Katja Oinas

Blockchain Technology in the Nordic Energy Market and in the Renewable Energy Sector

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Author:	Katja Oinas
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ABSTRACT:
The goal of this master's thesis is to research the current state of blockchain technology, identify opportunities and challenges of blockchain technology in the Nordic energy market and in the renewable energy sector and recognize possible use cases. Climate change and decreasing natural resources are the main drivers to finding new solutions to utilize renewable energy and boost energy efficiency. There is growing energy demands that cannot be met by conventional energy systems. The energy systems are changing to be dynamic with numerous participants, and man-aging this complex system needs automation. Energy trading is transforming, and a suitable communication and trading system between market participants is needed.

The Nordic countries have ambitious progress goals towards carbon neutrality by 2050. The Nordic energy market is one of the most successfully functioning regional markets in Europe and has a high share of renewable energy consumption, which has remained well above the EU average. Blockchain technology is a distributed system and includes a consensus protocol. New transactions are added to the blockchain agreed by all nodes. The most interesting area of adoption of blockchain technology is the energy industry revolution, and several researchers in the academic world believe that this technology can bring changes in the energy sector. So far, there is a lack of research of this kind; hence this research will give a solid foundation for future research.

First, in this master's thesis theory part is provided to give a comprehensive overview of the main concepts of the research. The central concepts of this master's thesis are Blockchain technology, the Nordic energy market, and the renewable energy sector. The definition and fundamental principles of blockchain technology are clearly stated that the reader understands the basics of this emerging technology. Then Nordic energy market is introduced containing market participants, current challenges, the transformation of the energy system, comprehensive setting of trends and megatrends and drivers of change in the energy sector, and finally, the renewable energy sector is introduced. The theory part supports the empirical part and gives justification for the research results.

The research was conducted as qualitative survey research by organizing surveys for several energy sector stakeholders in every Nordic country. The survey objective is to find an answer to the main research question and sub research questions from the five different dimensions with the help of the TESEI framework. This master's thesis concludes that blockchain technology is a potential solution for different challenges in the Nordic energy market and in the renewable energy sector. It could simplify many processes, help the Nordic electricity market be much more efficient, offer novel solutions, change business models in the long term, and inspire new ways of thinking about services related to the energy industry.

KEYWORDS: blockchain, blockchain technology, Nordics, energy market, renewable energy

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Abbreviations

greenhouse gases (GHG)

photovoltaics (PV)

distributed energy resources (DER)

low voltage (LV)

European Union (EU)

proof of stake (PoS)

proof of work (PoW)

delegated proof-of-stake (DPoS)

proof of capacity (PoC)

proof of burn (PoB)

practical byzantine fault tolerance (PBFT)

renewable energy certificate (REC)

transmission system operator (TSO)

high-voltage direct current (HVDC)

operations and maintenance (O & M)

solar photovoltaics (SPV)

distribution system operator (DSO)

renewable energy share (RES)

internet of things (IoT)

guarantees of origin (GO)

1 Introduction

1.1 Context

The foundation of the national economy is the electric power industry. It plays an essential role in the development of human society, supplying crucial energy to residential, commercial, industrial, and manufacturing customers around the globe. Weather and climate change conditions directly influence energy demand. In addition, climate warming is driven by greenhouse gases (GHG) which is caused by energy demand. (De Cian et al., 2019, p. 366). Due to reviving economic activities and fast-growing emerging economies such as China, electricity demand globally was expected to increase by 4.5% in 2021 (IEA, 2021, p. 25). In reality, it rose more than 6 % (IEA, 2022, p. 6).

This growing energy demand that cannot be met by conventional energy systems (Ahl et al., 2019, p.2). Climate change and decreasing natural resources, peak oil and air pollution are pressing to find novel solutions to enhance energy efficiency and use of renewable energy (RE). Aforementioned has led the way to the increased development and implementation of renewable energy production technologies like e.g., solar power photovoltaics (SPV). The indicated and other distributed energy resources (DER) are more often likely to be placed to the edges of the low voltage (LV) distribution network. The network infrastructure may lack the suitable appliances to allow this. (Van Leeuwen et al., 2020, p. 1).

There are two ways to enable the bidirectional flow of electricity, either the grid must be strengthened physically, or more modern control systems are needed. In general, there will be more complicated grid coordination. Citizens can get more opportunities even though the technical challenges of these solutions can be remarkable. (Van Leeuwen et al., 2020, p. 1).

At the same time customer expectations have changed, helped by digitalization. Customers want to communicate anytime, anywhere, and right away with their service provider, also in the energy sector. The European Union (EU) Renewable Energy Directive set a target for the renewable energy share of final energy consumption to every EU country, also for Norway and Iceland. The Nordic targets were more demanding than the EU overall had to meet before 2020: Finland 38%, Sweden 49%, Norway 67.5%, Iceland 72%, and EU overall 20%. All the Nordic countries have met their 2020 targets two years ahead of schedule. (Nordic Energy, 2021, p. 6).

The five Nordic countries – Finland, Sweden, Norway, Denmark, and Iceland have agreed on some of the world's most pioneering energy and climate policies (Nordic Energy, 2013, p. 8). The European Union and Nordic governments climate targets provide a guideline and a framework for developing the Nordic energy sector and energy market. The Nordic countries aim to be carbon neutral by 2050, whereby 85% would be carbon-free generation, with the remaining 15% covered by international carbon credits (Nordic Energy, 2013, p. 8). In addition, Nordic countries want to be a leader in the fight against global warming.

Three facts support the aim of the Nordic countries to be carbon neutral. The first is that compared with other parts of the world, the Nordic countries are blessed with vast renewable energy resources, and the second is that the Nordic people have proved to be experts at utilizing the opportunities these presents.

The world situation changed dramatically in the spring of 2022, when Russia invaded Ukraine. On these days Russian oil and gas must be replaced by other energy sources. This unfortunate third fact will boost the Nordic countries energy transition towards renewable energy. The importance of energy self-sufficiency is emphasized.

This energy transition also needs citizens' joint contribution for example by actively reducing energy consumption, switching to renewable energy and by changing the way of life to be more sustainable. The citizens who are participating as prosumers will help this transformation, since this will accelerate investments in renewable energy production. (EEA, 2022, p. 5)

With the growth of renewable energy, energy trading is changing from a centralized way to a distributed one. (Wang. et al., 2019, p. 1). Energy landscape is changing to a dynamic and complex system where multiple actors participate and this can be managed only with automation. This leads to a suitable communication and trading system between market participants is needed.

Several advancements in ICT technology, such as new devices and platforms and increased renewable energy resources has led to increasing demand for decentralized energy management and the information transactions (Hasankhani et al., 2021, p. 1).

This research topic is becoming an important concern because the energy industry is very complex and increasing demand for renewable energy sources is changing the current networks. The blockchain technology can simplify many processes and could help the Nordic electricity market to be much more efficient and could feasibly offer novel solutions for different challenges in the Nordic energy market and in the renewable energy sector. In addition, it could change business models enabled by blockchain in the long term and monetize new blockchain platforms.

According to Brilliantova et al. (2019, p. 38) there are smart grids that provide a connection to merge small energy producers while energy supply and demand are balanced. The higher energy efficiency and lower carbon emission is enabled by these markets and requires a technology that assists peer-to-peer exchange and a solution for this is blockchain technology.

Li et al. (2019, p. 58) state that blockchain technology is a forceful and reliable tool for distributed data storage and management.

Research of Hasankhani et al. (2021, p. 1) verifies the blockchain technology as an auspicious option to boost the renewable energy share.

1.2 Research gap, research question and objectives

There is an obvious research gap regarding blockchain and its use in the Nordic energy market and in the renewable energy sector. There exists several research about blockchain technology in the energy domain but there is a lack of knowledge in its application to the geographical area limited to the Nordic countries. According to Ahl et al. (2019, p. 5), some studies have investigated and formed frameworks for decision making of the energy system, spotlighting on the social, environmental, economic, and technological norms. In this research, we use a wide analytical framework called TESEI developed by Ahl et al. (2019), which also includes an institutional dimension and gives a comprehensive overview of the context.

The research question for this master's thesis is: *How can blockchain technology advance and improve the Nordic energy market and the renewable energy sector?*

In addition to achieving a research goal, three supportive sub research questions are presented: *What is the current Blockchain state in the Nordic energy market and in the renewable energy sector?* And *What are the opportunities, and challenges of blockchain technology in the Nordic energy market and in the renewable energy sector?* and *What are the potential use cases of blockchain technology in Nordic energy market and in the renewable energy sector?*

This research shows what kind of a state blockchain technology has in the Nordic energy market and in the renewable energy sector as well as the opportunities and challenges from the five different dimensions, which are defined later in this work. In addition, it gives an overview about blockchain use cases, which could be utilized.

1.3 Scope, structure of thesis and contribution

This master's thesis consists of six main chapters. The first *chapter 1* is Introduction, and its goal is to lead the reader into the research topic. This chapter also includes the main research question and three sub research questions and objectives. In addition, the scope, structure of thesis and contribution is introduced for the reader. The thesis's theoretical framework includes the theory of blockchain technology, energy markets in the Nordics and the renewable energy sector and is introduced for the reader in *chapter 2* Literature and market review. These topics are essential for the research, and the aim of the theoretical framework is to provides summaries about the literature utilized in this research. *Chapter 3* Research Method introduces the data collection and analysis methods as well as reliability and validity of the research.

Chapter *4*, Results, includes the survey results, and should help understand how blockchain technology can advance and improve the Nordic energy market and the renewable energy sector, the current blockchain state in the Nordic energy market and in the renewable energy sector as well as opportunities and challenges from the five different dimensions. After that, we move to *Chapter 5* Discussion, discussing how blockchain can be utilized in the Nordic energy market and in the renewable energy sector and the contribution of findings and related limitations. Finally, in *chapter 6*, Summary and Conclusion, the research is summarized and concluded.

The research is carried out qualitatively. The reason for this is that there is not much earlier research data available, and in addition, qualitative research allows gathering literature more freely. Reliability can be brought up through perspectives and experiences that emerge from the literature.

The material in the empirical section is collected through a survey conducted in all Nordic countries. The five-dimensional analytical framework, called TESEI developed by Ahl et al. (2019), is used. This framework includes 1) technological, 2) economic, 3) social, 4) environmental, and 5) institutional dimensions.

With the help of this research, we will get a comprehensive understanding of blockchain potential to solve problems in the Nordic energy market and in the renewable energy sector, and this will create a solid foundation for future research that may have the supporting effect of the Nordics to becoming carbon neutral in 2050.

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2 Literature review

2.1 Blockchain technology

The emerging blockchain technology is increasingly adopted in different sectors, despite the fact that blockchain technology is commonly associated with cryptocurrencies such as Bitcoin. This technology holds great promise to change systems which rely on a third party. Blockchain technology has many features which give potential to bring substantial benefits and innovation to various application areas. Blockchain has an ability to impact many different sectors such as supply chain, logistics, healthcare, finance and of course the energy sector.

2.1.1 Definition and overview of fundamental principles

In broad perspective, the blockchain could be described as a distributed system that generally includes a consensus protocol for acquiring reliability in a network, in other words, a set of policies agreed upon and applied by all nodes. They are rules that govern what and how new transactions can be included to the blockchain. (Ghiro et al., 2021, p. 2).

The main goal of blockchain technology is to get rid of intermediaries and substitute them with a distributed digital network which aim is to secure the integrity of a ledger and verification of transactions. In general, other users are connected to public pseudonyms addresses to make anonymous transactions unknowable and untracked (Mollah et al., 2021, p. 22).

To achieve trust, security, and agreement in a decentralized network a consensus mechanism is needed (Zhangh, C. et al., 2020 p.7). It is the backbone of blockchain technology. The stable and secure operation of the blockchain system is directed by consensus mechanism efficiency. (Zhangh, C. et al., 2020, p. 9). Consensus provides decentralization of control through an optional process known as mining (Bashir, 2018, p. 35).

To achieve the wanted results in a consensus mechanism, various requirements must be met. In Table 1. is shown requirements.

Requirement	**Definition**
Agreement	The same value is decided by all honest nodes
Termination	All honest nodes finish the consensus process and finally make a decision
Validity	The values must be the same, agreed by all nodes and value which is proposed by at least one honest node
Fault tolerant	Even if there are faulty and malicious nodes, the consensus algorithm should work in their presence (Byzantine nodes)
Integrity	A single node can only make a decision once in a single consensus cycle. This is a requirement.

Table 1. Requirements that haves to be met for a consensus mechanism (Bashir, 2018, p. 35).

The two most usual consensus mechanisms are proof of stake (PoS) and proof of work (PoW) which will be introduced in more detail. Other mechanisms are delegated proof-of-stake (DPoS), proof of capacity (PoC) and proof of burn (PoB).

The equity proof is used by the PoS consensus mechanism. The node with a larger interest in the system is issued the accounting right. Each node has the same difficulty in mining, in the PoW consensus process. The PoS consensus process is following: the more coins are consumed, the lower the difficulty in mining and the higher the probability of discovering the block. (Zhangh, C. et al., 2020, p. 9).

The function of PoW consensus mechanisms is to make sure data consistency and consensus security. This is achieved by competing the computing power of distributed nodes (Zhangh, C. et al., 2020, p. 8). The consensus of the whole network is achieved by performing mathematical operations. This will lead to decentralization, prevent double payment, and the agreement of the transaction is reached within a limited time frame. Thus, the operation of the system is stabilized. (Zhangh, C. et al., 2020, p. 9). The downside of PoW compared to PoS is that it uses more energy.

Figure 1. presents a basic level architecture diagram of a basic blockchain. The first block is a unique block: the genesis block. It differs from other blocks because it has no prior block and doesn't contain information.

