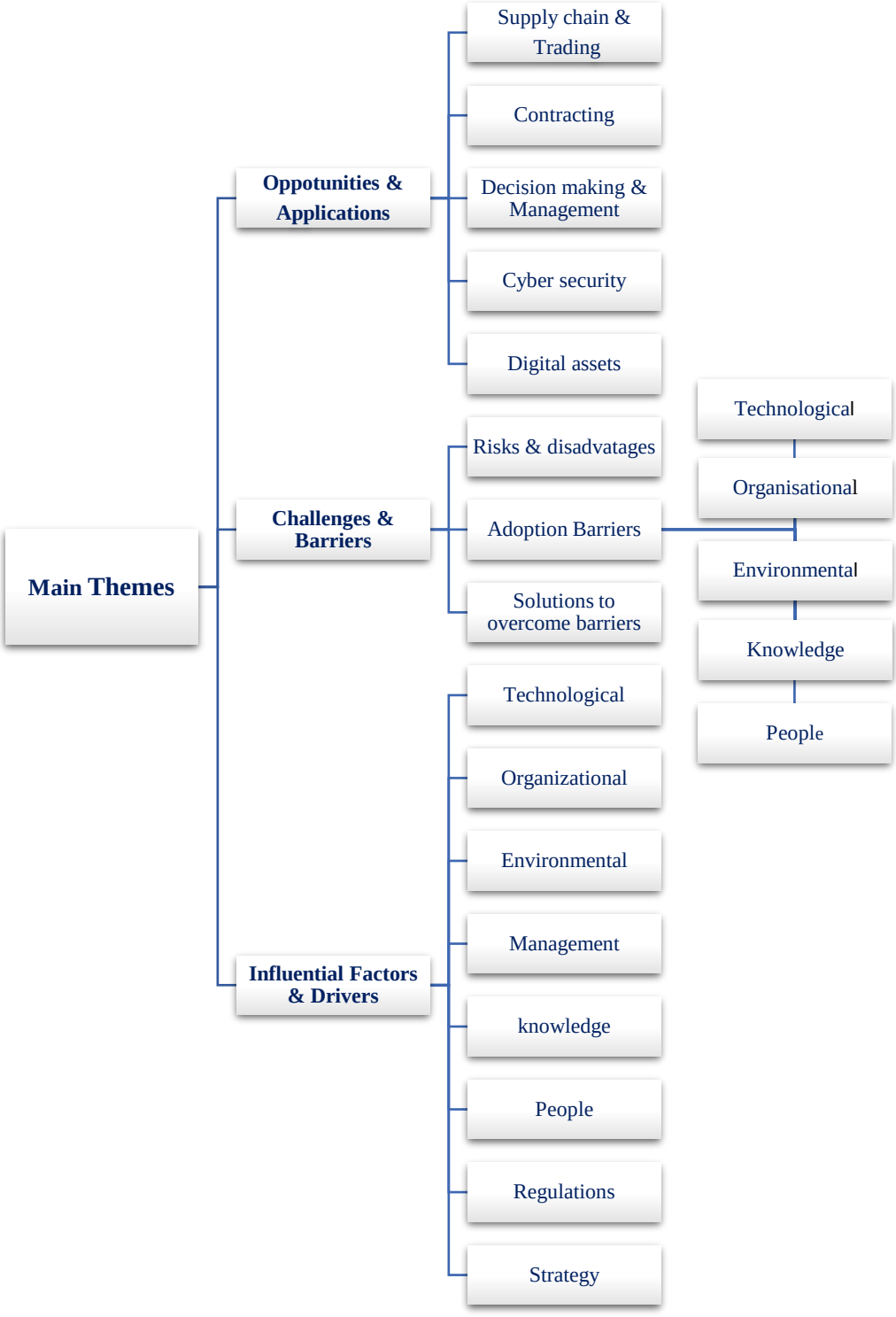

Figure 20. Overview of the Themes & Sub-themes

6.4.1. Theme 1. Opportunities and applications of blockchain in the oil and gas industry

In line with goal of the study and the first research question, the researcher seeks to understand the value proposition through blockchain utilization in the oil and gas industry. In this section key opportunities and applications of blockchain technology in the oil and gas industry are presented based on a review of the related literature and the analysis of the findings from interviews for this thesis.

Based on the results gathered from the interview data the main reasons for blockchain application in industries including oil and gas are the unique features and functionalities of this technology. The findings apparently confirmed the theories on blockchain in that the most prominent features were identified as decentralization, transparency, disintermediation, traceability, immutability, auditability, and security. These principles can increase the efficiency by reducing costs, and administrative time and increasing productivity. Similarly, there are various use case and application scenarios in the literature which indicate a high degree of confirmation between the results obtained from the participants and the available theory on the topic. In the literature about blockchain features in the oil and gas industry transparency, decentralization, immutability, and auditability are considered the most important properties of blockchain (Ahmad et al., 2022).

In line with the studies done previously, the findings of the study indicate that blockchain technology can benefit various sectors in the oil and gas industry which can be divided into the following main areas:

- Supply chain and trading
- Contracting
- Management and decision making
- Cyber security
- Digital asset

Findings from the interviews show that the main areas in which blockchain adoption can benefit the oil and gas industry the most are respectively: supply chain and trading, contracting, and then management and decision making. In what follows the researcher explains how will blockchain technology add value to these different areas with its distinct functionalities. In other words, the role of blockchain features in the oil and gas industry is clarified. Digital assets

discussed in the result section in also another area of blockchain application in the oil and gas industry.

6.4.1.1 Supply chain and Trading

As mentioned earlier the value chain of oil and gas industry is huge due to the multiple links the industry has with various stakeholders such as producers, shippers, suppliers, etc. And based on the type of operation such as drilling, exploration, transport, shipping, etc., oil and gas supply chain is classified into three main categories of upstream, downstream, and midstream. Therefore, many participants are involved from the time oil and gas are produced until its distribution to the customers, and lack of trust among the participating organizations is a big issue (see Figure 21). In each phase, a large number of transactions and contracts are involved. The major problems are then limited or lack of *transparency* of the operations and transactions, low data visibility, human error and fraud or compromise. These problems can be addressed by the application of blockchain.

It was explained in the literature about blockchain functionalities in section 4.1.3. that transactions become more transparent using blockchain technology. Transactions are stored on all network nodes consistently and all authorized participants can have access to them and view them. This visibility increases the success rate of transactions and reduces disputes. Transparency of operations in the oil and gas industry can build trust among the stakeholder organizations. The cryptography and timestamping of blocks can assist stakeholders in the oil and gas industry to verify the data and transactions. A blockchain based trading system permits the validation of transactions through consensus therefore transactions can not be manipulated and the conflicts arising from duplication and inconsistency no longer exist.

