AALBORG UNIVERSITY
STUDENT REPORT

MASTER THESIS PILOT PROJECT

Blockchain beyond its hype:

validity of blockchain utilization in providing peer-to-peer electricity trading service

June 2019

AALBORG UNIVERSITY
STUDENT REPORT

Fourth semester at the
Technical Faculty of IT and Design
Sustainable Energy Planning and Managment
Rendsburggade 14
9000 Aalborg

Title:

Pilot project on validity of blockchain utilization for peer-to-peer electricity trading

Project:

Master thesis

Project period:

February 2019 - June 2019

Author:

Anna Maria Kozubal

Supervisor:

Frede Hvelplund

Pages (excl. appendices): 58
Pages (incl. appendices): 76
Appendices: 7
Deadline: 07-06-2019

Abstract:

Current trends of decarbonization and decentralization of the energy sector drive a shift towards implementation of distributed renewable energy sources. This expansion causes challenges for energy systems, mostly due to limited flexibility in production and supply of energy coming from small-scale renewables. One of the ways to overcome these challenges is digitization which is said to support integration of these production units into efficient systems.
At the same time blockchain is getting a lot of attention in the energy sector. It is associated with high potential to foster the aforementioned digitization by being introduced in several applications. Throughout many of them, the most popular one is operating trading platforms for peer-to-peer electricity systems.
The aim of this report is to investigate if blockchain characteristics are able to fulfill needs faced by peer-to-peer electricity trading systems. The main focus here lays in two aspects: environmental by examining if technology can lead to reduction of fossil fuel consumption and thus carbon footprint; and economic by checking if it can be operated with low costs for end-users of these trading systems.

Preface

This Master thesis project is written as a conclusion of the 2-year Master's program of Sustainable Energy Planning and Management at Aalborg University. The collective case study which is a subject of elaboration in this Master thesis is partly based on the project developed during the third semester of the degree while doing internship at EUROSOLAR – The European Association for Renewable Energy in Bonn, Germany.

After a consultation with supervisor of this thesis Professor Frede Hvelplund, it has been decided to call it as a "pilot project". It is due to the fact that topic of the thesis is recognized as new, thus very challenging. There occur therefore a lot of uncertainties about the topic and difficulties in accessing data necessary to undertake all the calculation required to answer the research question that has been posed. Therefore in order to keep everything clear, summaries of uncertainties and difficulties faced is Chapters 1, 5 and 6 are given in the very ends of these chapters.

In the light of previous, the purpose of this Master thesis is to outline a problem, do a mini analysis and prepare a background for additional analyses which should be done to entirely solve the problem.

Moreover, I would like to thank my supervisor for proper guidance through the semester, especially during the last couple of weeks. His help was extremely important when taking into account all objections related to the topic. I would also like to express my gratitude to: Francisco Boshell, Sean Ratka and Arina Anisie working on behalf of International Renewable Energy Agency, Dr Elisabeth Kellerer from E.ON, representatives of Power Ledger and ME SOLshare, respectively Steve Bedwell and Neel Tamhane as well as Barend de Bruin from SAS for being available for interviews. Many thanks to Maciej Ziółkowski, Bartosz Trzciński and Krystian Kowalewski for providing me with relevant consultancy about blockchain.

Reading Guide

Figures and tables are numbered according to the chapter of their appearance, e.g. the second figure in Chapter 3, is numbered 3.2.

The source notes appear in brackets in the report. These notes contain author's surname or the website if no author is signed and year of publication. They refer to the complete source list in the end of the report.

When it comes to numbers, dots are used to separate the integer from the fraction. This means that if willing to write two and a half it looks as following: 2.5. On the other hand, comas are used to separate thousands in big numbers, e.g. two thousands and five hundreds is going to be written accordingly: 2,500.

Appendices are placed at the end of the report and are denoted A, B and so forth.