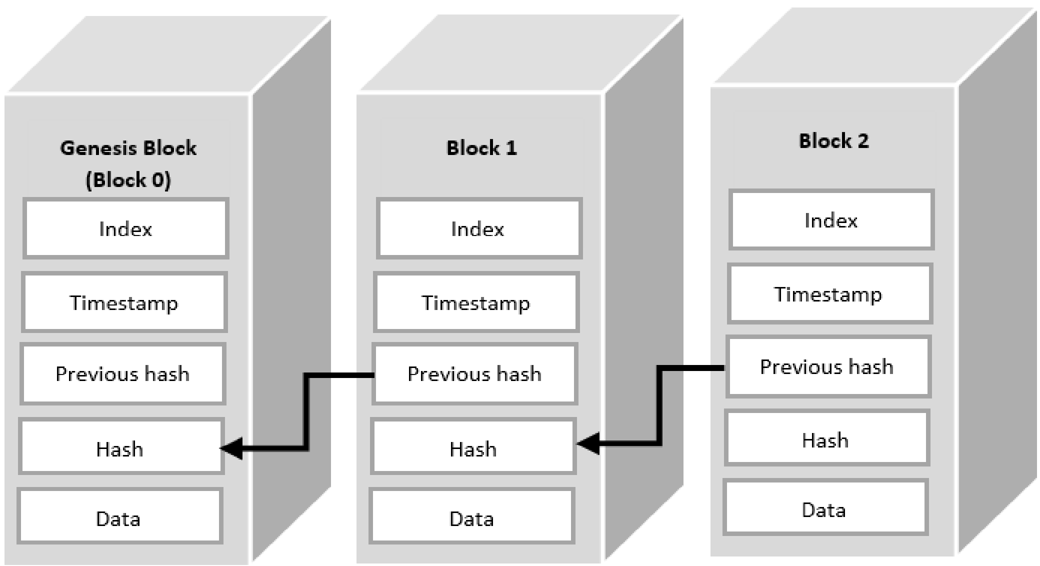

Figure 1. Architecture diagram of a blockchain

A blockchain is created by the network verifying, clearing, and storing transactions in digital blocks that are connected to prior blocks. The structure timestamps and stores exchanges of value so that they cannot be changed (Khalili et al., 2021, p. 5).

Blocks can be viewed and tracked by all actors any time, but cannot be changed afterwards, thus transparency is ensured (Teufel et al., 2019, p. 3). Blockchain systems can be tamper-proof, immutability and secure.

Bao et al. (2021, p. 3371) defines the process of block addition like this: *the node that has the right to package transactions puts the packaged transactions (block) on the existing blockchain and broadcasts it to the whole network. After the other nodes receive the block, they validate it, and if the block passes validation, all nodes will synchronize this block. Each packaged transaction is called a block, and the blocks are added to each other, extending the blockchain. The decentralized ledger is verified and maintained by all participating nodes according to a consensus mechanism, without the need for a trusted central intermediaries. The copy of the entire database is hold by the multiple nodes.*

According to Andoni et al. (2018, p. 146) hash functions and public-key cryptography ensures security. Cryptographic hash functions are either mathematical algorithms or one-way functions. These takes an input and transforms it into a hash output. One of these is a SHA-256 hash function which outputs a value that is 256 bits long. An asymmetric cryptography protocol called public-key cryptography is also used. Each blockchain user holds a secret cryptographic key, private key, and public key. These keys consist of numeric or alphanumeric characters.

Table 2. shows six basic layers, that each blockchain type consists of.

Blockchain layers	**Principal components**
Application layer	Cryptographic currency

Contract layer	Smart contracts, algorithmic mechanism
Incentive layer	Distribution mechanism, smart contract, script codes
Consensus layer	Proof-of-work (PoW), proof-of-stake (PoS), practical byzantine fault tolerance (PBFT)
Network layer	Peer-to-peer network, propagation mechanisms
Data layer	Data block, chain structure, time stamp, hash function

Table 2. Layers of blockchain technology (Tesfamicael et al., 2020, p. 132431).

Figure 2. shows four types of blockchain, public, hybrid, private and consortium blockchain. The division is made according to environment and type of node. In the public blockchain everyone has the opportunity to participate in the consensus process to write the data or block into it. Data is available for everyone for reading purposes. Only authorized users can generate blocks in a private blockchain, and permissions are allowed only to organizations in a centralized manner. The group of members controls the consortium blockchain. (Tesfamicael et al., 2020, p. 9). Hybrid blockchain is a combination of public and private blockchain and includes the best features of both blockchain.

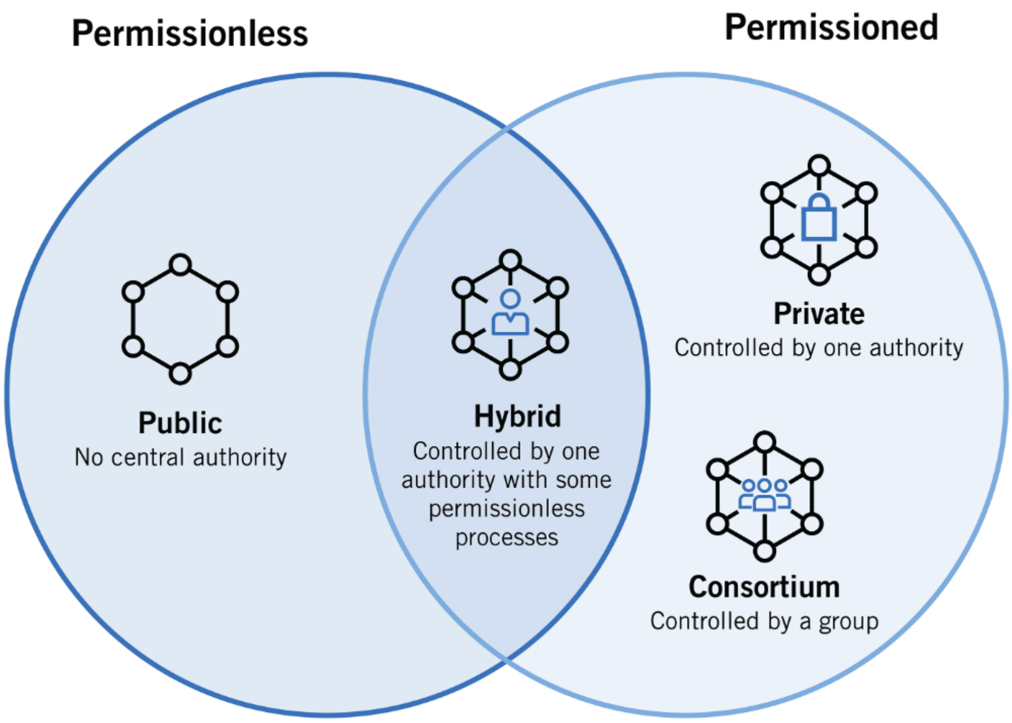

Figure 2. Types of blockchains (Wegrzyn et al., 2019).

With smart contracts business is taken to another level when self-executing scripts are stored on the blockchain and there is no need for a middleman. Smart contracts are getting more and more attention from businesses.

According to Andoni et al. (2019 p. 146) Walport (2015) states a smart contract is an application in blockchain and makes the potential of blockchain technology a reality. These contracts' terms are computer coded instead of legal language.

Macrinici et al. (2018, p. 2337) defines smart contracts as a value flow. Smart contracts are based on specific terms and conditions and are digital, which is the only difference compared to contracts in the real world.

2.1.2 Motivation for blockchain

People are today very aware about food safety, and an effective, reliable system is required to track the origin of the products and minimize risks. This problem can be solved effectively with the help of blockchain technology. As an example, the origin of food can be determined. This improves the health of customers remarkably. Agricultural products can be tracked and controlled across the entire supply chain. (Pashar et al., 2020, p. 2).

Energy industry revolution is one of the most interesting areas of adoption of blockchain technology and energy sector influencer and utility companies believe that this technology can bring changes in the energy sector. According to a survey of the German Energy Agency blockchain technology can affect many things like boost the efficiency of present procedures and processes related to energy, development of IoT platforms and applications. In addition, innovate P2P trading of energy and distributed generation.
In addition, they state that blockchain technology has the potential to greatly enhance present practices of energy companies and utility companies by improving internal processes, customer services and costs (Andoni et al., 2019, p. 151).

Bürer et al. (2019, p. 7) have come to a conclusion in their research, that blockchain technology does not necessarily completely change energy sector transformation in the short-term. They have highlighted several limitations for this, such as grid reliability and security and consumption of energy issues, risk of regulation and technological immaturities for companies. The biggest reason for this is the complexity of managing the grid. At the moment they believe that blockchain gives inspiration or impulse for new business models and novel ways of thinking about energy services. In this context indeed they see that blockchain has an impact in the energy sector transformation despite blockchain applications not getting mainstream confirmation.

There are plenty of sources that participate in data gathering in the energy sector. Data can be collected from the physical flow of the electricity, network traffic related to smart meters, sensors, customers, and other information that is recorded and stored for trading and other purposes like auditing and monitoring. (Lu et al., 2020, p. 3).

According to Reyes (2022, p. 2) Gangale et al. (2013), state that the lack of trust has been a barrier for consumers' willingness to share information about new technical, regulatory and market solutions related to energy.

Security, privacy and trust are the key attributes, which must be taken into account when adopting blockchain technology in the energy sector. Data security is essential because data leak could have serious impacts on e.g. national energy security. Energy companies customer's share more information about their energy usage and are thus more prone to invasion of privacy.

The trust producing technology blockchain can both make the grid more resilient and secure and accelerate the energy transition. In Table 3. is a summary of the common security, privacy, and trust objectives and the descriptions of how blockchain can achieve them.

Objective	**How blockchain can achieve**
Confidentiality	In public blockchain the records are not normally encrypted; Cryptographic techniques
Integrity	Data structure cryptographically protected by hash function, merkle tree, nonce, and time-stamp; decentralized access can be detected and prevented by manipulated records

Authentication	Verification of the valid user that sent can be ensured by signed records inside the blocks by users single private keys
Auditability	Publicly available records / transactions in public blockchain
Authorization and access control	User-defined authorization and access control count on smart contract; certificates of attribute
Privacy	Keeping secret identities by using hash functions to enable pseudo-anonymization, proof of zero-knowledge
Trust	Algorithms of consensus, trust is distributed through the entities in the network
Transparency	Complete transparency is achieved by maintaining permanent distributed ledger which includes all transactions, logs, events, and records
Availability	Full replication of the blockchain and multiple entities being able to form connections with others is made possible by decentralized architecture
Automaticity	Entities can communicate and exchange values using the blockchain and perform actions with the automation provided by the blockchain and smart contracts

Table 3. Summary of the common security, privacy, and trust objectives and the descriptions of how blockchain can achieve these (Mollah et al., 2021, p. 25).

2.1.3 Energy use cases

There exists a diversity of use cases affiliated to energy companies' business processes and operations. In this chapter, four particular use cases are introduced.

Renewable energy certificate (REC) is a certificate guaranteeing that the electricity is produced from renewable energy sources like solar, wind, and hydro power. Green energy sources and trades have created an active market for renewable certificates in Europe.

According to Andoni et al. (2019, p. 163) there are various innovators, who work for renewable, or carbon certificates use cases related to blockchain technology, trading, and automation of acknowledgment. For small energy suppliers, high costs and practice are an obstacle to claim carbon offsets. The central authority regularly conducts audits which may lead to mistakes or fraud.

Positive impact of blockchain technology for these certificates are automation of granting green certificates and reduction of transaction costs. In addition, they could form a global market for assets, increase transparency in the market and prevent double spending. Blockchain technology has limitations which are provided by services certification and verification. For example, energy production could be automatically certified by a smart meter integrated with blockchain solutions, but there is a lack of exploring the potential of tampering.

The P2P energy trading between producers and consumers in microgrids is enabled by blockchain technology. According to Khalid et al. (2020, p. 1) P2P energy trading can reduce costs of energy consumption and dangerous gas emissions. This is because renewable energy sources generate energy and in addition smart grid resilience increases.

Wongthongtham et al. (2021, p. 2) state that mutually beneficial transactions are enabled by blockchain based P2P energy trading. It allows prosumers to sell their excess electricity directly to local consumers without middlemen. This produces benefits for both parties. Feed-in-tariffs allow prosumers to earn more money and consumers could pay less for electricity. A dynamic market like this benefits from both parties. The reason for this is the battery technology, which can be used to store renewable energy.

The wholesale energy trading consists of complex practices that require third-party intermediaries. According to Andoni et al. (2019, p. 152), Ernst & Young (2017) state that present practices take a lot of time and are slow. This is because verification of transactions and reconciling several times from the beginning to final settlement. The low speed of transactions and exchanges are reasons that distributed and minor producers are eliminated by the market.

Direct trade between consumers and a producing unit is allowed by blockchain with smart contracts. This same applies for an energy retail supplier without the middleman. An independent agent works after the best offer on the market, and in a certain period of time satisfies the consumer's forecast demand. The contract is saved on the blockchain and executed automatically at the specified delivery time, payments are also made automatically according to the smart contract. Andoni et al. (2019, p. 152).

Andon et al. (2019, p.163) states that Euroelectric states that many blockchain innovators are working on new solutions based on decentralized network management and control and automation. The benefits that can arise from this are the improvement of the supply and demand balance and the coordination between the transmission and distribution system operation, the visibility of distributed resources and assets, and automated verification of grid assets.

Because the throughput and transaction speeds are low, real-time verification is not possible. Enormous new data sets are created from electricity networks like metering, control and communication systems and grid infrastructure that are already in use, which are connected to the blockchain. These data sets should be closely managed and prevent cyber-attacks. (Andoni, 2019, p. 163).

2.1.4 Blockchain business models

There is a debate that blockchain is a promising technology to convert all existing business models. In addition, several research highlights that blockchain has potential to optimize numerous processes, reduce the intermediaries and lower costs. Although there exist several obstacles to beat before this technology can be implemented. Weking et al. (2019, p. 1) argues that despite the fact there are promising use cases, research and practice are yet in their infancy about changing existing and creating new business models.