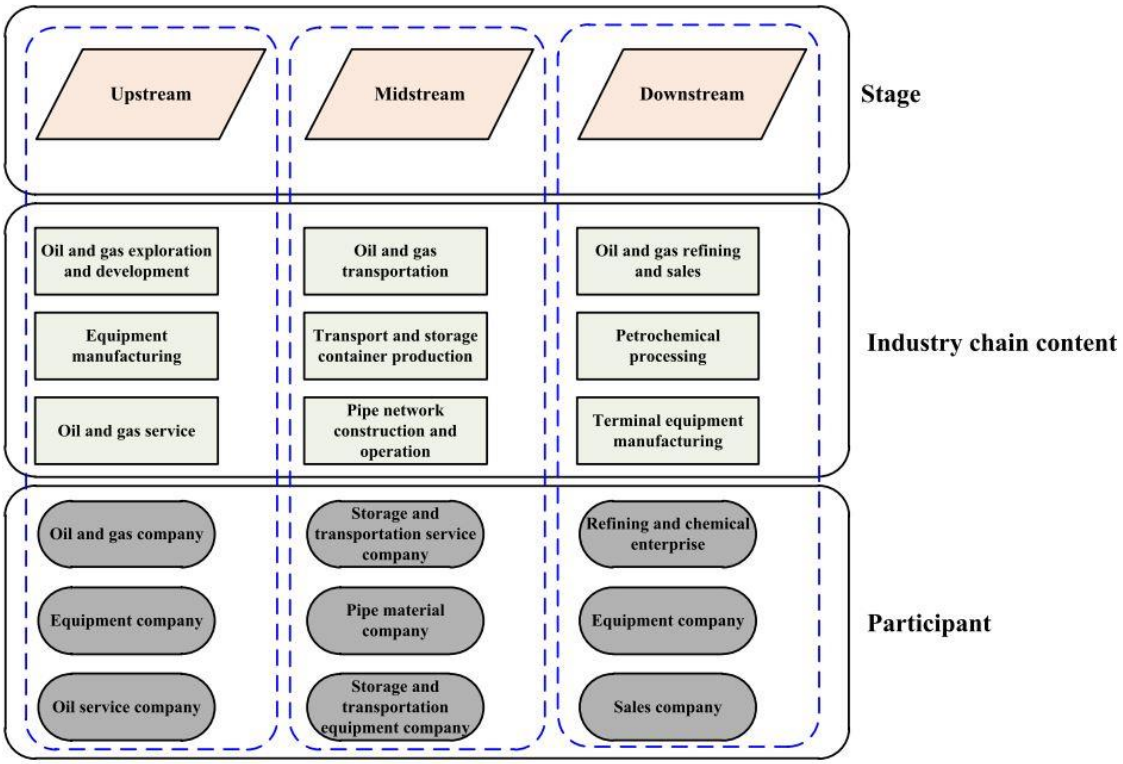

Figure 21. Oil and gas industry chain. retrieved from Lu, Huang, et al. (2019)

There are many use cases and scenarios of the application of blockchain technology in different sectors of oil and gas value chain in the literature. Figure 22. gives an overview of opportunities for blockchain in the oil and gas industry. A detailed explanation of each case is not the purpose of this thesis, and the goal is to only highlight the principles of blockchain based on which blockchain can be beneficial.

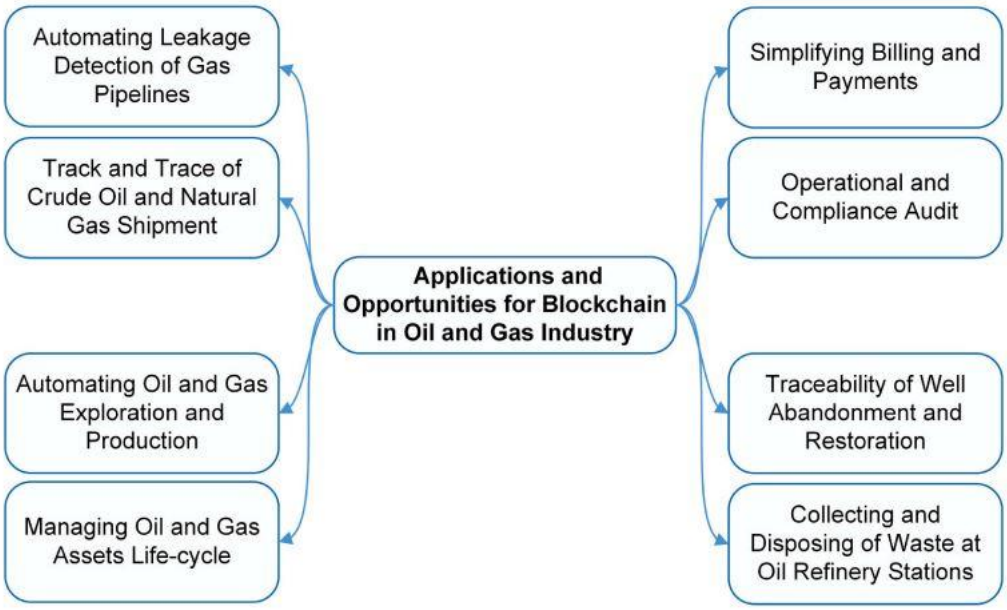

Figure 22. An overview of the potential applications and opportunities for blockchain in the oil and gas industry. Retrieved from Ahmad et al. (2022)

In what follows a brief description of some of the applications and opportunities is given. These use cases were chosen because they were also explained by the participants of this study since they are working on similar projects using blockchain technology for problem solving. Therefore, it can be claimed that both primary data from the interviews and the secondary data gathered from literature are consistent with each other.

- **Monitoring pipelines and leakage detection:**

  The importance of pipelines in the transportation of oil and gas over long distances can not be ignored. Therefore, the safety and maintenance of pipelines matter a lot. Blockchain is used for the real-time monitoring of pipelines and detecting errors such as leakage, theft, or intervention. The recorded data using the sensors attached to the pipelines about the condition of the pipelines and their lifespan can assist in timely detecting and locating the leakage or even predicting the leakage.

  There are already different monitoring techniques such as pressure point analysis, acoustic emission, fiber optic sensors, etc. however in all these techniques centralized systems are used to store and process the data from sensors on-field (Adegboye et al., 2019). If blockchain is used as a database then problems regarding reliability, availability, and security of data will be solved by the features of this technology.

Blockchain can assist in verifying that all activities are done in compliance with human safety laws. Blockchain can register and verify all the information from IoT sensors in a reliable and highly trustable and transparent manner. Smart contracts can be generated to the pipeline operators giving notifications about any leakage issue while sharing the location for appropriate service that is needed and so many other possibilities.

- **Trace and track of oil and gas shipment**

  Here the researcher discusses how the track and traceability functions of blockchain can benefit the oil and gas industry based on the data collected from the participants and data available in the literature. From the time oil and gas are produced until it is transported from the wellhead to the refinery, and then from refineries to the end users as petroleum products many organizations, components, and processes are involved in the supply chain. such as pipelines, trucks, railroads, sea routes. All the involved participants need to interact with each other in a trusted network.