Report overview

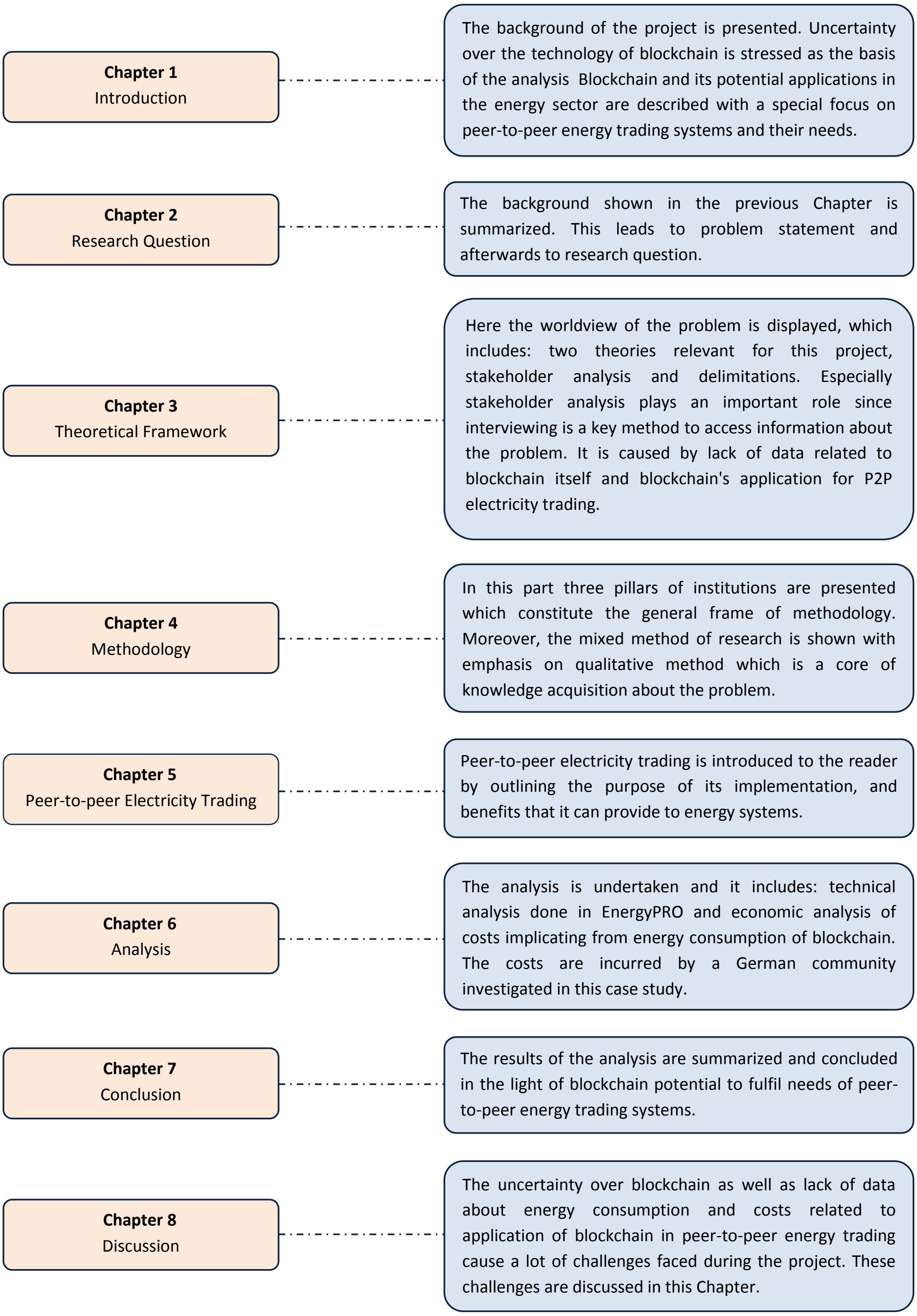

Figure 1. Overview of report and contents of the chapters included in the report

Nomenclature

Abbreviations

ct	Eurocent
DER	Distributed Energy Resource
DSO	Distribution System Operator
FiT	Feed-in Tariff
IBM	International Business Machines Corporation
IoT	Internet-of-Things
IRENA	International Renewable Energy Agency
P2P	Peer-to-peer
PoA	Proof of Authority
PoS	Proof of Stake
POV	Point of view
PoW	Proof of Work
PV	Photovoltaic
RE	Renewable energy
SAS	Statistical Analysis System Institute
TSO	Transmission System Operator
tx	Transaction
Wh	Watt-hour

Table of contents

Introduction 1

1.1 Basic situation for my analysis

According to the latest report of The Intergovernmental Panel on Climate Change [2018], the global warming of 1,5 Celsius degrees compared to temperature levels from the pre-industrial era can significantly impact the condition of our planet. Since energetics is mostly responsible for such an event, there is a huge necessity for improvement in this particular sector. It can be done for example by implementing concrete energy policies which are providing favourable conditions for energy transitions worldwide. According to International Renewable Energy Agency [2019] there are several ways to accelerate transitions towards clean energy supply, but the main focus lays in three aspects: decarbonization, decentralization and digitization.