There exist various studies about blockchain business models. According to Xu et al. (2019, p. 3), Filipova (2018) suggests that business processes can be affected and improved by blockchain technology. This includes automation increasing, reduction of intermediaries and administration, opportunities for data tracking and audits, minimizing the risk of errors, frauds, transactions, and processing time, implementation of innovative payment solutions and supporting democratic decision-making.

One good example of business model change is how blockchain technology affects central banks and lawyers. Their business model changes from hourly payment to product-specific payment. The need for intermediaries is replaced by the control of trust in decentralized systems, and the change in charging is due to how the blockchain itself works. (Macrini, 2018, p. 2337).

Orlov (2017) in turn classifies seven blockchain business models in the energy domain. Orlov summarizes that blockchain-based business models have three benefits. These are lower energy costs, increased efficiency and promoting green energy. These features embedded in the dimensions of the business model's value chain, value proposition and value capture enables organizations to lower costs at the end of the business and increase value for customers.

2.2 Energy markets in Nordics

In this chapter, first the Nordic energy market participants are introduced. Iceland is excluded in this research because it has an independent energy system. Then four challenges which have influence on the structure of the electricity system are explained. After that the transformation of the energy system is introduced and trends and megatrends that influence the Nordic energy markets are presented. Finally, drivers of change in the energy sector are introduced.

Nordic countries have deregulated their energy markets and these have already been integrated through the Nord Pool power exchange since 2000. Cooperation in the Nordic Energy Market is very unique. Cooperation in the future will be affected by the development of new energy markets, e.g. gas and biofuels and their connection to the existing electricity market. There exists no clear wind energy target in the Nordics. Factors other than economic potential limit the growth of onshore wind power in the Nordic countries. (Chen et al., 2021, p. 2).

The Nordic electricity system is undergoing change and these changes will possibly be even more visible within three years. Figure 3. shows primary energy production 2020 in the Nordic countries, 75 % of the Nordic primary production came from Norway. The other countries produced much less.

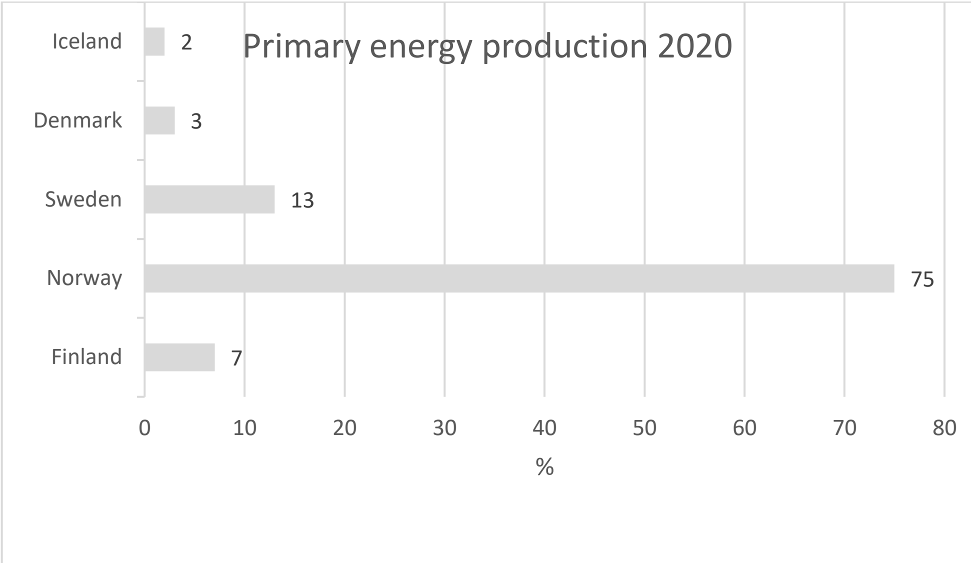

Figure 3. Primary energy production 2020 in the Nordic countries (Nordic Statistics database, 2022).

Hydro power is the major energy source of electricity in Norway. It plays a vital role in transition towards carbon-neutrality because it is currently the only low-carbon power producing technology that enables flexibility in several fractions of seconds to hours cost-effectively over several months. (Halleraker et al. , 2022, p. 2). Negative side is that hydro power has environmental and social threats e.g. use of water and land can cause imbalances in the ecosystem.

Figure 4. shows that in the year 2020 hydro power share was 92 % and wind power 8 %. Norway has great wind power potential and one of the largest offshore wind potential in the world.

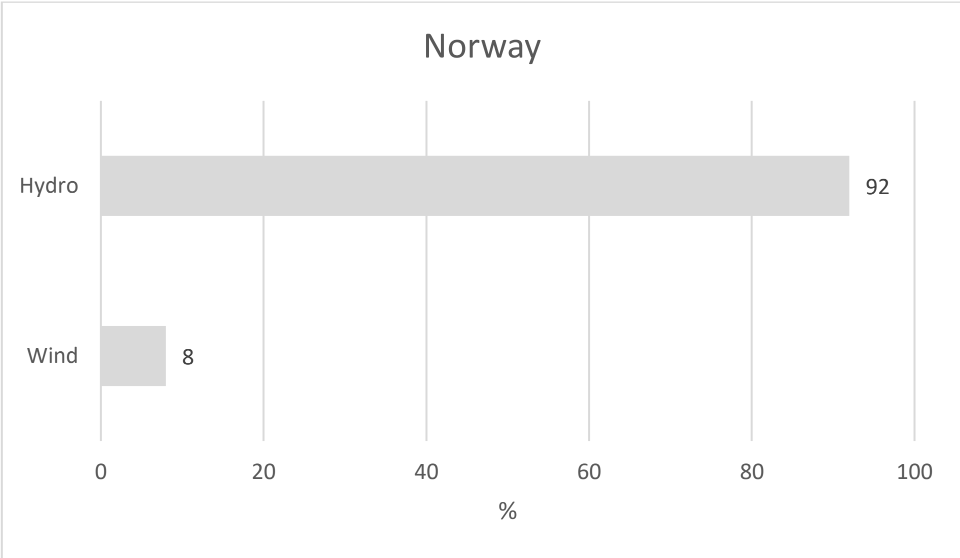

Figure 4. Norway's electricity production by source 2020 (Nordea, 2022).

Denmark is the leading wind and solar power producer in the world. Figure 5. indicates that over 80 % of the electricity is from renewable energy and less than 30 % from fossil fuel sources in the year 2020 in Denmark. Denmark has huge areas of shallow water depth in the North Sea territory, where conditions make for suitable wind sources. (Statista, 2022). Denmark has also one of the largest offshore wind potential in the world.

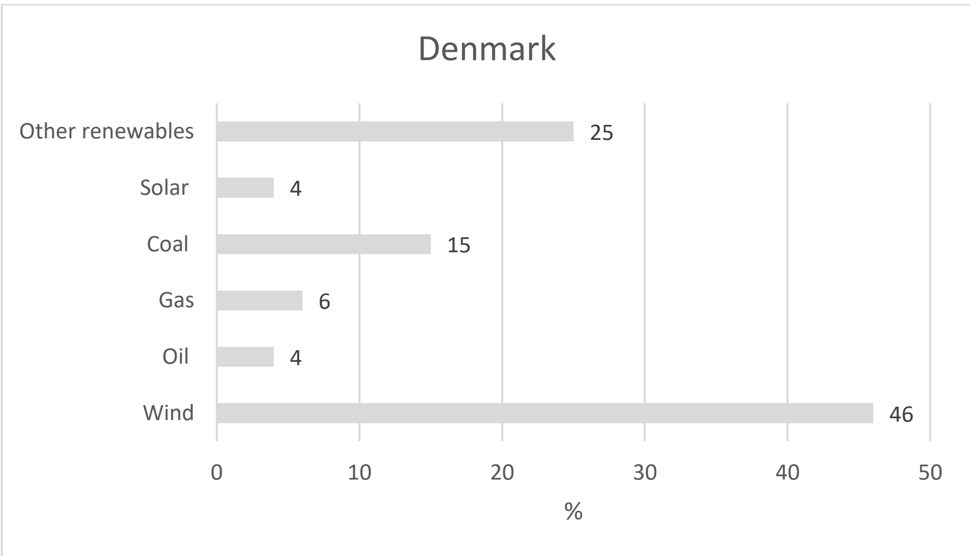

Figure 5. Denmark's electricity production by source 2020 (Nordea, 2022).

Finland's energy consumption and energy needs are high. Finland is a very industrialized country, which needs a lot of energy and has a cold climate. In addition, a high standard of living takes its share of energy. Figure 6. shows that in Finland 52-% of electricity was from renewable energy in the year 2020. Last year, wind power brought investments of almost three billion to Finland. It increases Finland's energy self-sufficiency at a good speed. (Mauno, 2023). Around 30 % of electricity is produced from nuclear power and 15 % from fossil fuel resources.

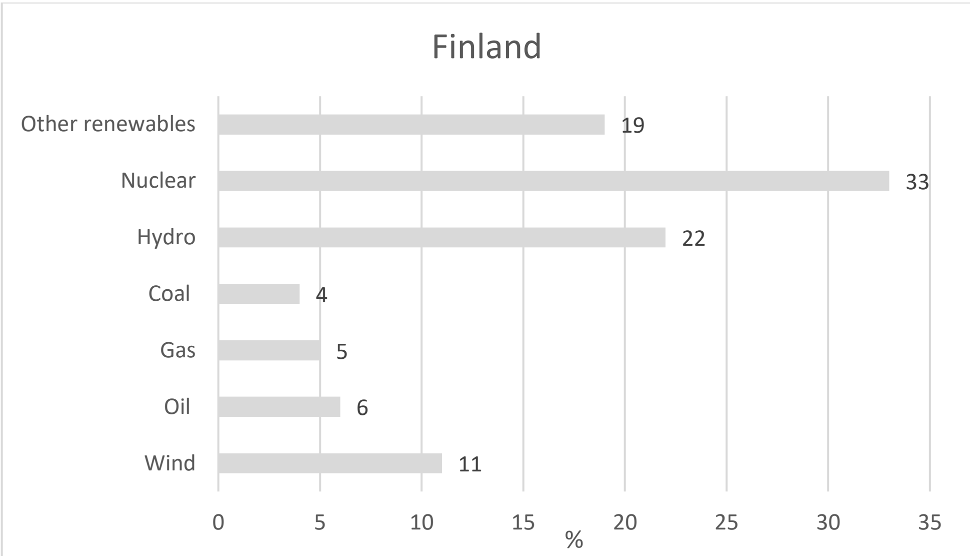

Figure 6. Finland's electricity production by source 2020 (Nordea, 2022).

Figure 7. indicates that the electricity production in Sweden consisted of 42-% of hydro power. In second place was nuclear power which had a share of 32-%. Other renewables' share was 24-% and the rest 6-% of electricity was produced from oil.

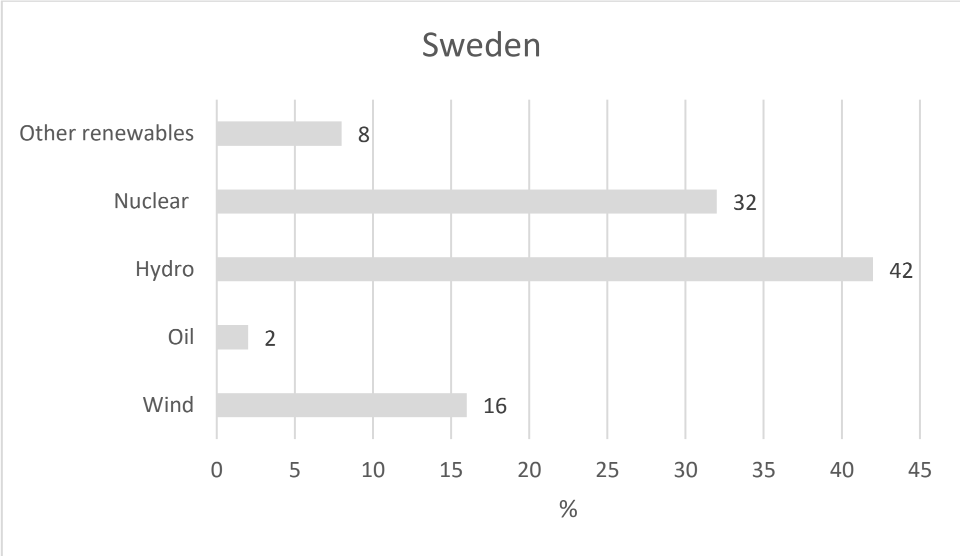

Figure 7. Sweden’s electricity production by source 2020 (Nordea, 2022).

2.2.1 Market participants

Every Nordic country has one transmission system operator (TSO), which is a state-owned company, and they are regulated as natural monopolies with revenue gap regulation, except Denmark, where a cost-plus regulation is applied (Grigoryeva, 2018, p. 129). TSO’s in the Nordics are Fingrid (Finland), Svenska Kraftnät (Sweden), Statnett (Norway) and Energinet.dk (Denmark). TSO’s responsibility is to secure the supply and the high-voltage transmission grid. There are also many other participants involved in the Nordic power market such as producers, distributors, brokers, traders and financial analysts etc.

A commercial report of four Nordic transmission system operators (Nordic Power System, p. 2) states that the roles and cooperation of the stakeholders will change, when the Nordic power system changes. Existing market participants are influenced and new participants are born. For example prosumer, which is an end-user that produces and consumes power, is a new market participant and will have an effect on current business models in the Nordic energy market.

2.2.2 Current challenges

The Nordic countries have a major role in the European energy system and have proven to be a trendsetter in the development and execution of clean energy policy. Despite these facts, the Nordic countries face a number of challenges. Here are introduced four of them.

Efficient utilization of energy generation and balancing and inertia is enabled by adequate transmission capacity. It also helps to ensure the security of supply. (Nordic Power System, 2016, p. 6). Chen et al. (2021, p. 2) in addition mention that capacity adequacy is important to ensure energy security.