  Tracking functionality of blockchain can assist in monitoring and verifying the current location of oil and gas, shipment state, transportation route. Updated data can be effectively recorded and verified on blockchain. Due to decentralization characteristic of blockchain, the data is immutable and can not be modified. Therefore, such records provide *data provenance* of the oil and gas products which can help identify fraud or trace substandard products and detect the stations where impurities were added and penalize them. *Traceability* can result in preventing compliance violations and enforces trading policies (Ahmad et al., 2022). The shipment tracking is done by attaching sensors to the trucks or trailers and any illegal attempt can be immediately noticed (Salah et al., 2020).

  Therefore, the tracking and traceability functionalities of blockchain can have great impact on the oil and gas value chain.

- **Automating the exploration and production (E&P)**

  In this section, the researcher is looking at the costly phase of E&P in the oil and gas industry by considering the data collected from the participants of the study and the related theory to analyze how blockchain technology can add value to this sector. Among the participants being interviewed Rebecca Hofmann formerly working in Equinor and Raquel Clement from Chevron, both board member of Blockchain for

energy Consortium, provided invaluable information about their hands on projects and innovative solutions in the oil and gas E&P sector.

In the exploration and production sector many organizations and several external stakeholders and involved to explore, drill and produce oil and gas. Blockchain offers "a single source of truth", a single, consistent and unified source of data that can be available and accessible to all authorized members of the network. All the organizations involved can view transactions and updated data in real time and can share the data.

In modern oilfields, IoT based sensors are used to collect data such as injection rates, fluid data, drill rates, temperature, and pressure (Mohammadpoor & Torabi, 2020). When the data is stored in traditional systems, they will be vulnerable to modification by competing companies or hackers but these problems can be lessened significantly if the data is stored on private blockchain due to immutability feature of blockchain. Using blockchain payments can be automated and because many transactions are involved in the E&P processes, this will increase the speed and reduce the time and cost. Payments to offshore service companies can be based on the equipment usage rate. The large seismic data can also be stored and protected by creating hash codes on the data. (Ahmad et al., 2022).

- **Asset lifecycle digital management**

  Asset management methods are transformed with the emergence of technologies such as big data and IoT. Predictive maintenance of assets is now possible through digital twin, and blockchain technology can assist in tracking the information related to the asset life cycle (Lu, Guo, et al., 2019). Asset management is an important issue in the oil and gas industry since several types of assets are involved including machinery and equipment. Moreover, equipment management activities such as procurement, installation and infrastructure development, shipments, repairment, and maintenance are very complex and multifold activities that many partners are involved. Existing web-based systems are centralized and can not provide all partners with real-time data and limit their control access. Blockchain technology can solve this problem by transforming operational models and increasing strategic decision making based on real-time data. Real time data is collected from physical assets through specialized sensors. Data collected ensure the safety standards of equipment by tracking the location of the equipment that need maintenance and recording the maintenance history (Ahmad et al., 2022).

There are many other use cases of blockchain in the oil and gas value chain all of which utilize about the same features of blockchain. Blockchain principles that can change traditional supply chains are traceability, transparency, and immutability. Blockchain technology and smart contracts together with IoT devices can modernize the traditional supply chain in the oil and gas industry (Haque et al., 2021).

Many recent cases for application of blockchain in the oil and gas industry are currently done by experts in the Blockchain for Energy Consortium in U.S. Blockchain For Energy Consortium is based on the collaboration of top energy companies where they bring innovative solutions to the oil and gas industry. They leverage blockchain for enhancing efficiency, reducing costs, and improving timeliness. They are detecting, evaluating, and piloting use cases for generating value using blockchain in the oil and gas industry. they add value in the oil and gas value chain in terms of faster transactions, decreased disputes, enhanced safety, reduced costs, and increased security (*Blockchain for Energy*).

6.4.1.2 Contracting

Smart contracts are designed with the goal of automating the services within different sectors of the oil and gas which helps in creating a more seamless supply chain. by efficiently executing the terms of a contract without the need for trusted intermediaries, Smart contracts can minimize fraud, arbitrations, and also transaction costs. In the oil and gas industry, the large volume and size of the contracts and transactions require heavy manual work. Smart contracts solve this problem by automating the recording and tracking all terms of the contract. All the information is distributed among authorized participants in a transparent format (Lakhanpal & Samuel, 2018).

The data collected from the participants of this study contains data from Data Gumbo which is a smart contract company. They are currently using smart contracts in the oil and gas industry and their solutions could have added value to the industry. This is in line with previous literature about value adding through smart contracts in different industries.

Data Gumbo transforms transactions by removing trust issues in business relationships across the oil and gas value chain. This could cut costs significantly. They also provide the companies with a network to share field data with their counterparties leading to automated service verification and then execution of agreed-upon payments for the service after occurrence. GumboNet is generated based on a private blockchain that is utilized for expanding

collaborative, automated, and P2P business networks. It generates value by improving performance, security, and transparency as well as trust. The competitive advantages of the company are easy tracking of transactions on the digital ledger, and 90 percent reduction in invoice reconciliation, full use of IoT sensor data, reducing the interval between tasks and costs, and providing industrial smart contract templates (*Data Gumbo*).

6.4.1.3 Management and decision making

Most of the participants of the study believed that blockchain technology can have an impact on the management and decision making in the whole value chain process ranging from exploration and development to design and maintenance of devices and equipment, resource allocation, completion, production, etc. Blockchain technology with its features and functionalities can reduce the workload and reduce non-productive time and cost.

The decentralization characteristic of blockchain and the distributed storage of data makes the data available to all authorized participants. This feature is very important and helpful in the oil and gas industry since stakeholder organizations can have immediate access to the authentic data to make efficient and timely decisions. Blockchain makes timely and uninterrupted communication among the stakeholders possible and secure. This will increase the productivity of the industry. In management decision making it is necessary to have access to one source of data that contains all the information stored on one system, because data on various separate systems may have different structures, and formats, they can also be altered. Having one immutable source of data can improve the correctness and authenticity of the decisions. It is also mentioned that blockchain can provide voting applications using smart contracts since many decisions in the oil and gas industry are made based on management voting (Lu, Huang, et al., 2019). Blockchain can simplify the management process through automation, fast data exchange, and creating transparency and integrity in the data. By relying on trustable data decisions made are more reliable and scientific.

Some cases of making better decisions in the oil and gas industry through blockchain implementation are for example when multidisciplinary teams are involved in making decisions for the success of a field. For subsurface analysis blockchain can make the data related to all the wells readily available which can positively affect decision making. The data can be safely stored on blockchain and can be used as historical data later. This can mitigate the problem of data scarcity for instance in reservoir characterization projects. In drilling and

completion phases blockchain technology in connection with IoT can improve data exchange and automation of the operations (Lakhanpal & Samuel, 2018). Better decisions can result in production optimization and increased efficiency in the whole value chain.