While decarbonization and decentralization directly lead to implementation of more variable renewables, digitization enables for their integration into efficient energy systems [International Renewable Energy Agency, 2019]. Indeed, the expansion of distributed Renewable Energy (RE) sources, such as solar, is causing a lot of challenges for existing systems, mainly due to limited flexibility in production and reliability in supply [Stram, 2016]. In response to that challenges several solution are proposed aiming on providing optimal balancing of energy supply, e.g. better forecasting of energy production [Madsen, 2016], introduction of sector coupling [Parra et al., 2017] or diffusion of prosumerism and peer-to-peer (P2P) energy trading [Liua et al., 2019].

In recent years several digital innovations in energy sector have emerged the market aiming on enabling new technologies, creating new business models but most importantly improving systems operation which is required when facing the expansion of RE. Approximately 200 trial-projects have been created for implementation of these innovations in recent years [International Renewable Energy Agency, 2019]. Especially the power sector is experiencing significant growth in global investments in digital infrastructure, which has been constantly increasing by more than 20 % annually since 2014 [World Energy Council, 2018b].

One of the emerging innovations is utilization of blockchain in energy solutions, such as P2P energy trading. As estimated by World Energy Council [2018b] up to 300 million dollars were invested in over 100 energy-related blockchain applications so far. While multiple start-ups appeared at the market, companies with longstanding experience, such as General Electric, Siemens, Engie or Shell, also decided to invest in the technology.

The blockchain technology which is mentioned in the previous Paragraph can be briefly explained as a decentralized and distributed database that works in an open source model of a P2P network, does not contain any centralized data storage area and is used as a bookkeeping system to register transactions which are made among participants of this network [Atlamab and Willsa, 2018]. All the aspects of the technology are profoundly described in Paragraph 1.3.2.

1.2 Uncertainty as a base of my analysis

The interest in blockchain in the energy sector is justified due to its potential to revolutionise the way transactions are proceeded between energy companies and end users or end users interacting directly, which thus drives a shift from a centralised structure towards decentralised systems. According to the latest World Energy Issues Map shown in Figure 1.1 which is a result of interviewing 39 energy leaders by World Energy Council [2018c], blockchain together with Internet-of-Things (IoT) has been identified as one of the most influential applications within the digitalisation elements in the energy sector. At the same time, it is associated with a high uncertainty. This can be explained that energy leaders think that technology might have a big impact on digitalisation of the energy sector, however they are not sure how it can be exactly utilized.