Balancing Nordic, European and national perspectives in transmission planning is very complicated. In order to fortunately deal with foreseen system challenges are these issues extremely important. (Nordic Power System, 2016, p. 6).

Transmission planning faces challenges which are valuing all benefits properly and applying the correct assumptions. In recent years future developments surrounded with unpredictability are making it more demanding to forecast the upcoming energy system. In addition, when evaluating transmission investments, not all the benefits of the transmission capacity of the electricity system are accordingly valued. (Nordic Power System, 2016, p. 6).

To ensure operational security there exist two challenges that have to be overcome. High-voltage direct current (HVDC) ramping and larger imbalances caused by forecast errors present a challenge for TSO’S. For securing real-time balance, maintaining sufficient frequency and balancing reserves is critical. More unpredictable power generation will outcome in more forecast errors in the Nordic power system. (Nordic Power System, 2016, p. 5).

In turns insufficient inertia in a power system can cause that frequency drops are too fast. This can lead to that frequency can reach the load-shedding value before reserves have reacted adequately. Phasing out of nuclear units, high energy imports through HVDC connections and higher volumes of renewable energy share reduces inertia levels. (Nordic Power System, 2016, p. 5).

With the exception of Denmark, all Nordic countries are energy-intensive and the energy industry is an important contributor to the economy, but is unfortunately also a large source of emissions. The Nordic region is sparsely populated and over times high demand, limited generation and transmission capacity on cold winter days have caused problems for Nordic power systems. Driven by Norway's production, oil and gas production remains significant (IAE, 2013, p. 1).

The management and operation of electricity systems encounters new challenges due to the fact that increased flexibility measures are needed to secure safe operation and solidity as renewable energies are challenging to forecast, fluctuating and weather conditions depending. Flexibility measures include the merging of rapid acting supply, demand response and energy storage and services related to electricity trading. (Andoni et al. 2019, p. 143).

2.2.3 The transformation of the energy system

According to Grigoryeva et al. (2018), Amundsen et al. (2006) and Bredersen (2016) state that some consider the Nordic electricity market as being one of the most well functioning regional markets in Europe. In addition, renewables are dominating the energy mix, which guides the future European system.

Probably the most ambitious and progressive energy and climate policy in the world is in the Nordic countries. All the Nordic countries have a number of long-term policy goals and binding climate targets, as well as the ambition to develop fully or mainly fossil fuel free or carbon neutral. Denmark, Sweden and Norway have devoted 100% and Finland to 80% renewable energy penetration. (Sovacool, 2019 p. 569).

Kilpeläinen et. al. (2019, p. 448) propose that to achieve streamlined cooperation, stakeholder interaction and policy coordination are required. The realistic transition requires many participants from public, private, and nongovernmental organization sectors. Participants acts as innovators, regulators, and advocates of essential solutions and policies.

According to Ahl et al. (2019, p. 207), Yarime et al. also highlight a need for participants involvement, sharing of knowledge and building of skills for energy sector transformation. Stakeholders' supportive participation is critical since the transition of energy will pervade strongly into society.

There are several issues that make energy transition slow. First persistence of stiff chains of social behavior and not simply adaptable material constructions. In addition, old and new paths must be evaluated, and regional coordination is required because of cross-border effects of the solutions and policies. (Kilpeläinen et al., 2019, p. 20).

The pros for energy system transition in the Nordic market is that Nordic countries have cross-border transmission lines which are well-connected. In addition, Nordic countries have close ties on political and economic issues. Because of this, the cross-country transmission capacity between the countries has developed. (Grigoryeva, 2018, p. 128).

2.2.4 Trends

The trends have influence on the Nordic energy market.

According to Chen et al. (2021, p. 8) traditionally key power drivers are fuel and emission quota prices and specially in electric systems with remarkable coal and gas power plants shares. As there exists no coal power production in Sweden and Norway, and in addition Denmark and Finland are forbidding coal in electricity production before 2029 and 2030, coal prices are reducing impact on the Nordic electricity markets.

Because of this, the review of Chen et al. (2021, p. 8) shows that key energy drivers are gas and emission allocation prices in the Nordics in the two coming decades, with extreme unpredictability.

In the long term, market signals and policies are affecting power generation capacities. A general trend is that environmental and safety concerns are slowly limiting nuclear power and eliminating coal, while particularly wind and solar power, will in gradual manner enhance their share of electricity towards 2050. In the Nordics, solar power has a less important role than wind power (Chen et al., 2021, p. 2).

2.2.5 Megatrends of the energy sector change

The future fossil-free Europe with merged power markets due to prosperous renewable energy sources can give advantage to the Nordic countries. (Chen et al., 2021, 2). In addition to clean energy, societal opposition to certain technologies and increased awareness of sustainable development indicators will affect the Nordic electricity market in the long term. In addition, best efforts of simplicity and transparency must be ensured all the time. (Chen et al., 2021, p. 1).

Climate change is the biggest challenge in the long term, and the energy industry has been at the top of the fight against climate change. It is a crisis which moves slowly but changes the world rapidly.

Globalisation and digitalisation causes changes in the Nordic energy market. For example the 15-minute imbalance settlement period will be taken in use on 22.05.2023 in all Nordic countries. The change will be implemented throughout Europe. The 15-minute imbalance settlement is a prerequisite for the European-wide integration of the electricity market. (Fingrid, 2021).

Increasing urbanization also in the Nordics has increased demand for energy. On the other hand, urbanization in cities can lead to technological innovations and efficiency gains. At the same time reduce energy consumption and per capita resources. This megatrend has a plain change to reach for sustainable long-term development. (Fridberg, 2022).

2.2.6 Drivers of change in the energy sector

In the Nordic countries the changes to the generation mix and expanding merging with the rest of Europe are driving the changes of the energy system (Grigoryeva et al., 2018, p. 127).

Climate policy, which encourages the development of renewable energy sources and technological developments including digitalization are the main drivers according to a report of Statnett, Energinet, Svenska Kraftnät and Fingrid. In addition, a general European framework for planning, markets, and operation are main drivers. (Nordic Power System, p.2).

The report of Fovino et al. (2022, p. 28) states that blockchain technology is confirmed to be a multi-functioning method to support practical decision-making in the climate-neutrality and energy fields. The positive thing is that the EU’s Research and Innovation programmes reserve a significant budget to test blockchain solutions in several sectors including the climate and energy ones.

In addition, the report states that the energy sector is growingly making research into innovative blockchain solutions aiming to streamline system and market operations and propose new services.

In turns Andoni et al. (2022, p. 167) state that blockchain technology can be disruptive for energy companies, and meet different challenges like legal, regulatory and competition barriers.

2.2.7 Renewable energy sector

The Nordic energy mixes are diverse and Nordic countries have strong regional integration. Finland and Sweden are known for bioenergy, Norway for hydropower and Denmark is a pioneer in wind power. Wind and solar energy have an important role in the green transition of Nordic energy systems.

In the Nordics renewable energy consumption has grown consistently over the past decade. The most renewable energy consumption has risen in Denmark. From 2005 to 2019 Denmark's renewable energy consumption rose an average 5.3 percent annually. During this period Finland's renewable energy consumption rose in turn 2.9 percent, followed by Sweden at 2 percent, while Norway came last, consumption rose an average 1.7 percent annually. (Nordic Energy Research, 2021).

The wind power consumption is the world highest in Denmark. In 2019, it met 45 percent of Denmark's electricity demand. Two thirds came from onshore and one third from offshore wind. (Nordic Energy Research, 2021).

The Nordic electricity system is leading the regional coupling of electricity grids in the world. Transmission lines and interconnectors link countries across land and sea, at the same time efficient electricity trade is ensured by the common spot market. The well-functioning Nordic electricity system has some features that increases security of energy supply, cuts down systems costs and clears the way for renewables integration. Emission-intensive power production in nearby countries is replaced by clean electricity export aids. In addition, transmitted hydropower provides balancing services for variable renewables. In this case, the Nordic electricity system plays a dominant role in achieving EU climate targets. (Nordic Energy Research, 2021).

2.3 Summary of the literature and market review

Climate change and the decreasing of natural resources are essential parts that require finding new solutions to utilize renewable energy and increase energy efficiency. At the same time energy demand is growing and the traditional energy systems cannot satisfy that. The ongoing energy crisis - Russia's war of aggression in Ukraine and the rise in energy prices - challenges energy and grid companies as well as consumers. The importance of renewable energy production is increasing because the importance of energy self-sufficiency is emphasized. The energy systems are becoming more dynamic with multiple participants, in addition intelligence and international interdependencies stand out. The management of such complex systems requires automation and blockchain could be a solution for this problem.

The Nordic energy market is one of the most successful regional markets in Europe, with a high share of renewable energy. The Nordic countries have ambitious goals towards carbon neutrality by 2050 and have the most advanced energy and climate policies in the world. Regardless of this, the Nordic countries face many challenges. To achieved the desired future of cost-efficient low-carbon economy, Nordic energy markets must be well-operating and innovations and the commercialization of energy related technologies must be in place.

Blockchain technology enables the elimination of third parties and the creation of secure contracts and transactions. Blockchain technology has many opportunities in the future, e.g., to improve the practices and processes of energy companies and industrial companies, customer service and lower costs. The revolution in the energy sector is the most interesting application area of blockchain technology. There exists an obvious interest of energy companies to utilize the potential of blockchain technology, but consumers and some participants in the energy industry are not yet familiar with this technology.

3 Research method

This study is a qualitative survey study. There is no previous theory related to the study and research problem is new so that is the reason why this research method is used. An exploratory methodology is used since only few earlier research exists. In addition, existing research problem get a better understanding, but final results are not obtained. Also during the research, the researcher has flexibility and can modify changes. (Bhat, 2022). In this study too, changes had to be made due to the low number of responses.

Information gathering is performed by using survey for a predefined group. Survey included structured questions and open questions. Surveys are nowadays easy to carry out online and respondents have easy access to them. Information is available in real time to the researcher. The downside of surveys compared to interviews is that you cannot ask defining questions to clarify the answers.

The five dimensional an analytical framework, called TESEI created by Ahl et al. (2019) is used to find out opportunities and challenges of blockchain technology. This framework includes 1) Technological, 2) Economic, 3) Social, 4) Environmental and 5) Institutional dimensions (TESEI). Energy innovations are multidimensional in nature so the use of this framework is justified.

3.1 Data collection method

Data gathering for this research was implemented as a structured survey. The data collection process was carried out between May 2022 and December 2022. First the survey was sent to 400 contacts in Finland, Sweden, Norway and Denmark. Contacts are in the field of energy business e.g. electric utility, producer of renewable energy, grid operator, service company, aggregator and other stakeholders involved. The data collection process included the preparation of the survey structure, the collection of contact information and implementations of the survey.

The first survey round in May did not produce enough answers, so the survey was sent again in August to the same group. The second round was no better than the first, so the survey was made a little easier to answer. The survey was sent a third time to the same group. In addition, the survey was advertised on LinkedIn and posted to one of the LinkedIn groups, which members are involved in solar and wind power in the Nordics. In addition it was sent to contacts which are involved in the Powered by Blockchain project and the Blocklane group.

3.2 Data analysis method

The data analysis is a qualitative data analysis method. This method involves the process and procedures for analyzing data. In addition, it provides to a limited extent understanding, explanation, and interpretation of figures and topics in literal data. (Valcheva, 2023). The data analysis consist of several steps: gathering the answers, reading the answers, categorization the data, drawing up graphs, observations from the answers and reporting the results.

4 Results

Figure 8. indicates that 85 % of the respondents have heard about blockchain technology and 15 % have not heard yet about it. Figure 9. shows that 45 % of the respondents work at a company which size is more than 500 people, 36 % of respondents work at a company which size is from 50 to 500 people and the rest of the respondents at a company which size is less than 50.

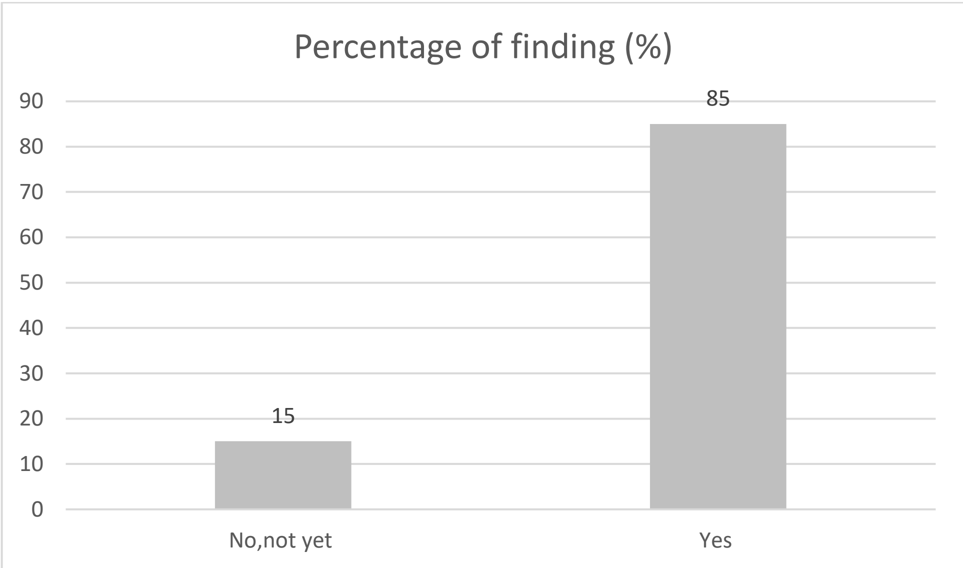

Figure 8. Level of awareness of blockchain technology (percentage of finding %)

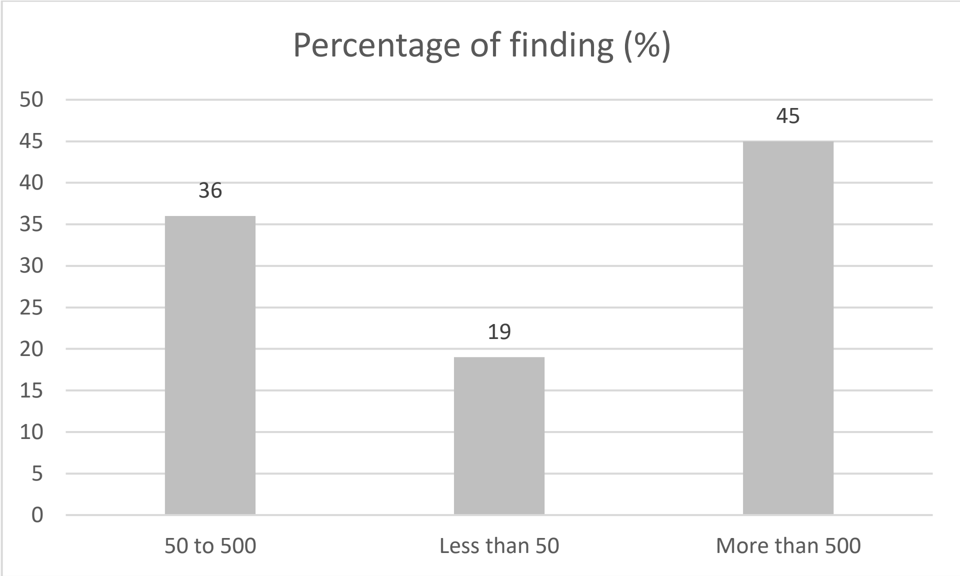

Figure 9. Company size (percentage of finding %)

In Figure 10. it is indicated that Finns and Swedes answered the survey equally, the shares being 43 %. The Danes answered the survey the second most, with the share being 13 % and the Norwegians the least with the share being 2 %.