6.4.1.4 Cyber security

Cyber security was one of the key concepts discussed by most of the respondents. Almost all believed that blockchain technology can reduce the risk of cyberattack by storing the data in a distributed manner. Furthermore, due to characteristics of decentralization, transparency, immutability, and encryption, it is very difficult and challenging to tamper with the network, and data tampering can be detected by blockchain increasing its operational resilience. These features can improve cyber defense since the platform is more secure through its consensus mechanisms and cannot be accessed by unauthorized participants. All the features of blockchain do not mean that it is not susceptible to cyberattacks. It is only claimed that the risk of network attack is less than in other centralized networks. In the oil and gas industry, nearly three-quarters of oil and gas companies in the U.S. experienced one cyberattack in 2016 (Lu, Huang, et al., 2019). Using private blockchain in the oil and gas industry may solve this problem although it is still subject to more investigation.

6.4.1.5. Digital asset

There is not much literature about digital assets in the oil and gas industry. However, in the primary data participants provided examples of the current use case where blockchain technology is utilized for tokenizing assets, monetizing assets, and tracing the ownership of the assets such as land or seismic data and intellectual property. Therefore, blockchain is used as a technology for creating digital wealth. CEO of Ziyen Energy argued that operating on the blockchain facilitates greater fractional energy asset ownership. The buyer and seller can have access to a cheaper and faster method to buy and sell an asset on an open market and this is possible without a reduction in the value of the asset. Tokenization creates a new level of liquidity in the energy industry and it provides transaction efficiency and transparency across intermediaries (Tian et al., 2020). Digital asset ownership will transform the market structure of energy industries in the future, although the potential of tokenization has not yet been fully realized. ZiyenCoin is a token issued by Ziyen Energy company for trading energy products in

the oil and energy industry. They are transferring energy tokens between the stakeholders in the oil and energy industry and update the owner of the tokens on blockchain platforms (Ahmad et al., 2022). Another example is Venezuela's government oil and gas cryptocurrency named Petro for secure and transparent trading of oil barrels on blockchain. Bilur, a British company is another example that is tokenizing oil and gas assets.

6.4.2. Theme 2. Challenges and barriers to the adoption of blockchain

This section presents the analysis of findings related to the second research question: What are the challenges and barriers to implementing blockchain technology in the oil and gas industry?

The findings related to the second theme of the research, or the second research question are presented in three sections for better clarification. The first section discusses the risks and disadvantages of blockchain based on both primary and secondary data. The second section discusses the adoption barriers detected from the interview data. The third section reviews the solutions proposed by the participants for overcoming adoption barriers.

6.4.2.1. Risks and disadvantages

Blockchain technology is still in its infancy and a new technology inevitably faces many challenges in its early adoption and first application scenarios.

According to the data collected from the participants of this study, the biggest risk associated with the technology is the wrong application of the technology which means there are many cases where blockchain has been used where there was no need at all to use the technology. The problem could simply be solved by already existing databases. This can bring disappointment in the technology, and it might be considered a money waste. while the true disappointment is the lack of expertise to utilize the technology where it is needed to be applied. There are not many professionals in blockchain applications. There have been many cases where using blockchain has only complicated the problem by bringing a complicated solution to a simple problem while the goal is to solve a complicated problem by bringing a simple solution according to Zara Zamani. Therefore, it should be considered that blockchain is not necessarily better than traditional databases in all cases. Expertise is needed for the correct application of the technology.

Over 50% of the participants believed that there is no technological risk with blockchain as a tool and if there are cyber security issues it is the same as any other technology. Only 15% of participants believed there are technological risks. They counted immaturity, complexity, scalability, and lack of standardization as the challenges with the technology that are still unresolved.

Data quality is also another issue. It has been dealt with both by the participants of this study and in the literature. Blockchain does not guarantee the quality of the data that is transmitted to it, Blockchain is only responsible for the data's accuracy and quality once it is stored in the blockchain. Therefore, the source of the data needs more consideration, the source of data determines data quality, not blockchain.

Participants believed that energy consumption is considered a big environmental risk of blockchain depending on the consensus mechanism. Most of the participants agreed that blockchain is energy consuming when there is *mining* process. Energy consumption when there is no mining is not high like in private or hybrid blockchains utilizes in the oil and gas industry or other industries. Participants discussed that when talking about energy consumption it must be compared with how much energy is consumed in other parts and aspects of the industry then it can be understood that blockchain is not that energy intensive.

The immutability characteristic of blockchain can be considered as both advantage and disadvantage with regard to data privacy. The reason is that the data cannot be erased or modified. Therefore, sensitive information and personal data must be encrypted to ensure data privacy. Although blockchain is based on encryption standards it is not absolutely safe. In comparison with other database systems blockchain has more security.

Susceptibility to exposure and lack of control is another risk with blockchain that was found in the data. Transparency is considered a risk, especially for those who are afraid of the revelation of their information. The scope of transparency in the firms is still an issue.

There are many risks associated with this technology in the literature as well. According to Lu, Huang, et al. (2019), these risks are divided into three main categories of operational risks, cyber risks, and legal risks.

There is still no regulatory framework for blockchain, and some illegal acts may occur in the operation of blockchains such as illegal use of information, illegal transactions, and tax evasion.

The operational risks associated with blockchain are lack of long-term experience with technology which can result in management problems over time. Moreover, security deficiencies and loss of data and identity are other challenges. Transaction costs of public blockchains are also high. Cyber risks are fraudulent behaviors such as hacking users' passwords or wallets (Lu, Huang, et al., 2019).

Lakhanpal and Samuel (2018) referred to the infrastructure challenge and argued as users store their transactions blockchain grows to the extent that there are large amounts of data stored on each node that are of no interest to them and they regarded this as a waste of computational resources. Moreover, the growth of chains leads to more energy consumption for block validations, and this is counted as another challenge, especially with regard to public blockchains.

6.4.2.2. Adoption barriers

During the interviews, the discussion about technology adoption barriers was closely intertwined with the discussion about the challenges and risks of the technology. The researcher considered participants' responses as a whole, in order to come up with the main categories of blockchain adoption barriers. A holistic approach to all the answers provided by the respondents helped the researcher to analyze the results more accurately. Based on the findings the main barriers that impede the adoption of blockchain in oil and gas were considered as:

- Lack of awareness
- Lack of expertise/ expecting immediate results
- Traditional business views
- Conservativity of oil and gas industry/ extreme centralisation of the industry/ resistance to decentralize
- Top management resistance to adopt the technology/ fear of change
- Mindset and attitude
- Lack of regulations/ absence of standardization
- Technological barriers such as complexity, immaturity, scalability
- Regulatory barriers

Referring to the theoretical framework on technology adoption barriers which was discussed in chapter 4 section 4.3. The integrated theoretical framework is used in this study to analyze the data collected from the participants about barriers to blockchain adoption in the oil and gas industry. The reason for using an integrated framework is the broad nature of responses and

comprehensive goal of the research. Perspectives from the respondents must not be confined to considering only one theoretical framework. By choosing the integrated framework, the data was examined through different theoretical lenses including technological, organizational, environmental (TOE), technology acceptance model (TAM), theory of planned behavior (TPB), and unified theory of acceptance and use of technology (UTAUT). For more explanation about each theory refer to section 4.3. The following main categories of barriers were detected by the researcher as major roadblocks to blockchain adoption:

- ***Technological barriers***

  The technological barriers discussed by the participants of this study centered around the limitations of blockchain technology such as the *immaturity* of the technology, *scalability*, *complexity*, and *security* problems.