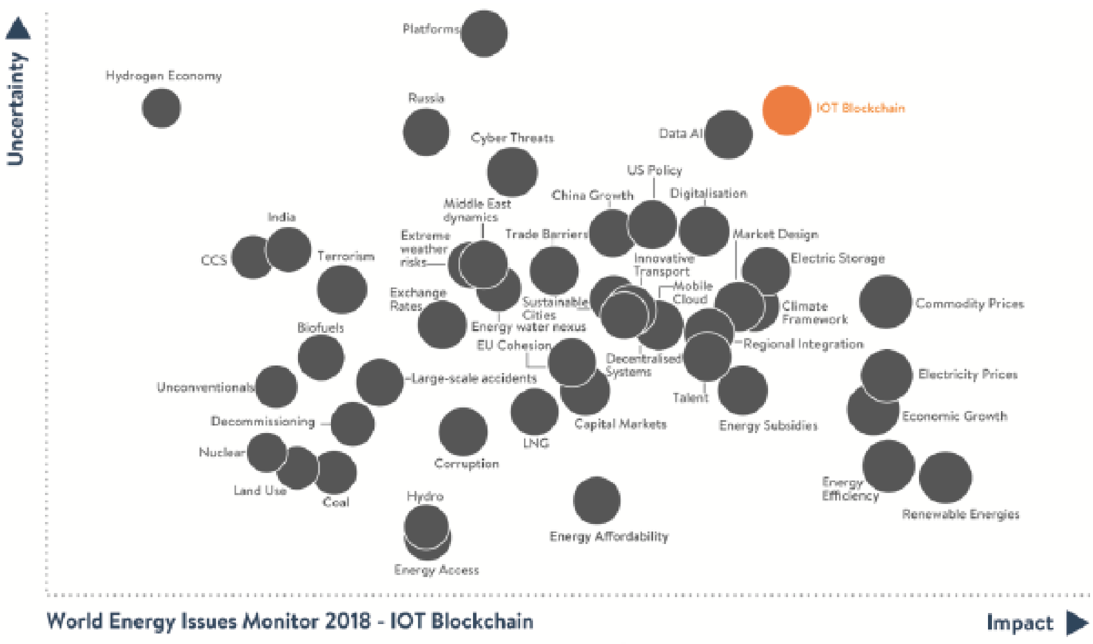

Figure 1.1. World Energy Issues Monitor Map [World Energy Council, 2018c]

It is thus summarized that blockchain is accompanied by high expectations and huge uncertainties at the same time. These uncertainties can be caused by relatively low maturity of the technology which as displayed in Figure 1.2 is ranked in halfway between Stage 2 *Not Mature* and Stage 3 *Early Adaptors Phase*. It might be linked to limited experience in implementation of this technology [Boshell, 2019; Ratka, 2019] as well as other challenges related to blockchain, such as feasibility, scalability or regulation [World Energy Council, 2018b].

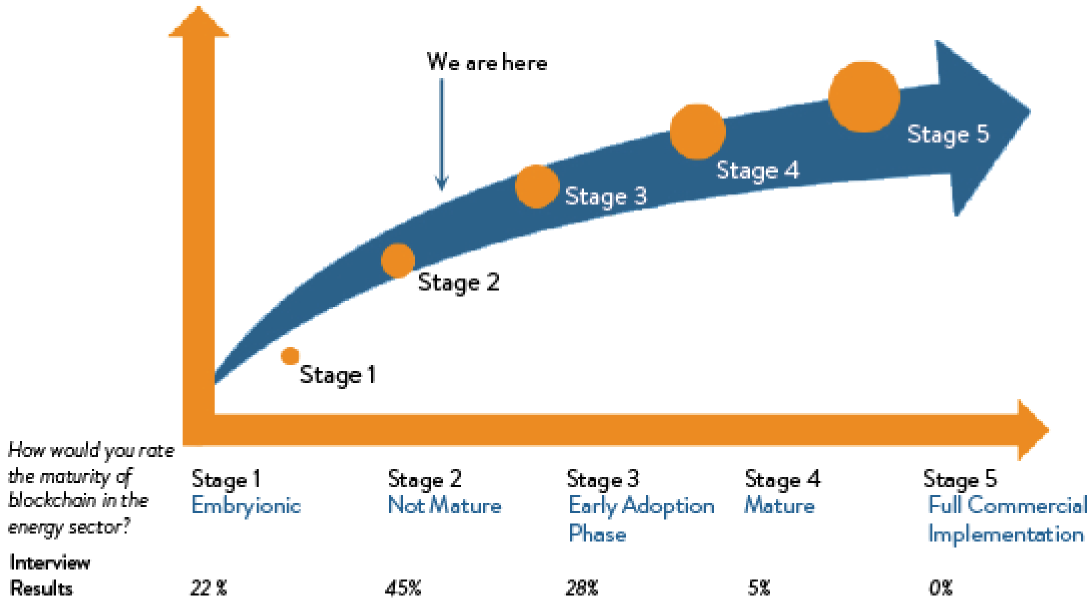

Figure 1.2. Blockchain Maturity Map [World Energy Council, 2018b]

Nonetheless, it is unquestionable that blockchain technology is getting a lot of attention recently. Besides the advantages that its utilization is supposed to provide for energy systems and their users which are described in Paragraph 1.3.3, blockchain provides a lot of challenges in its operation. Among others, the technology requires amounts of electricity, mostly due to high demand of computational power needed for the purpose of authorisation of transactions (explained thoroughly in Paragraph 1.3.2) [Tamhane, 2019; de Bruin, 2019]. As it has been estimated, its electricity consumption has already achieved a level of Swiss power system and a carbon footprint of over 30,000 kt of CO_2 annually [Barnard, 2018]. At the same time, since 2017 a lot of projects aiming on implementation of alternative blockchain technologies which are less energy intensive are being developed [World Energy Council, 2018a].