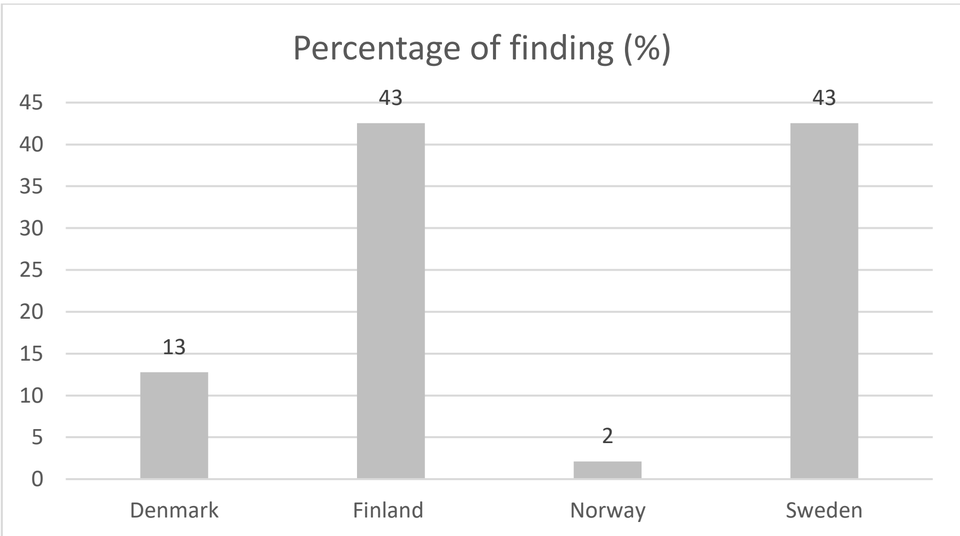

Figure 10. Home country of the respondent (percentage of finding %)

Figure 11. shows that 44,7 % of companies have plans for implementation regarding blockchain technology. 44,7 % of companies have not planned or implemented and 10,6 % have already implemented.

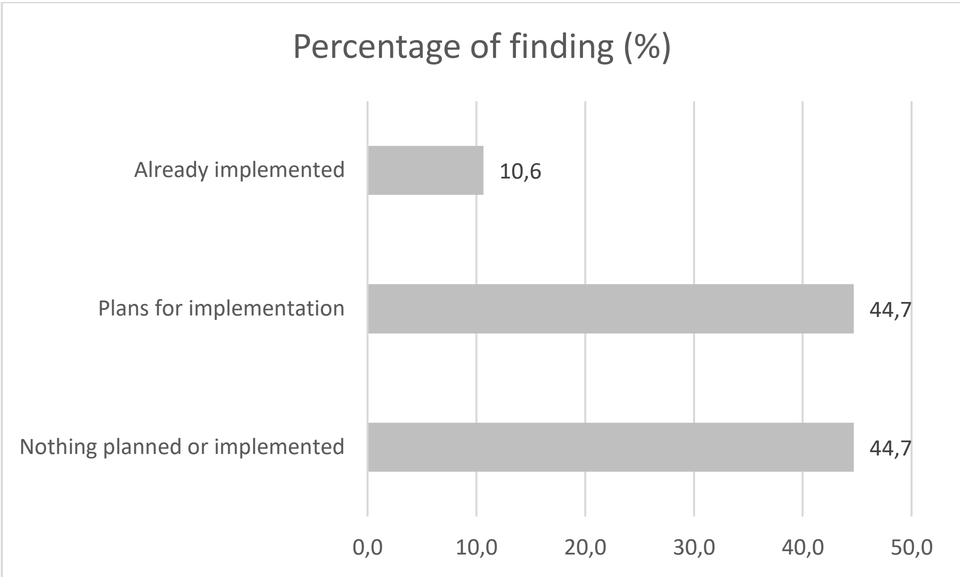

Figure 11. Companies' actions regarding blockchain technology (percentage of finding %)

Companies have implemented or planned the following actions regarding blockchain technology.

The answer does not indicate what is going on.

"It is currently in the planning, the specific implementation time to be determined."

The answer is related to digital currencies and not actually to the energy sector.

"The settlement of transactions in digital currencies."

One company has some actions going on regarding electric power development.

“For better electric power development.”

One company has some plans but does not indicate what it concerns.

“It is only a preliminary completion plan.”

One company has implemented one project and it will be closed.

“The project has been implemented at all levels, gradually breaking down.”

One company has taken use of blockchain technology in their service.

“Blockchain technology has been introduced to promote public service facilitation and transparency, equality and precision.”

One company has actions on a small study.

“Small study.”

Next reasons are introduced why potential use cases of blockchain technology couldn’t be identified.

“In almost all energy cases, including microgrids, there is a need for a centralized controller to make sure that the common grid connection isn't violated and that local energy transfer between two points in the electricity grid is physically possible (not always certain depending on the load of surrounding cables at the time). This, together with the accountability towards the central grid connection and the central grid control (ultimately SvK here), then requires a central control and connection point for the transaction which makes most of the use of blockchain unnecessary. Individual transactions in e.g., a microgrid could be tracked with blockchains, but since there are so many other aspects that require central control and accountability there's really no point in having the blockchain as well.”

“Blockchain is not familiar to me.”

“The reason is that we have not identified any potential use cases. There is no real need for blockchains. Current solutions are fine.”

“Blockchain technology is at its' core a means to store information but brings its own unique restrictions and advantages. Some of these advantages might seem interesting at first, but when examined more closely isn't necessarily an advantage. For example, one of the usually cited benefits is being able to store immutable data which can be independently verified is less relevant when you're dealing with data points which might be inaccurate when first measured and which could be updated multiple times before the values become finalized. When it comes to the needs for the private sector in Sweden, I would argue that for data management there is demand for a system like the one already implemented in Norway or Denmark, where there is a centralized source, an 'Energy Hub' where each company can seek relevant information regarding each EAN-object or fetch data when needed.”

“Not aware of”

In Figure 12. it is shown how companies view the potential dissemination of blockchain technology. 61,7 % of companies think that blockchain technology is a Game Changer for the energy industry. 25,5 % of companies believe that it is for niche applications, and the rest of companies believe that blockchain’s role is small to non-existent.

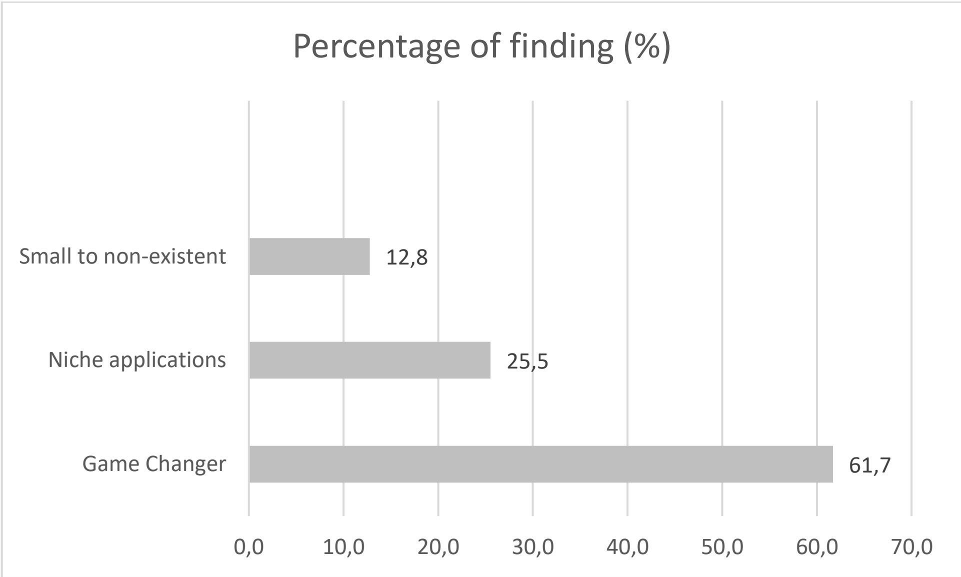

Figure 12. Companies' view on the potential dissemination of blockchain technology (percentage of finding %)

4.1 How can blockchain technology advance and improve the Nordic energy market and the renewable energy sector

Blockchain technology can simplify and give flexibility for many processes, transactions, and services. Through these features the Nordic electricity market can be much more efficient and offer novel solutions for different challenges in the Nordic energy market and the renewable energy sector. In addition, it could change business models enabled by blockchain technology in the long term and give inspiration to new ways of thinking about services related to the energy industry. Business operating efficiency and better-informed decisions are enabled by digital technologies and everywhere available data. The greater accessibility of transactions by partners is enabled by blockchain processes. (Andoni et al, 2019, p. 151).

Hasankhani et al. (2021, p.10) state that blockchain technology has an ability for reduction of time, cost, and difficulty of energy trading. This is because third-party intervention is made possible by blockchain technology. With blockchain technology energy markets can get more flexibility and even small operators can participate in providing energy. In addition, it gives the opportunity for citizens to save energy and earn money.

In the energy industry blockchain enables secure data management of all business actions. It creates trust through tamper-resistant data storage. Data in the energy industry becomes transparent since blockchain technology verifies and validates transactions. It also entitles data sovereignty. Individual-centered information management is enabled by smart contracts in blockchain. Blockchain technology also has some features that can solve problems related to cyber security. Blockchain technology has an ability to provide practical solutions to many problems encountering energy applications like storage systems.

4.2 Opportunities

Next search results of blockchain opportunities are introduced in five different dimensions.

4.2.1 Technological

Figure 13. indicates 9 technological opportunities. In the current study the following key technological opportunities are noted: Automatic management of energy & bidding strategies, smart contracts, energy storage, smart metering, data storage, cyber security, operations and maintenance (O & M) of microgrid, reliability and frequency and voltage control.

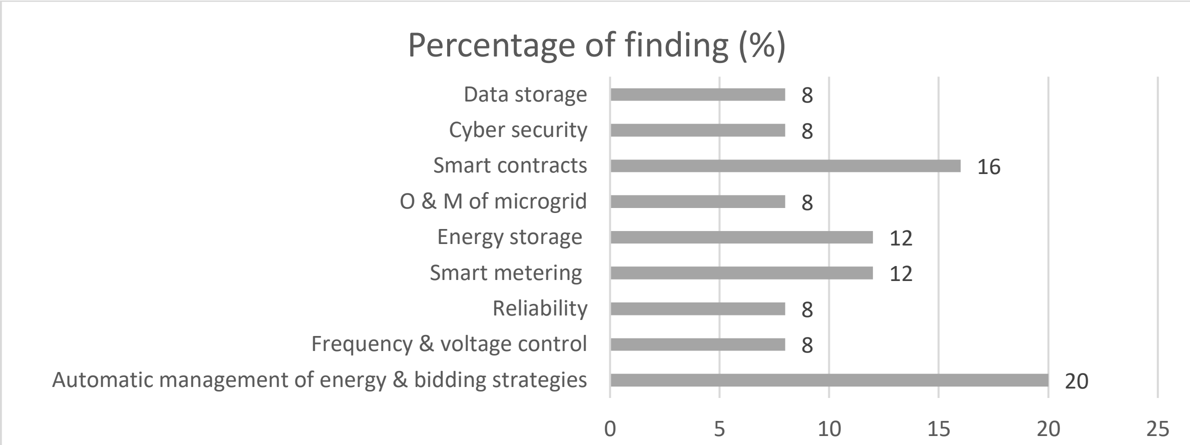

Figure 13. Technological opportunities (percentage of finding %)

According to the survey the greatest technological opportunity is automatic management & bidding strategies. Research of Ahl et al. (2021, p. 203) indicates several benefits that automatic management of energy based on bidding strategies can enable like managing a peak power to avoid technical burdens. In addition, costly network reinforcements can be avoided. Also, energy in the microgrid can be balanced by supplies and loads.

Results of the survey shows that smart contracts are seen as a big opportunity related to blockchains. Smart contracts enable individual-centered information management, where a person could manage what information about various events he or she wants to give to companies. The individual can regulate the transfer of data herself and see how the data stored about her has been viewed in other operators of the network. In addition, blockchain applications with smart contracts provide reliable and secure energy trading and information flow (Hasankhani et al., 2021, p. 9).