  These technological barriers are also reflected in the literature. According to Casino et al. (2019), the immaturity of blockchain technology causes technical challenges such as scalability, and usability (Casino et al., 2019). It is said in the literature that the technology needs more development. Blockchain technology has security issues and there are some instances of system attacks and hacks of blockchain, especially in the cryptocurrency environment (Kouhizadeh et al., 2021).

  It should also be mentioned that based on the results of this study most of the participants believed that the barriers are less technology-oriented and they counted awareness, knowledge, expertise, and attitude as the biggest barriers. These barriers are presented and discussed in different categories.

- ***Organizational barriers***

  The organizational barriers which emerged from the data were: *top management resistance to support*, *organizational readiness*, and *organizational resistance to support* the adoption of blockchain as new technology. Another barrier in the case of oil and gas organizations is the traditional and conservative nature of the industry. Oil and gas organizations are not very willing in sharing their information as information is counted as a competitive edge. The rules and policies regarding how much information should be shared and with whom and to what level are all very complicated and vary from one organization to another. Therefore, oil and gas organizations are not

very interested in the transparency principle of blockchain. This is also confirming the theory about lack of new organizational policies for using blockchain technology (Lacity, 2018). Changing the organizational culture is difficult. The industry in general is counted as a slow adopter of new technologies. Another barrier is the costs associated with the implementation of the technology and many organizations are not willing for additional financial investments.

Based on the results of this study organizational barriers have a great influence on hindering and delaying the adoption of blockchain technology.

- ***Environmental barriers***

The environmental barriers detected from the data are governments and *lack of governmental policies and regulations,* the governments still do not fully support the adoption of blockchain because of the novelty of the technology and because technology is not completely proven in many aspects. *Market competition and uncertainties* especially in the oil and gas industry are counted as another barrier. Ethical practices can be considered in this category. *Lack of policies* regarding information disclosure between the partners in the supply chain is considered as another barrier. This barrier is evident in the data and also in the theory. According to Hughes (2018), different participants in the supply chain may have different *privacy needs and policies related* to the information and data sharing in the supply chain (Hughes, 2018). Another environmental barrier to the adoption of blockchain which was discussed by participants of the study and is supported in the literature is the different *geographical and cultural differences* of the partners of the supply chain.

- ***Knowledge Barriers***

There was a widespread conviction among participants of this study that the most important adoption barrier is lack of awareness, knowledge, and lack of expertise about the technology among managers and practitioners of the oil and gas industry. Employees' technical knowledge about blockchain is very low. One major cause of this lack of knowledge can be explained by the complexity of the technology itself. The technology is difficult to understand, and it is not easy to find out where the technology best fits. Due to lack of expertise, people come up with the wrong applications of the technology which is then counted as waste of money and causes disappointment in the

technology. In addition to the difficulty of the technology, education, and training about the technology is very low. What can be concluded here is the fact that education, training, and knowledge sharing about the technology are very important to overcome this barrier. There are still many people who do not know the technology and they associate the technology with cryptocurrencies like bitcoin.

- ***People Barriers***

  People barriers focus on individuals' mindsets and attitudes, behavioral beliefs, and intentions. The two theories that focus on people's attitudes and perceptions about the new technology adoption are TAM and TPB. The theory indicates that people's perceived usefulness of the technology and perceived ease of use of the technology are determining factors in technology adoption (Zamani, 2022). Based on the findings of the study one of the barriers is the negative perceptions toward blockchain technology which comes as a result of the immaturity of the technology and security issues. The complexity of the technology and the fact that it is not easy to understand is in contrast with perceived ease of use and therefore is a barrier. The results from the data indicate people's mindset and attitudes toward blockchain adoption are big barriers.

There were of course other barriers mentioned by the respondents such as lack of leadership, political barriers, etc. The researcher focused on barriers with the highest frequency in the responses and set aside the outliers since a detailed analysis of all the barriers is out of the scope of this research.

6.4.2.3 Solutions for overcoming adoption barriers

This section deals with the solutions to fix or narrow down the numerous bottlenecks that prevent blockchain adoption in the oil and gas industry. This section is closely related to the previous section where the adoption barriers were discussed however it focuses on the findings in relation to the solutions that emerged out of the interview transcriptions. The findings were supported by the literature and some of the solutions are presented in this section. The overall results show there was a general agreement among the participant about the importance of *collaboration and partnership* and the solution they suggest is building consortium where experts come together and form collaborative groups to tackle problems and find solutions that benefit everyone. Moreover, they can create awareness about how the technology can benefit the industry. There was a consensus on the *promotion of success stories* as another important

solution to adoption barriers. This can remove negative perceptions and guide toward the correct implementation of the technology.

The problem with lack of talents can be solved if academia and educational institutions start offering blockchain courses and add them to curriculum. Academia and organizations must work together to train and develop a talent pool that can be of tremendous help for the different organizations such as oil and gas companies in near future.

More *research and case experiments* are needed about blockchain to remove and solve the current issues with the technology before its mass application. Universities play a crucial role in expanding the research opportunities in this area to move both theoretical and technical levels of understanding to the next level and provide better solutions to the existing challenges about blockchain.

Change management is necessary to solve problems with emerging technologies. Innovations move organizations towards change and in the complex process of adopting and implementing the new technologies, many barriers must be addressed. Change management provides strong tools to deal with such complex situations (Kouhizadeh et al., 2021).

Findings emphasized the importance of attitude and perceived beliefs about this technology. Successful implementation of the technology is the best way to change attitudes and negative perceptions about the technology. *New leadership* can help overcoming these barriers.

6.4.3. Theme 3. Influential factors in the adoption of blockchain technology

Based on the findings from both primary and secondary data the most influential factors in the adoption of blockchain technology are listed in the following table. The categorization is based on Zamani (2022)'s Integrated framework of technology adoption and 11 categories of influential factors proposed in this framework. Relevant explanations were given in the results and review of the literature chapters. To avoid repetition the summary of the findings is listed in the table which is presenting the gist of previous discussions. Findings are inclusive of all the information gathered from the participants in their responses to all interview questions. It can be seen from the table that the findings from the data are in accordance with the findings in the literature. The categories investigated in this study for blockchain adoption in the oil and gas industry are initial and exploratory. However, they can provide a timely information base for initiating further in-depth exploration. Consideration of influencing concepts by managers and decision makers can strongly guide them in the process of blockchain adoption.