All together arises a lot of doubts. Some are huge fans of blockchain and some stay a bit more sceptical about the technology. While Creyts [2018] from Rocky Mountain Institute compares blockchain potential to Internet revolution in '90s, Dowling [2018] from The Faraday Grid describes it as a "solution looking for a problem".

The following paragraphs are going to provide in-depth information about blockchain technology, its characteristics and possible applications in the energy sector with a special focus on P2P energy trading.

1.3 What is blockchain?

1.3.1 A glimpse on blockchain history

The invention of blockchain technology was introduced to the world in 2008 by Satoshi Nakamoto - a person or a group of people whose personalities remain still unknown [Nace, 2019]. Since then the popularity of blockchain in several applications is continuously growing. It became especially widespread in finance, mainly by utilization of cryptocurrencies such as Bitcoin, Ethereum or Litecoin. It has been estimated that over 2000 virtual currencies exist currently at the market and their main purpose is enabling for trading of various assets [CoinMarketCap, 2019].

Throughout cryptocurrencies, one of them is getting a special attention. According to Mourdoukoutas [2018], if owning 10,000 in March 2018, approximately 3 out of 4 young people would invest in Bitcoin. The currency was invented in 2008 as the first application of blockchain and the original idea standing behind it was to simplify online payments by making them quicker and cheaper [Nace, 2019]. Bitcoin got esteemed in 2017 when its price jumped from around 500 U.S. dollars in summer 2016 to approximately 5,000 U.S. dollars in mid 2017 [Nace, 2019] and finally achieved record-high level of around 19,000 U.S. in December 2017 [Markets Insider, 2019]. However, since then its price has significantly decreased [Markets Insider, 2019] which might be related to lack of credibility for blockchain (see Figure 1.1 again).

Nonetheless, taking into account how quickly and widely has utilization of blockchain conquered the world of finance and how much popularity it is getting in the energy sector, a following question arises: can this technology find reasonable application in the world of energy which has so much different needs than world of finance? It is said that blockchain owns the phenomenon to its unique characteristics, which are a subject of the following paragraph and are analysed with a focus on the energy sector.

1.3.2 What stands behind the technology of blockchain

As it has been already said, blockchain is a distributed virtual ledger which enables for direct transactions between participants of a network. The idea of blockchain as a basis for P2P trading without any intermediary in-between the peers is thus displayed in Figure 1.3 below.

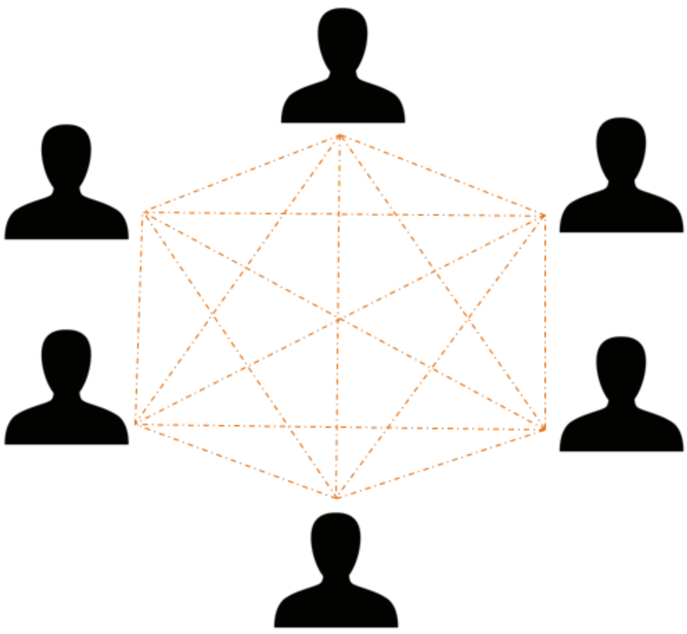

Figure 1.3. Blockchain as a virtual ledger for P2P transactions

As shown above, participating users of blockchain-based virtual platform are able to proceed transaction directly between each other. Thus, any centralized structure does not exist, such as banks as intermediary institutions for money transfer when talking about finance for instance. [Andoni et al., 2019]

Figure 1.4 below displays in 6 steps the way of blockchain operation on a given example of procedure of a P2P transaction.