The third greatest opportunity is energy storage and smart metering. With the help of blockchain technology energy storage is becoming a profitable option. In addition, renewable energy is also promoting taking over energy storage solutions. In order to activate blockchain services in energy communities and enable peer-to-peer energy trading, an interoperable and sufficient smart metering infrastructure is necessary

(Fovino et al., 2022, p. 4). Intelligent smart metering implemented with blockchain can save a lot of money, because there is no need for a middleman. According to Andoni et al. (2019, p.151) with blockchain and smart contracts, smart metering can make automated billing for consumers possible. In smart grids, smart meters play a key role because they can provide useful information about the consumer profile and consumption. This can lead to a load forecasting and reduced load peaks. (Fovino et al., 2022, p. 20).

Data storage and cyber security are also seen as a technological opportunity of blockchain. Storing data on the blockchain is lowering costs compared to cloud storage systems. The decentralized functioning of data storage improves the security and privacy of user’s data. Data is also easily accessible by all network participants and enables monitoring and verification of electricity services possible. It also helps the quality of the services. (Yang, 2020, p. 2). Cybersecurity can be improved due to blockchain features. Problems associated with the networks, security of devices, and users of them can be resolved with these. (Taylor et al., 2020, p. 148).

According to the survey reliability and frequency and voltage control are technological opportunities. Reliability is a very strong feature of blockchain. Blockchain technology has proved the capacity for resolving privacy, security, and reliability challenges that prevent improvements. Automated frequency and voltage monitoring systems with control congestion is enabled by blockchain (Aklilu et al., 2021, p. 20).

Lastly, O & M of microgrid has been identified as a technological opportunity. Keisang et al. (2021, p.19) state that O & M has a central role in securing sustainability and long-lasting accessibility around the operational lifetime of the elements of solar photovoltaic systems during increasing confidence of final consumers in solar power.

4.2.2 Economic

In Figure 14. 4 economic opportunities are indicated. The economic dimension involves opportunities related to business models, real-time pricing, scheduling, and competition.

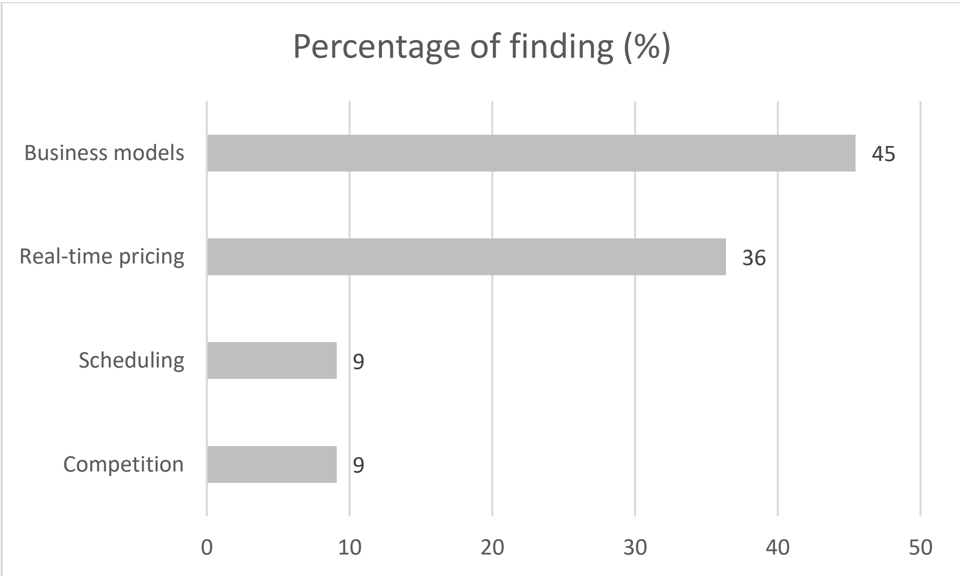

Figure 14. Economic opportunities (percentage of finding %)

According to the survey, business models are seen as the greatest economic opportunity related to blockchain. Business models in Nordic countries could provide several benefits for customers. The business model of operations changes, and the key is decentralization, which is one of blockchain main features. This leads to time and cost reduction, lowering prices for consumers and increasing profitability for investors. In addition, blockchain technology enables transparent, secure communications, transactions, and data management for managing business.

Results of the survey shows that real time pricing is the second greatest economic opportunity of blockchain technology. Blockchain based real-time pricing mechanism could notify consumers of their energy usage to control congestion during peak-hours. The trustability and fairness of real-time pricing is guaranteed by the consensus mechanism and the transparency of blockchain.

The third greatest opportunities are related to scheduling and competition. Blockchain enables power energy and demand scheduling practices. Trough experiment of Li et al. (2021, p. 1) dispatching power can be near to the real dispatching power according to encountering the normal operations demands of each equipment, comprehending the energy conservation of electric power, in addition gives technical support to establish greener power grid in Nordics. Blockchain could develop the Nordics energy market operations to become more efficient and transparent. This could lead to better competition in the Nordic energy market. In addition, it could improve customers' choice to switch energy suppliers. (Burger et al., 2022, p. 3).

4.2.3 Social

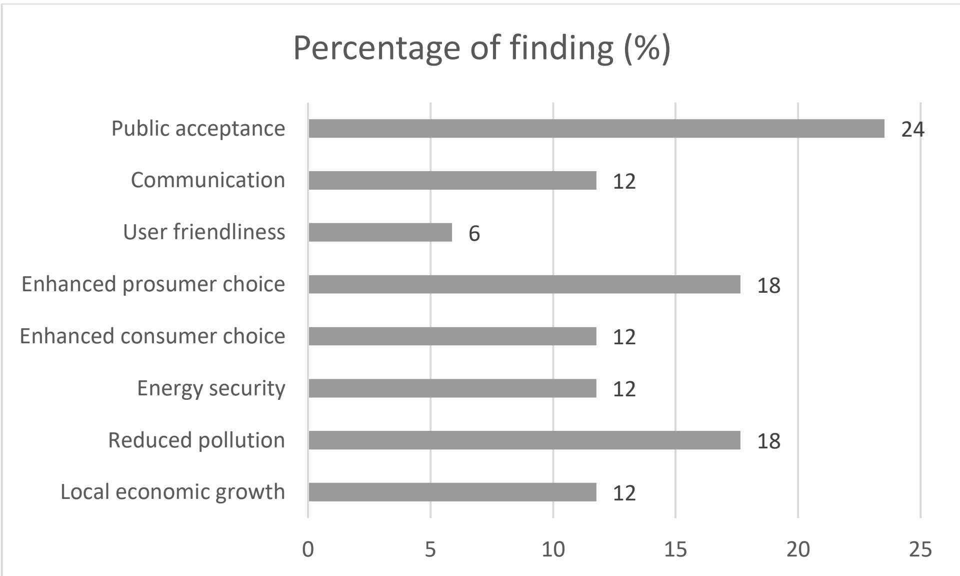

Figure 15. Social opportunities (percentage of finding %)

Figure 15. shows social opportunities. In the current study the following key social opportunities are noted: public acceptance, enhanced prosumer choice, reduced pollution, communication, enhanced consumer choice, energy security and local economic growth, and user friendliness.

The survey indicates that public acceptance is the greatest social opportunity. Since blockchain technology is a disruptive technology, it can be assumed that it will achieve public acceptance slowly. According to Ahl et al. (2019, p. 11) local economy acceleration, which is emerged from local resource use and profit creation, can instill public acceptance.

The second greatest social opportunity is enhanced prosumers choice and reduced pollution. Blockchain will enhance prosumer choice enabling greater flexibility and monetize excess energy. It will also permit the registration of the ownership of the energy which supports merging into a better competitive energy market. Blockchain improves renewable energy adoption through distributed solutions and at the same time emissions and pollution reduces. Blockchain can track data like the carbon footprint of products, services, and processes and waste emissions of a factory.

According to the survey the third greatest social opportunity is related to communication, enhanced prosumer choice and consumer choice, energy security and local economic growth.

According to Ahl et al. (2019, p. 14) communication strategies must clear the way for new digital energy services. This same applies also for blockchain services related to energy. In policy development user viewpoints and actions in the latest energy systems are needed. Concerns on data privacy and security may grow when the digitalization of the grid users grows.

Ahl et al. (2019, p. 12) state that in shared economies blockchain can entitle consumer choice along multi-centered governance. Consumers can have their own identities in the energy market. In addition, Ahl et al. (2019, p. 12) state that Tanaka et al. and Mengelkamp et al. also spotlighted the enhanced consumer choice. This is due to blockchain's ability to manage distributed information. For example, ability to select favoured energy source and to track all transactions back to its origination. This may provide important socioeconomic benefits and more sustainable behavior but requires the development of new market regulations and incentives.

The peer-to-peer electricity community is a group of prosumers exchanging electricity among themselves automatically enabled on blockchain. Prosumers are allowed to trade energy locally within a geographically limited area. This leads to bigger energy efficiency. Interaction between peers is crucial for managing and scheduling energy transactions and for metering and accounting transactions. This kind of community can rely on an external TSO or distribution system operator (DSO) for managing load balancing and energy security. (Fovino et al., 2021, p. 17). Blockchain also enables secure transactions and payments for energy trading.

The last greatest social opportunity is local economic growth. Local economic growth arises for example through action of the peer-to-peer community. Peers may have local exchanges in the community, which can trade their own energy production. Conditions and prices may be more appropriate to those of a traditional operator. Various energy venues are also possible prosumers to create for maximizing market efficiency. (Fovino et al., 2021, p. 17).

4.2.4 Environmental

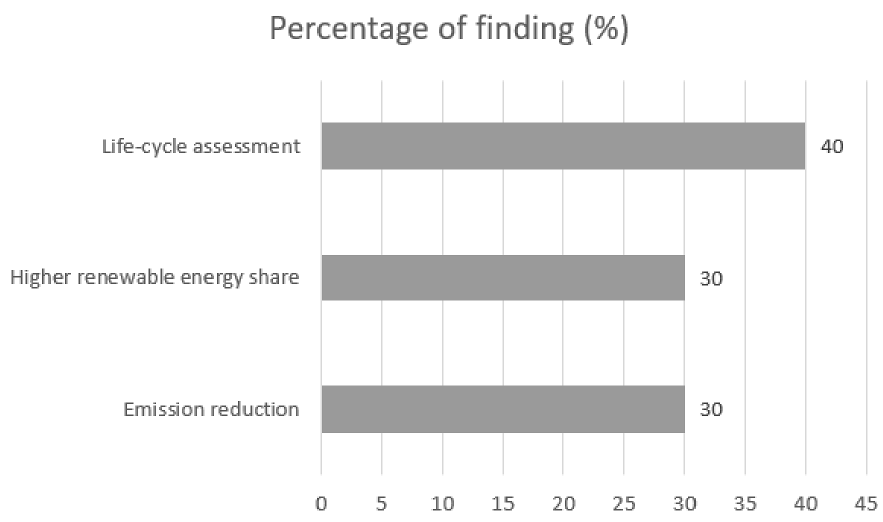

Figure 16. Environmental opportunities (percentage of finding %)

Figure 16. shows environmental opportunities. The following key environmental opportunities are noted: life-cycle assessment, higher renewable energy share, and emission reduction.

Survey shows that life-cycle assessment is the greatest environmental opportunity. Life-cycle assessment is possible with blockchain. It enables tracking microgrids end-of-life impact and recycling.

The second greatest environmental opportunity is related to higher renewable energy share and emission reduction.

Juszczyk et al. (2022, p. 1) state that the ongoing energy systems are integrating with increased renewable energy shares (RES). However, renewable energy share is a source of difficulties in operations management of electricity systems. Distributed energy markets require technology explanations that supports sharing of energy and information. Blockchain technology is a solution for the problems that are caused by higher renewable energy share.

Blockchain is seen as a powerful tool that can significantly improve traceability of greenhouse gas emissions (European Commission, 2022). Tracking and reporting of emissions reduction across the supply chain is enabled by blockchain.

4.2.5 Institutional

In Figure 17. institutional opportunities are shown. The following institutional opportunities are noted in research: emission regulations, market policy, co-development, prosumers licenses, blockchain governance and grid codes.

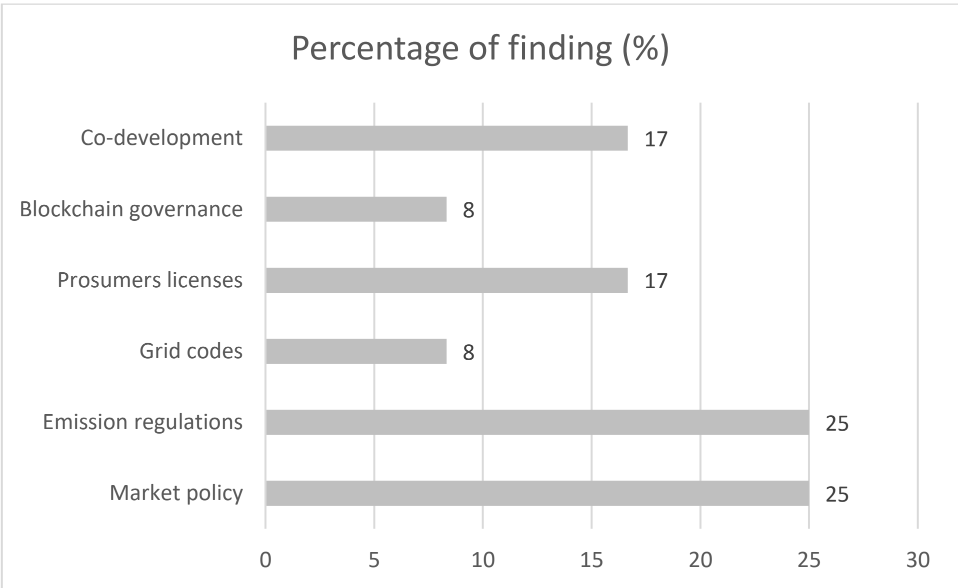

Figure 17. Institutional opportunities (percentage of finding %)

According to the survey emissions regulations and market policy are the greatest institutional opportunities.