Influential factors	*based on the findings of interviews*	*Based on the literature reviewed*
Technological	Technical issues such as maturity, complexity, scalability, security, privacy, effectiveness, perceived usefulness, quality of data, ease of use, perception of technology, technological readiness,	compatibility, complexity, interoperability relative advantage, perceived benefit, ease of use, technology risk, availability, technological support
Environmental	Trading partner pressure, market transparency, geographical location, market trends, cultural influences	Competitor's pressure, customers' pressure, external support, social influences, globalization, network
Management	Top management support, top management commitment, top management knowledge, management attitude, management education, top management lack of skills, leadership, management willingness	Top management support, top management commitment, top management knowledge, top management use of technology, visionary leadership, management motivation and involvement
Organizational	Organization characteristics such as centralisation/ decentralization, organization attitude, organization culture, organisation ethics, innovativeness, mission	Organizational readiness, innovativeness, organisation scope, structure, capability, size, satisfaction with existing systems, research collaboration
Knowledge	Awareness, technical knowledge, experience, education, technical skills, employee's training, knowledge sharing,	Employees and managers technical knowledge, knowledge constraints, prior IT experiment, stakeholder's awareness, policy makers' knowledge
People	Mindset, individual attitude, intention of adoption, openness to change, performance expectancy, fear	perceived trust, employee's commitment, ethnicity, resistance, engagement
Financial	Cost, profitability, ROI	Cost, Return of investment (ROI), financial supports
Resource	Human resource with skills, IT resources, knowledge resource, training resources	Financial resources, human resources with skill, technology access, time,
Strategy	Communication, collaboration, R&D strategy	Short term/ long term vision. Perceived risk
Regulation	Government regulations, government support, government awareness, government readiness, institutional push	Government regulations, government support, government awareness, government readiness, legislation, public policies, institutional push
Infrastructure	Infrastructure limitations	IT infrastructure, infrastructure limitations, organisational infrastructure

Table 12.Categories of influential factors in blockchain adoption

7. Validation

7.1. Validity and Reliability

Considering Creswell's strategies for ensuring validity, to ensure the validity of research, the researcher used the triangulation principle by using both primary and secondary sources of data to build up a complete picture of the issues under study. The researcher examined evidence from different sources of data to justify the themes. The themes were established based on data from both the literature review and the perspectives of the participants. The researcher has tried to include sufficient levels of details by providing rich descriptions so that the results can be more reliable. Although the results are not generalizable, but the findings can be transferable since they can contribute well to the current body of knowledge about blockchain. Transferability adds to the validity of the research. To achieve reliability in the data, raw data were coded and for each interview question an acceptable level of saturation in the participant's responses was observed which could indicate adequacy was addressed in the data.

Participants were asked to provide responses to a representative set of questions that covered the entire aspects of the topic under investigation. The interview questions were open and semi-structured. Therefore, the researcher is quite sure of the content validity of the research. The researcher triangulates two methods of data analysis for the analysis of data, content analysis and thematic analysis methods were used to add to the validity and accuracy of the analysis.

Detailed descriptions of participants and settings were given to provide external validity. The findings of this study are testable, so they are applicable by other researchers in other settings.

The researcher remained unbiased during the study and no preconceptions on the part of the researcher coloured the study's conclusions. The researcher gained the knowledge about blockchain technology adoption during conducting the research without any prior knowledge about the technology. The researcher presented negative or discrepant information to acknowledge findings that ran contrary to the study's key themes since the credibility of data and data interpretation were among the main concerns of this research.

7.2. Contribution of the study

Literature about the implementation of blockchain in the oil and gas industry is still limited which is an indication that the application of blockchain in the oil and gas is in experimental stage. There is lack of in-depth research on how the technology is currently adding value to the

industry. But there are studies about successful use cases where the technology could benefit the industry by increasing efficiency, transparency. This is proving that blockchain has excellent potential to be utilized in oil and gas in specific areas. However, there are still many challenges, risks, and unknown issues with the technology. There are operational, technical, and regulatory challenges that need to be addressed carefully both in general and in the context of oil and gas in particular.

From the theoretical perspective, this research has confirmed most of the issues identified in the literature. The findings of this study indicated that blockchain application in the oil and gas industry has a promising future.

This study revealed that high levels of expertise, knowledge and experience are required to detect the right problems in the oil and gas industry where blockchain can provide value adding solutions. It is a complicated decision where blockchain is really needed and where it brings competitive advantage compared to other databases already in use. Therefore, there is an extensive need for increasing awareness, and knowledge for this technology in both the industry and academia.

8. Conclusion

This empirical research advances the general understanding of blockchain technology adoption in oil and gas industry by first presenting an overview of the current status of research and development in this field. Second, by shedding light on the current challenges of the technology itself and the barriers related to blockchain adoption in the oil and gas industry. Third, the research proposed some solutions to overcome the obstacles that impede the adoption of this technology in the industry. Finally, the main categories of influencing concepts in the adoption of blockchain technology in oil and gas were considered based on the integrated framework.
The findings of this study are based on the data gathered from the managers, decision makers and entrepreneurs in the oil and gas industry. Therefore, the results obtained from this study might have been of interest to experts in both industry and academia in planning and strategizing for blockchain adoption in the oil and gas industry.
The study sought to answer the following research questions:

1. What are the key opportunities and applications of blockchain in the oil and gas industry?

2. What are the challenges and barriers to implementing blockchain technology in the oil and gas industry?

3. What are the influential factors in the adoption of blockchain technology in the oil and gas industry?

In order to achieve the aim of this study and find answers to the above mentioned questions, a review of literature was carried out to map the up to date body of knowledge about the topics of interest. Then a qualitative research based on semi-structured interviews was conducted and the collected data were analysed with the content analysis and thematic analysis methods. The data were coded and categorized to provide a better understanding of the main themes of the study. The findings revealed the most widely experienced issues about blockchain adoption in the oil and gas industry that not only were confirming many findings from the existing literature but also were providing a more up to date understanding of the issues under investigation.

Data related to theme 1, revealed that blockchain technology can play a positive role in the oil and gas industry by bringing novel solutions to the existing problems in the whole value chain of the industry. Based on the primary and secondary data blockchain has shown potential to

create value in exploration, production, refinery, logistics, and supply chain mainly through its distinct features of transparency, decentralization, traceability and immutability. Five areas were considered in more detail where blockchain can provide value adding solutions: Supply chain and trading, contracting, decision making and management, cyber security and digital asset. Findings from both literature and interview data indicate that supply chain & trading, and contracting are the two areas that are more receptive to blockchain technology. Blockchain based systems can automate the business operations and increase the efficiency. This was confirmed by both the participants and reviewing industrial case studies.

However, the researcher could still find some controversies and unresolved issues in the data that need more investigation regarding the financial and technical issues, legal and regulatory frameworks, and energy consumption. The data revealed that the participants were aware of all the challenges and still believed that its adoption will benefit the industry. According to literature successful adoption of blockchain in oil and gas is affected by many factors which need to be addressed before its implementation.

The researcher then shifted her attention to the challenges and barriers in the adoption of blockchain in oil and gas which defines the second theme of the research.