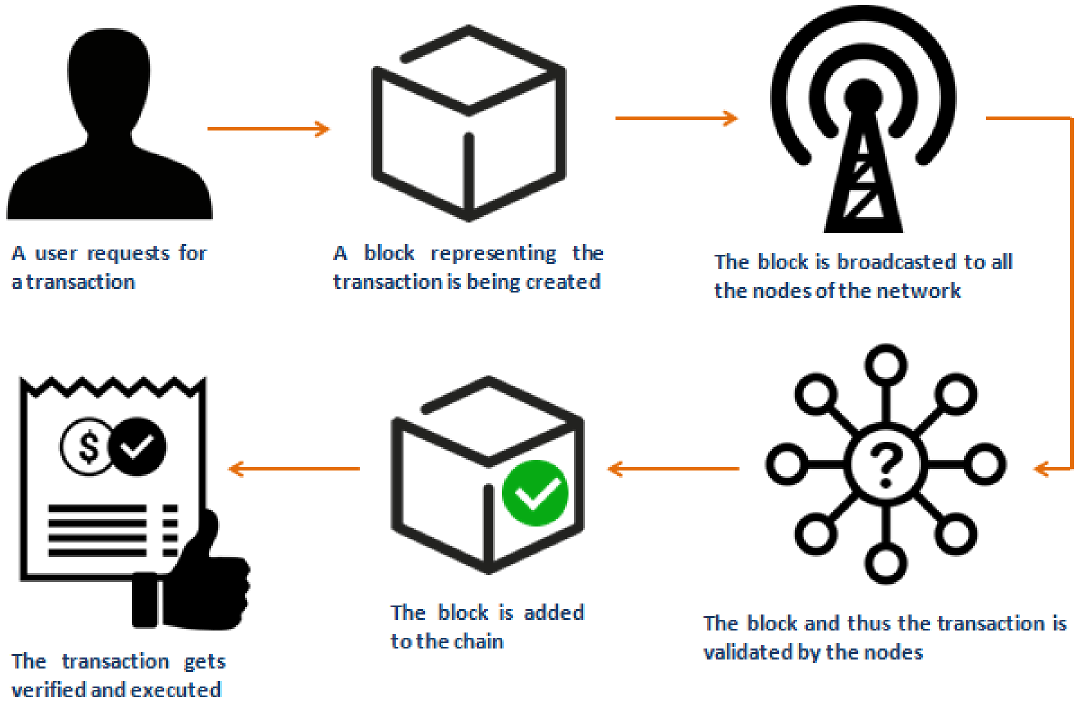

Figure 1.4. A step-by-step view how blockchain works [Dhar, 2018]

Step 1: A user requests for a transaction

Any user can request for a transaction via the blockchain-based platform at any time. The transaction are most often aiming on trading assets, which could be buying or selling electricity for example. Each transaction between participants has a completely unique number which is generated from a mathematical equation, so-called hash function. Utilization of this function enables for mapping data of any size into data of a fixed size. If the function is reliable and secure, the mapped data is assigned to an output in the form of a purely random string. [Konstantopoulos, 2017]

Step 2: A block representing the transaction is being created

Data about a transaction, i.a. about sender and receiver and information about the hash function used to map the data with specific hash which is unique for every block and can be compared to a fingerprint are aggregated into a larger formation called block. Any block also contains information about hash number of the block created just before. [Decuyper, 2017]

Foregoing is summarized in Figure 1.5 herein.