Emission regulations' mission is to lead industries towards zero pollution and zero carbon by advanced technologies and blockchain technology belongs to them. Market policies and standards are essential for blockchain success. Microgrid participation and market competition can be expanded by entitled interconnection and with simple tariffs and market policies. (Ahl et al., 2019, p. 15).

Survey shows that co-development and prosumers licenses are the second greatest institutional opportunities. Ahl et al. (2019, p. 17) state that co-development is essential to entitle the private and public sectors and inform new policies. According to Ahl et al. (2019, p. 17) Yarime and Karlsson highlight a need for participants collaboration, sharing of knowledge, and building of skill for energy sector innovation. According to Ahl et al. (2019, p. 16) prosumers' licenses are must for prosumers to be part of the power market. Licenses generally presume major-scale producers and companies.

The third greatest institutional opportunities are blockchain governance and grid codes. One superior institutional opportunity is that blockchain enables decentralized governance, control and power is shifting to citizens. Grid codes are needed for microgrid interconnection, islanding, and smart metering and these are key aspects in the context of the legitimate design of microgrids and suited to governance landscapes (Ahl et al., 2019, p. 17).

4.3 Challenges

Next, search results of blockchain challenges are introduced in five different dimensions.

4.3.1 Technological

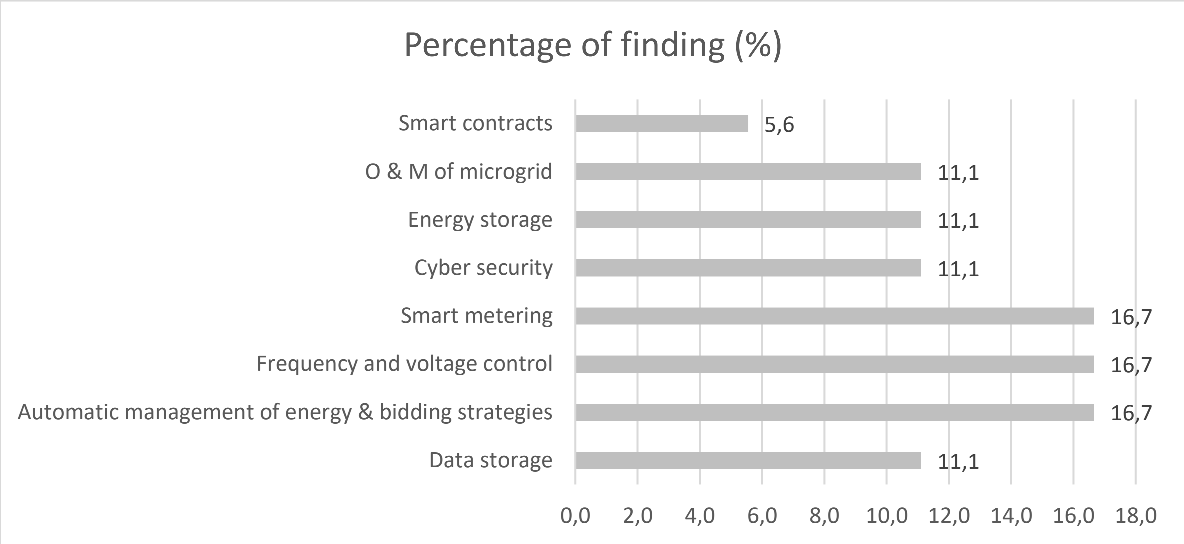

Figure 18. Technological challenges (percentage of finding %)

Figure 18. shows technological challenges. In the current study the following key technological challenges are noted: smart metering, frequency and voltage control, automatic management of energy and bidding strategies, O & M of microgrid, energy storage, cyber security, and data storage, smart contracts.

Smart metering, frequency and voltage control and automatic management of energy & bidding strategies are identified for greatest technological challenges.

According to the European Commission (2023) smart metering infrastructures are not developed enough for blockchain. According to Sun et al. (2019, p. 2790) power quality and more accurately voltage control is significantly impacted by the high penetration of DER like wind or PV in the distribution network (DN). There exist several challenges that need to be handled shortly such as appropriate collection and compromise of different control architectures, sufficient parameter settings of local controllers, and profitable coordination of many DER's to control voltages at the same time cutting down production reduction.

If the voltage and frequency are not appropriately controlled by grid-forming DER and the microgrid controller, sudden significant change in renewable energy production may guide to voltage and frequency unpredictability (Sun et al. 2019, p. 2795).

One reason for automatic management of energy & bidding strategies to be a challenge might be the probability of uncertain issues and difficulty of energy management which is caused by immature technology (Hasankhani et al. 2021, p.7).

According to the survey the second greatest technological challenges are related to O & M of microgrids, energy storage, cybersecurity, and data storage.

Keisang et al. (2021, p. 12) emphasizes the criticality of the O & M in solar PV systems in their research. To be able to secure high system availability, accuracy, safety while operating at a challenging level of efficiency and effectiveness, participants must think up and improve system planning, maintenance planning, operational measures, and application approaches. There are several issues that must be understood in O & M of microgrids like several configurations, control architectures, and ways of operation in microgrids. There exist various types of challenges which vary depending on component design, system optimization goals and depending on fitting location.

The use of energy system storage must be effective because energy produced compared to conventional production sources is expensive. The depreciation due to lifetime degradation and charge and discharge losses are affecting this. (Morstyn et al., 2018, p. 3654).

Smart grids consist of numerous sensors, devices, and networks so it is obvious that it is an interesting target for vicious attacks especially since it includes sensitive customer data. Cyber security brings the biggest challenges that the smart grid and the internet of things (IoT) ecosystem will have to address in the near future. (Mengidis, 2019 p. 23).

Blockchain's ability to store data is not efficient, especially if large sizes of files are stored. This challenge needs improvements because the amount of data grows, and it needs fast storage in the future.

Survey shows that the third greatest challenge is smart contracts. Leskinen (2020, p. 88) states that blockchain with smart contracts have not yet proved its benefits for energy markets such as the Nordic energy market. The implementation of this technology with smart contracts on a large scale is also very uncertain. These technologies should still be monitored and continuously developed, because they can be used to achieve promising application in the energy sector.

4.3.2 Economic

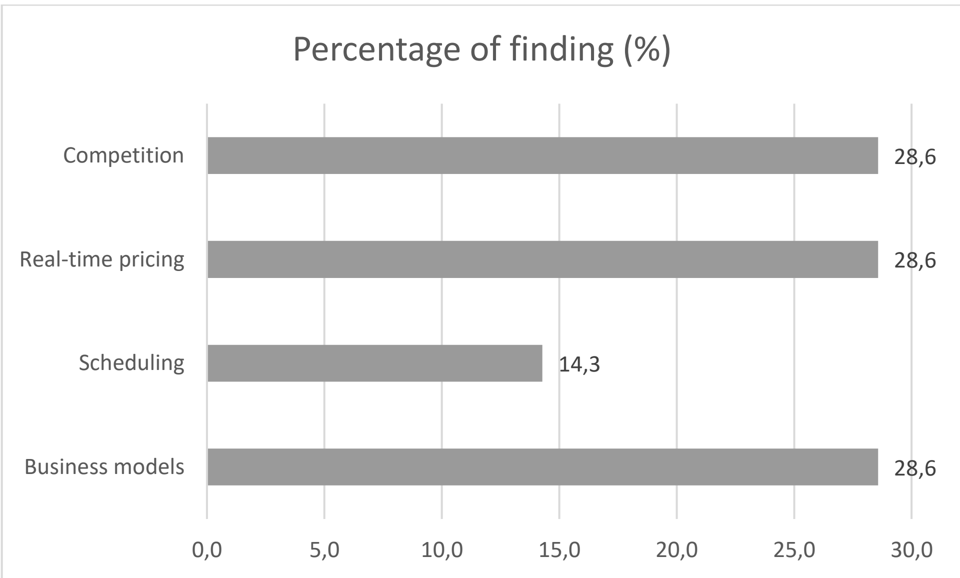

Figure 19. Economic challenges (percentage of finding %)

Figure 19. shows economic challenges. In the current study the following key economic challenges are noted: competition, real-time pricing, business models and scheduling.

According to the survey the greatest economic challenges are competition, real-time pricing, and business models. The Nordics electricity market is the world's most competitive. In peer-to-peer trading, which is enabled by blockchain, the challenge is how to form a price which is competitive with the spot market. According to Oktian (2022, p. 1) real-time pricing implementation is operating expense heavy from the network supply side and is laborious to convince consumers. Bürer et al. (2019, p. 2) state that there is a lack of data about each business model and energy usage ramifications in the context of blockchain.

The second greatest challenge is scheduling. According to Li (2021, p.1) the power grid has been influenced by the comprehensive operation balance of the power system, the negative impact of the corresponding balance maintenance and constant increase of the complete amount of access. This is an obstacle, and some scientists say that advancing the whole supply and demand schedule can be understood through the operations of numerous energy complementary. There is a lack of enough developed technology that has been properly implemented in power energy scheduling.

4.3.3 Social

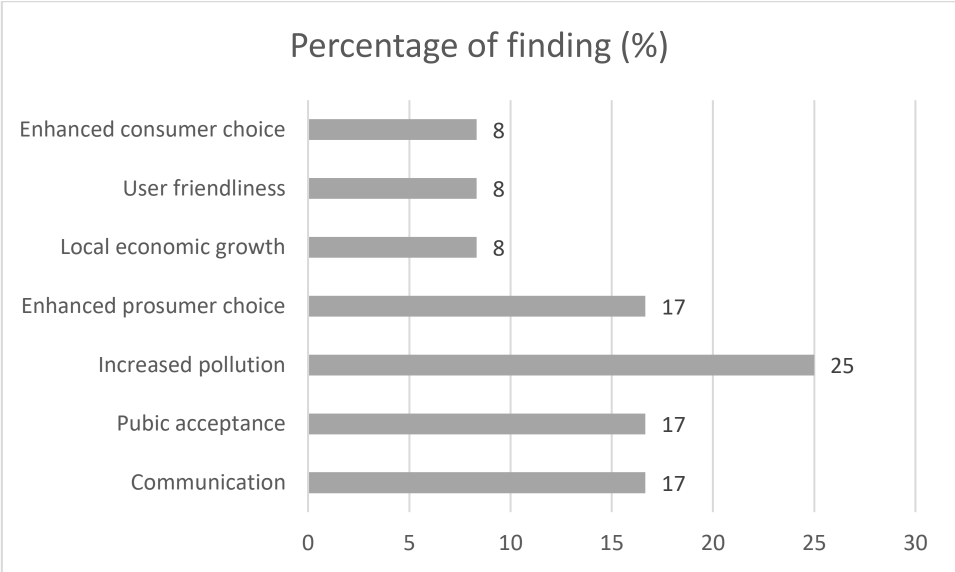

Figure 20. Social challenges (percentage of finding %)

Figure 20. shows social challenges. The following key social challenges are noted: increased pollution, enhanced prosumer choice, public acceptance, communication, enhanced consumer choice, user friendliness and local economic growth.

Results show that increased pollution is the greatest social challenge. The blockchain technology demands a lot of electricity and that causes greenhouse gas emissions and pollution. In addition, mining causes noise and other impacts in nearby areas where mining takes place.

The second greatest social challenges are related to enhanced prosumer choice, public acceptance, and communication. The enhanced prosumer choice leads to energy companies needing more information about their customers in real time to be able to provide useful personalized information to them. This same applies to the enhanced consumer choice. The public acceptance depends on several reasons such as massive adoption, lack of expertise on blockchain technology and lack of trust among users. What comes to communication, the communication between separate blockchains do not work. In addition, there is no standard that enables communication between different networks. (Brown, 2021).

According to the survey the third greatest social challenges are user friendliness and local economic growth. There exist interfaces for blockchain ledgers that are complex form adoption and specific areas like user experience (UX), system efficiency and lack of blockchain protocols. The local economic growth can be driven by blockchain, but it demands clear policies and at the moment there is a lack of them.

4.3.4 Environmental

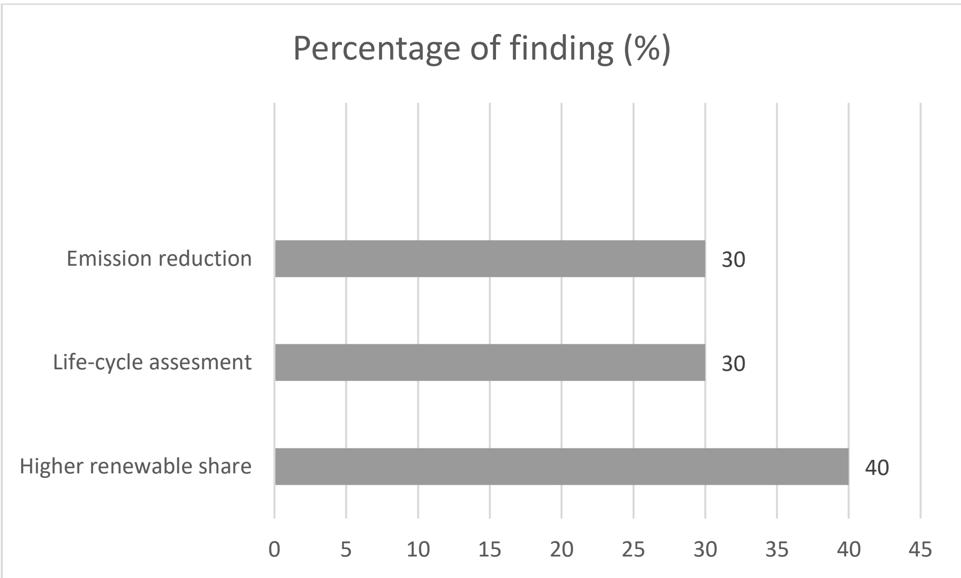

Figure 21. Environmental challenges (percentage of finding %)

Figure 21. shows 3 environmental challenges. The following key environmental challenges are noted: higher renewable share, emission reduction and life-cycle assessment.