Concerning energy consumption, participants claimed that in the oil and gas industry due to the implementation of private and hybrid blockchains the energy consumption challenge is less. However, leveraging public blockchain platforms to automate the supply chain utilizes a large amount of energy and computational resources due to mining. In spite of this fact, some participants still claimed that the energy consumption in public blockchains is far less compared to many other activities that are occurring on daily basis in the world all of which consume loads of energy. They believe public blockchains provide data security, integrity, and reliability and the energy consumed is worth it, however, it still remains as an issue of concern, and precise investigations are required. Apart from high energy consumption oil and gas organisations have privacy concerns when it comes to public blockchains.

Five categories of adoption barriers were investigated based on the primary data analysis and the categories were backed by theory available in the literature. From among the categories of organisational, environmental, technological barriers, knowledge barriers, and people barriers, the two categories of knowledge barriers and organisational barriers constitute the most prominent obstacles to the adoption of blockchain technology in the oil and gas industry. This

is also supported in the literature. Regarding the technological barriers the available literature is not in accordance with the findings of the primary data. Since less than 25% of participants believed that technical shortcomings of blockchain can be considered as a barrier, the researcher could detect some degree of bias among participants' responses regarding technological barriers.

The research was extended by investigating the influential factors or drivers in the adoption of the technology in oil and gas based on the integrated framework. The most evident influencing concepts were regarded as knowledge, organizational, regulatory, people, environmental and technological categories. Examining these concepts can accelerate the adoption process and guide the proper application of the technology where it really fits and provides value adding solutions. Considering the influential factors can help decision makers and managers do better planning and evaluation before technology adoption.

Overall, by reviewing the relevant literature and gaining updated insights from the experts around the world, the adoption of blockchain technology was investigated in the context of oil and gas industry from different angles. The industry currently has little knowledge about blockchain technology. This study is an attempt to create more awareness among practitioners and encourage academia to conduct more blockchain-related research in the oil and gas industry since this industry constitutes an important industrial sector in the world and of course in Norway.

There are still many questions that need to be answered more precisely before deciding on adopting this technology. The goal of incentivizing innovation in the industry is not breaking the tradition but making constructive change. Technologies should be applied only if they work for the betterment of the industry, society, and more importantly the lives of individuals. Therefore, there is a need for consortiums including professionals from both academia and industry practitioners, with diverse and comprehensive areas of expertise and knowledge to join and move together in the process of adopting emergent technologies. Consortiums that their goal and responsibility is not to promote a technology but to protect the world using that technology.

9. Implications for further research

Based on the findings and conclusions of this study and current literature about blockchain adoption in oil and gas, it was understood that most research in this area is exploratory and a limited number of studies are in development and testing. Therefore, more advanced research is needed from a process and development perspective rather than mere exploration in the oil and gas industry. More research is needed to specifically investigate different categories of adoption barriers in the oil and gas industry. Moreover, due to the evolving nature of blockchain technology more solutions and application opportunities will emerge that will need closer investigations. Therefore, more research is needed to investigate the evolving process of blockchain adoption in the oil and gas industry.

10. References

Adegboye, M. A., Fung, W.-K., & Karnik, A. (2019). Recent Advances in Pipeline Monitoring and Oil Leakage Detection Technologies: Principles and Approaches. *Sensors, 19*(11), 2548. https://www.mdpi.com/1424-8220/19/11/2548

Ahmad, M. I. (2015). Unified theory of acceptance and use of technology (UTAUT). *LinkedIn Pulse*, 179-211.

Ahmad, R. W., Salah, K., Jayaraman, R., Yaqoob, I., & Omar, M. (2022). Blockchain in oil and gas industry: Applications, challenges, and future trends. *Technology in society, 68*. https://doi.org/10.1016/j.techsoc.2022.101941

Ajao, L. A., Agajo, J., Adedokun, E. A., & Karngong, L. (2019). Crypto hash algorithm-based blockchain technology for managing decentralized ledger database in oil and gas industry. *J, 2*(3), 300-325.

Andoni, M., Robu, V., Flynn, D., Abram, S., Geach, D., Jenkins, D., McCallum, P., & Peacock, A. (2019). Blockchain technology in the energy sector: A systematic review of challenges and opportunities. *Renewable & sustainable energy reviews, 100*, 143-174. https://doi.org/10.1016/j.rser.2018.10.014

Antipova, T. (2020). *Integrated Science in Digital Age 2020*. Cham: Springer International Publishing AG.

Aslam, J., Saleem, A., Khan, N. T., & Kim, Y. B. (2021). Factors influencing blockchain adoption in supply chain management practices: A study based on the oil industry. *Journal of Innovation & Knowledge, 6*(2), 124-134.

Baker, J. (2012). The technology–organization–environment framework. *Information systems theory*, 231-245.

Blockchain for Energy. https://www.blockchainforenergy.net/

BP Energy Outlook, 2022 Edition. (2022). https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2022.pdf

Casino, F., Dasaklis, T. K., & Patsakis, C. (2019). A systematic literature review of blockchain-based applications: Current status, classification and open issues. *Telematics and informatics, 36*, 55-81. https://doi.org/10.1016/j.tele.2018.11.006

Creswell, J. W. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications.

Creswell, J. W., & Poth, C. N. (2016). *Qualitative inquiry and research design: Choosing among five approaches*. Sage publications.

Data Gumbo. https://www.datagumbo.com/industries#oilandgas

Deloitte. (2017). *Blockchain: Overview of the potential applications for the oil and gas market and the related taxation implications*. https://www2.deloitte.com/content/dam/Deloitte/tr/Documents/energy-resources/gx-oil-gas-blockchain-article.pdf

Distributed ledger technology: beyond block chain. (2016). [Report]. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/492972/gs-16-1-distributed-ledger-technology.pdf

Dorri, A., Roulin, C., Jurdak, R., & Kanhere, S. S. (2019). *On the Activity Privacy of Blockchain for IoT* 2019 IEEE 44th Conference on Local Computer Networks (LCN),

Dubey, R., Gunasekaran, A., Bryde, D. J., Dwivedi, Y. K., & Papadopoulos, T. (2020). Blockchain technology for enhancing swift-trust, collaboration and resilience within a humanitarian supply chain setting. *International Journal of Production Research, 58*(11), 3381-3398.

Dujak, D., & Sajter, D. (2019). Blockchain applications in supply chain. In *SMART supply network* (pp. 21-46). Springer.

Fraser, M. S., Anastaselos, T., & Ravikumar, G. V. V. (2018). The disruption in oil and gas upstream business by industry 4.0, Infosys, Bengaluru, India [White Paper]. https://www.infosys.com/engineering-services/white-papers/Documents/disruption-oil-gas-upstream.pdf

GreenSpand, G. (2015). *Avoiding the pointless blockchain project*. Multichain. Retrieved 21.05.2022 from https://www.multichain.com/blog/2015/11/avoiding-pointless-blockchain-project/

Haque, A., Hasan, M., Zihad, M., & Mondol, O. (2021). SmartOil: Blockchain and smart contract-based oil supply chain management. *arXiv preprint arXiv:2105.05338*.