The greatest environmental challenge is higher renewable share. The higher renewable share means that there is increased flexibility and stability requirements that blockchain technology must overcome.

According to the survey the second greatest environmental challenges are emission reduction and life-cycle assessment. When there is a wide use of the internet of things (IoT) devices, life-cycle assessment faces big data issues and there will be a storage problem which is a challenge (Zhang, A. et al., 2020 , p.8). There are several barriers such as scalability and skills shortage, system integration and regulatory concerns preventing an extensive maturity of blockchain solution utilization for carbon markets and that way it constructs a challenge for an emission reduction.

4.3.5 Institutional

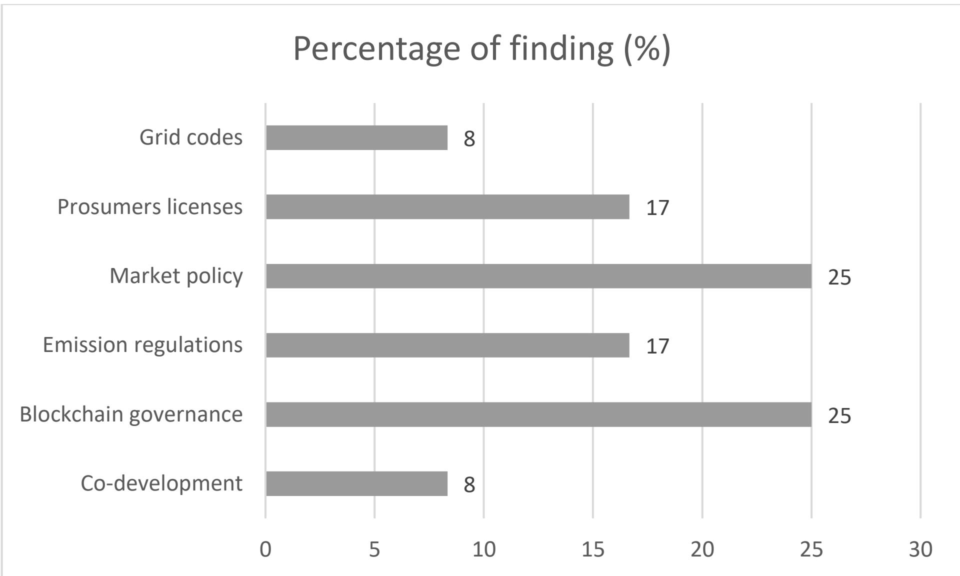

Figure 22. Institutional challenges (percentage of finding %)

Figure 22. shows 6 institutional challenges. The following key institutional challenges are noted: market policy, blockchain governance, prosumers licenses, emission regulations, grid codes and co-development.

The greatest institutional challenges forms market policy and blockchain governance. Market policies can be hard to change and those must serve their purposes over extended periods of time. That means that there comes risk that policy rushes become quickly outdated. According to Rikken et al. (2019, p. 409) there are several challenges in the domain of blockchain governance per stage and per layer. They state that van Deventer et al. (2017, p.4) state that a make-or-buy decision is a challenge for organisations when they are planning to establish applications or services on a blockchain. This has an influence on the governance of all other layers. In the design phase lack of peer review is also a challenge. The challenge in the operation stage is related to if it requires a mixture of manual and automated decisions. In the domain of the evolvement stage, the biggest challenge is a lack of research and experiment. (Rikken et al., 2019, p. 409). The infrastructure layer has many governance challenges and permissionless public blockchains have them a lot. Those blockchains that are not controlled by one organization have the challenge of how to govern them. There are also some common challenges that can be recognized. (Rikken et al., 2019, p. 410). According to Rikken et al., (2019, p.411) in the domain of application layer several challenges can be identified per type of application.

According to the survey the second greatest institutional challenges are related to prosumers licenses, and emissions regulations. To be able to supply the energy to the consumer a license is required, and this causes remarkable costs for prosumers. One challenge related to emission regulations is the weakness in the internet security of Emissions Trading Registries, which is exposed by criminals to steal emission allowances. Because weak regulatory oversight emission allowances can be mined (Braden, 2019, p. 34).

Third greatest institutional challenge is grid codes and co-development. Grid code requirements are constantly under change and becoming more and more demanding. This makes compliance a real challenge (DNV, 2022). Co-development of blockchain for global markets demands research and development and multidisciplinary teams since there exists challenges that must compete. New existing technologies must be locally adapted for new countries. (Ghosh et al., 2022).

4.4 Potential use cases of blockchain technology in Nordic energy markets and in the renewable energy sector

Not many potential use cases had been identified, instead advantages that can be reached with the help of blockchain technology and potential use cases had been identified. Also concerns towards this technology had been identified.

First, use cases are introduced:

- Guarantees of origin (GO), Renewable energy certificates
- Flexibility such as FCR-D, FFR, + other forms of energy trading
- Supply chains, waste management
- Work order management
- IoT authentication
- Asset registry
- Automatic energy bidding for small volumes

“New models and forms of business, such as distributed energy, energy storage and electric vehicle applications, smart energy use and value-added services, green energy trading, and big data service applications, have been accelerated. Global energy development is shifting from "resource generation" to "technology generation", and from traditional development energy technology to green energy technology.”

“Energy contracts between any party and about any actions: from supplying to consuming, gathering valid and truthful data.”

“Arguably you could possibly set up a system where it would be possible to bring the green energy certificate market to the public by making each certificate available on the blockchain. Where a business then would be able to point to their amount of tokens of green energy certificates to validate that they actually have made sufficient investments into green energy, but that seems arbitrary and backwards considering how the current system works."

Then, advantages of blockchain technology are presented.

"Blockchain can provide a trust mechanism and has the potential to change the financial infrastructure. All kinds of financial assets, such as equity, bonds, notes, warehouse receipts, fund shares, etc., can be integrated into the blockchain technology system and become digital assets on the chain, which can be stored, transferred, and traded on the blockchain."

"Decentralization, permanence, and anonymity. User trust in digital systems is built not by a central authority but by protocols, cryptography, and computer code."

"Blockchain technology is valuable, unique, decentralized, and irreplaceable."

"Simplify processes, infrastructure construction and improve operational efficiency."

Then, reasons are presented why potential use cases were not identified.

"Blockchain is not familiar to me."

"Not aware of any!"

The results also showed concerns that blockchain is useless.

"Trading fees or market prices are not a problem that needs solving. Hence, limited potential for blockchains. Plus, on real-time markets TSO is the single buyer, how to use blockchains then?"

“In a perfectly static world without corporation fusions, reorganisations, and no need for a dynamic GDPR regulation, this could be interesting and a viable way forward, now we have so many regulations and responsibilities that systems and logic vs benefits are not in balance for us. Its too much money for too little gain and a lot of confusion.”

“Customers are responsible for customer data; their part of facility data and we are responsible for our facility data. The goal is for AI to support optimized maintenance work.”

“In almost all energy cases, including microgrids, there is a need for a centralised controller to make sure that the common grid connection isn't violated and that local energy transfer between two points in the electricity grid is physically possible (not always certain depending on the load of surrounding cables at the time). This, together with the accountability towards the central grid connection and the central grid control (ultimately SvK here), then requires a central control and connection point for the transaction which makes most of the use of blockchain unnecessary. Individual transactions in e.g., a microgrid could be tracked with blockchains, but since there are so many other aspects that require central control and accountability there's really no point in having the blockchain as well.”

“I've tried to come up with some ideas on where blockchain technology could solve a problem in the sector but it's hard to realistically see a greater good from my limited point of perspective.”

“The reason is that we have not identified any potential use cases. There is no real need for blockchains. Current solutions are fine.”

5 Discussion

In this chapter, the results are discussed. The results answer the set research question. Finally, the limitations of the research and contributions are discussed.

5.1 How can blockchain be utilized in Nordic energy markets and in the renewable energy sector?

The aim of this study was to find out how blockchain can be utilized in Nordic energy markets and in the renewable energy sector. A research question was formed based on the research problem. The research area was the energy sector of the Nordic countries.

The results showed that blockchain technology can be utilized in many ways in Nordic energy markets and in the renewable energy sector. In addition, several opportunities and challenges were found. Although blockchain technology has many good sides, there are still things that need confirmation so that the technology can be implemented for wider use. However, several companies have plans for implementation of blockchain.

According to the survey, there seems to be a lack of knowledge about blockchain technology in the Nordic energy market. To beat this challenge there should first be more training related to blockchain technology. Secondly it would be preferable that big companies with small projects first would try to find solutions for the energy sector thereby getting attention to this technology and when they are successful move on to larger projects. Eventually decision-makers have the power how this emerging technology will be implemented in the energy industry. Then, if we talk about the adoption of the blockchain technology, it will probably be influenced by business law, regulations, and company cultures. The lack of regulation restricts companies from investing in blockchain technology. Incompetent regulation increases the risks for companies.

Despite several challenges associated with blockchain technology there exist several opportunities. Blockchain technology could bring several technological improvements, several consumer-related improvements, improvement for prosumers, in addition improve competition in the Nordic energy market and several social, environmental, and institutional improvements. The research revealed potential use cases and advantages of blockchain technology, and concerns.

The important findings of the research were produced by a qualitative survey conducted for several stakeholders. This master's thesis shows that blockchain is a promising technology in the Nordic energy market and in the renewable energy sector, but several challenges and bottlenecks exist to achieve market penetration. In addition, the results show what kind of use cases there exist in the context of blockchain. The mainstream adoption of this emerging technology needs several clarifications, and additional research, projects, and collaborations will be the trendsetters if blockchain technology can reach its full capabilities. Based on the findings, it can be stated that Andoni et al. (2019) discuss blockchain key challenges and future scenarios well in their research.

Andoni et al. (2019, p. 152) state that PwC's report argues that blockchain has the possibilities to change the present energy market structures although there are several barriers and technical challenges.

Energy systems are critical infrastructure, which is why security is a critical issue in the context of blockchain. Blockchain technology can reduce costs by bypassing intermediaries, but the challenge is the high cost of blockchain system development. The most extraordinary challenges in the adoption of blockchain technology are the lack of regulations and legal barriers. Blockchain technology has also an image problem due to the linkage to cryptocurrencies such as Bitcoin. A negative image of cryptocurrencies is coming from the criminal world where hackers use blockchain technology for questionable activities. However, blockchain reputation might become better over time, when blockchain has been adopted more widely.

One challenge is that there is a shortage of competent people with knowledge and the ability to apply blockchain technology in the electricity sector.

In order to restrain climate change, strategic planning is needed, at the same time public regulation sets more precise requirements for operations, and the importance of information security is emphasized in securing smart electrical systems. The currently prevailing energy crisis challenges energy and grid companies, and consumers also.

The biggest problem with using blockchain in the energy sector might be the person himself. It is very laborious to make people aware of this technology and then to get them to work towards a common vision. A golden recipe should be found somewhere.

5.2 Contribution of findings

This chapter presents the contributions which this study has to the blockchain technology in the Nordic energy market and in the renewable energy sector. When the topic is new and there is no earlier research on it, exploratory research is conducted.

Typically survey research includes large population-based data collection. The goal of this research was to get an extensive sample answer from respondents considerably quickly.

This research presents the opportunities and challenges of blockchain technology in the Nordic energy market and in the renewable energy sector. Also, several use cases are introduced. In addition, the conducted study shows how blockchain can be utilized in the Nordic energy markets and in the renewable energy sector.

The research brought a lot of new information. According to the study conducted, blockchain technology is not yet widely used in the Nordic countries, but it has the image of a game changer in the energy sector. The results also showed concerns about blockchain technology. Blockchain technology is not seen as helping the problems that the Nordic energy market has.

5.3 Limitations

There were several limitations identified such as the researcher conducting the study, data analysis, earlier research as well as research methods which affected the plausibility of the research. The researcher's competence and experience are limitations of this research. The researcher has no previous background in conducting this kind of research, in addition, her knowledge of blockchains and energy markets is very limited. Additionally, as the number of responses remained small, no statistical analysis could be performed. One limitation of the research is also earlier research, since there is a lack of applying blockchain technology in the Nordics. There is a lot of research on the blockchain itself, as well as on the Nordic energy market and renewable energy sector. The theoretical part could however be combined well from these earlier research. As research was implemented with a survey, one limitation was to obtain respondents' answers. Despite these limitations the conducted study is still seen to be giving relevant answers to the set research question.

6 Summary and conclusion

This chapter summarizes this Masters' Thesis. The research goal of this thesis was to find out how blockchain technology can advance and improve the Nordic energy market and the renewable energy sector. Three auxiliary questions were prepared to support this.

First, this Masters' Thesis introduced the theory part. Introduction is presented in Chapter 1. and the theory part is presented in Chapter 2. This included sub-chapters of Blockchain technology, Energy markets in Nordics, Renewable energy sector and Summary of the literature and market review. Chapter 3. includes a presentation of the research method including presentation of data collection method and data analysis method.

Then, the empirical part was introduced in Chapter 4. It included a chapter about how blockchain technology can advance and improve the Nordic energy market and the renewable energy sector. Opportunities, challenges, and potential use cases were also presented. The search results were discussed in Chapter 5. The conclusion of this Masters' thesis is presented in Chapter 6.

The conclusion of this Masters' thesis includes several topics that were found to potentially advance and improve the Nordic energy market and the renewable energy sector. Although blockchain technology is not currently widely used in the Nordic countries, it is worth continuing to be researched. Further, research could be done more deeply by interviewing the experts who have good knowledge about blockchain technology and the Nordic energy market. However, blockchain technology can change the Nordic renewable energy sector in several ways.

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