Hughes, E. (2018). Unlocking Blockchain: Embracing New Technologies to Drive Efficiency and Empower the Citizen. *The Journal of The British Blockchain Association, 1*(2), 1-15. https://doi.org/10.31585/jbba-1-2-(1)2018

Kouhizadeh, M., Saberi, S., & Sarkis, J. (2021). Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers. *International Journal of Production Economics, 231*, 107831.

Kshetri, N. (2021). Blockchain and sustainable supply chain management in developing countries. *International journal of information management, 60*, 102376. https://doi.org/10.1016/j.ijinfomgt.2021.102376

Lacity, M. C. (2018). Addressing key challenges to making enterprise blockchain applications a reality. *MIS Quarterly Executive, 17*(3), 201-222.

Lakhanpal, V., & Samuel, R. (2018). Implementing Blockchain Technology in Oil and Gas Industry: A Review. SPE Annual Technical Conference and Exhibition,

Liu, W., Liang, Y., Bao, X., Qin, J., & Lim, M. K. (2020). China's logistics development trends in the post COVID-19 era. *International Journal of Logistics Research and Applications*, 1-12.

Lu, H., Guo, L., Azimi, M., & Huang, K. (2019). Oil and Gas 4.0 era: A systematic review and outlook. *Computers in industry, 111*, 68-90. https://doi.org/10.1016/j.compind.2019.06.007

Lu, H., Huang, K., Azimi, M., & Guo, L. (2019). Blockchain Technology in the Oil and Gas Industry: A Review of Applications, Opportunities, Challenges, and Risks. *IEEE access, 7*, 41426-41444. https://doi.org/10.1109/ACCESS.2019.2907695

Marangunić, N., & Granić, A. (2015). Technology acceptance model: a literature review from 1986 to 2013. *Universal access in the information society, 14*(1), 81-95.

Miao, Y., Zhou, M., & Ghoneim, A. (2020). Blockchain and ai-based natural gas industrial iot system: Architecture and design issues. *IEEE Network, 34*(5), 84-90.

Milano, A. (2017). *China's Sinochem Completes Gasoline Export Over Blockchain System*. https://www.coindesk.com/markets/2018/04/02/chinas-sinochem-completes-gasoline-export-over-blockchain-system/

Mohammadpoor, M., & Torabi, F. (2020). Big Data analytics in oil and gas industry: An emerging trend. *Petroleum, 6*(4), 321-328.

Mohsin, A. H., Zaidan, A. A., Zaidan, B. B., Albahri, O. S., Albahri, A. S., Alsalem, M. A., & Mohammed, K. I. (2019). Blockchain authentication of network applications: Taxonomy, classification, capabilities, open challenges, motivations, recommendations and future directions. *Computer standards and interfaces, 64*, 41-60. https://doi.org/10.1016/j.csi.2018.12.002

Musienko, Y. (2019). *How to use blockchain in the oil and gas industry* https://merehead.com/blog/use-blockchain-oil-gas-industry/

Pathan, Z. H., Jianqiu, Z., Akram, U., Khan, M. K., Latif, Z., & Tunio, M. Z. (2017). Innovation-diffusion determinants of cloud-computing adoption by Pakistani SMEs. *Human Systems Management, 36*(3), 197-209.

PwC. (2016). *Blockchain – an opportunity for energy producers and consumers?* [report]. https://www.pwc.com/gx/en/industries/assets/pwc-blockchain-opportunity-for-energy-producers-and-consumers.pdf

Ray, S. (2018). *The Difference Between Blockchains & Distributed Ledger Technology* https://towardsdatascience.com/the-difference-between-blockchains-distributed-ledger-technology-42715a0fa92

Salah, K., Alfalasi, A., Alfalasi, M., Alharmoudi, M., Alzaabi, M., Alzyeodi, A., & Ahmad, R. W. (2020). IoT-enabled shipping container with environmental monitoring and location tracking. 2020 IEEE 17th Annual Consumer Communications & Networking Conference (CCNC),

Saunders, M. N. K., Lewis, P., & Thornhill, A. (2012). *Research methods for business students* (6th ed. ed.). Pearson.

Tian, Y., Lu, Z., Adriaens, P., Minchin, R. E., Caithness, A., & Woo, J. (2020). Finance infrastructure through blockchain-based tokenization. *Frontiers of Engineering Management, 7*(4), 485-499.

Treiblmaier, H. (2019). Toward More Rigorous Blockchain Research: Recommendations for Writing Blockchain Case Studies. *Frontiers in blockchain, 2*. https://doi.org/10.3389/fbloc.2019.00003

Wesenberg, H. (2020). *12 Disruptive Technologies Shaping the Future of Equinor*. https://www.loop.equinor.com

Zamani, S. Z. (2022). Small and Medium Enterprises (SMEs) facing an evolving technological era: a systematic literature review on the adoption of technologies in SMEs. *European Journal of Innovation Management*.

Zheng, Z., Xie, S., Dai, H., Chen, X., & Wang, H. (2017). An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends. *IEEE International Congress on Big Data (BigData Congress)*, 557-564. https://doi.org/10.1109/BigDataCongress.2017.85

Zuo, Y., & Qi, Z. (2021). A Blockchain-based IoT Framework for Oil Field Remote Monitoring and Control. *IEEE access*.

Appendix A. Interview Guide

1. General Information

a. Information about the interviewer:

b. Information about the Supervisor:

c. Information about the Goals of the study:

2. Practical information

a. Explaining who the participants in this study are and the reason they are invited to take part in this study.

b. Explaining who will have access to the interview

c. Asking for permission to record and transcribe the interview

d. Checking if the interviewee has any questions regarding the interview.

e. Starting the recording.

3. Commencement Questions:

- Would you please tell me when you first encountered and learned about blockchain technology?
- Are you involved in any projects utilizing blockchain technology?

If they own a company or business, the following questions will be relevant:

- Please tell me about your business
- What is your role and what project are you working on?
- How are you using blockchain technology for problem-solving?
- How did blockchain add value or revenue to your company?

4. ***Main Interview Questions directly related to the oil and gas industry:***

1. What are the underlying reasons that make companies use blockchain technology?

2. What are the key features of blockchain that can be applied in the oil and gas industry in your opinion?

3. Where in the oil and gas industry do you think that blockchain brings added value? In trading, Management and decision making, supervision, Cyber security?

4. What do you see as the main obstacles and barriers to implementing blockchain technology in this industry?

5. What are the solutions in overcoming these barriers to accelerate blockchain implementation in the oil and gas industry?

6. What are the influential factors in the adoption of Blockchain in the oil and Gas Industry?

7. Do you see any supporting factor/ Catalyser in the adoption of blockchain in the oil and gas industry?

8. Are there any risks or disadvantages related to the application of blockchain in oil and gas in your opinion?

9. What do you think the future of blockchain is in the oil and gas industry?

5. Closing the interview session

a. The interview will be transcribed, do you want to read it before we use it?

b. Is it possible to use your name and background information in the master's thesis?

c. Do you know of any documents, articles, or people that can contribute to this study?