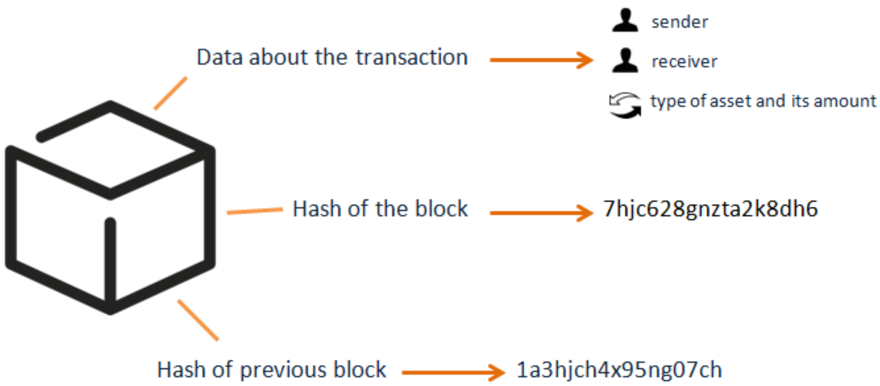

Figure 1.5. Data implicit in a block

Step 3: The block is broadcasted to all the nodes of the network

The block is visible to all participating users of the network thanks to the distributed ledger. It is also important to mention that any ledger can be either public or private. A public blockchain ledger is available for everyone, meaning that everyone can join the network. In contrary, becoming a member of a private blockchain ledger requires an invitation and afterwards a permission which must be validated by network authority. [Jayachandran, 2017]

Step 4: The block and thus the transaction is validated by the nodes

No matter what is the type or purpose of a virtual network, transactions that are executed within this network need to be authorised. It can happen in manifold ways. Throughout tens of them, the most popular ones are within rules called Proof of Work (PoW) and Proof of Stake (PoS). [Konstantopoulos, 2017]

When explaining PoW, validators of transactions, so-called miners, are competing with each other for the possibility to authorise a transaction. They do so by solving a cryptographic sequence, which enables them to add a new block to the chain. The successful miner is selected based on the computational work required to execute the transaction, which is known as *proof of work*, thus the name. When a miner succeeds, the solution is transmitted to the network, the miner is awarded in a financial way and other miners start working on other transaction. [Andoni et al., 2019]

The most significant flaw of PoW is the demand for high amount of computational power so miners are actually able to solve the cryptographic sequence [Konstantopoulos, 2017]. Moreover, the time needed to execute transactions within PoW is relatively long - one block can be created only once every 10 minutes [Andoni et al., 2019].

The alternative system is PoS where validators are selected in a deterministic way and the likelihood of being chosen depends on the size of his *stake* in the system. The *stake* is defined as the wealth of the validator e.g. the amount of cryptocurrency held in deposit or another type of commodity. This solution is resulting in faster blockchains that moreover have much lower electricity consumption. This consensus has some disadvantages as well though. Obviously there occurs a risk that the "wealthiest" people (meaning the once with the highest stake) participating in the network may not have the best intentions while deciding if transaction should be validated. [Andoni et al., 2019]

Lately a new consensus emerged and it sounds very interesting. Proof of Authority (PoA) assumes that not every participant of a network can be capable to authorise transactions. If willing to be a validator, user can request for that but has to be accepted by other authorised node. Validators are carrying out the process of validation within a standalone software. The consensus of PoA origins from PoS, therefore it also enables for faster transactions and consumes reduced amounts of power. However, it does not entirely solving the problem of high energy consumption - while a transaction is being validated some power is spent on verification of the nodes. [Achim, 2019]

Step 5: The block is added to the chain

When one block is full of data about specific transaction, another one is being created on a specific time-stamp and then linked to the previous block. They are inseparably connected due to the fact that every block contains information about hash of the previous one. Thus they form a characteristic chain of records that determines the sequencing order of events. [Andoni et al., 2019]

Step 6: The transaction gets verified and executed

The user is now eligible to trade the asset that was requested.

1.3.3 Advantages and disadvantages of blockchain

Blockchain is said to provide several advantages when it comes to its utilization in applications in different sectors. Based on interviews with experts as well as literature research the most crucial ones are described above:

- **Transparency.** As described in Paragraph 1.3.2, all the transactions, their order and changes between peer-parties are saved in a ledger, which is distributed and available for all the using participants, thus the whole system is very transparent in its structure. Moreover, an administrator of a system, if existing, is not able to make any changes in a ledger because of the immutable sequence of blocks [Kozar, 2019].
- **Security.** According to representatives from IRENA, security is one of the most crucial advantages of blockchain utilization and it emerges through a cryptographic scramble of the technology [Ratka, 2019; Boshell, 2019].
- **Ability to create and operate distributed nets.** This characteristic has been pointed out as a very useful for spurring increased investments in small-scale projects, e.g. in developing countries, according to Ratka [2019], Boshell [2019] and Peter [2018].
- **Trustworthiness.** According to Kellerer [2019] who works at E.ON, ability to digitally foster trust between self-serving parties is a key characteristics of blockchain, regardless the sector it is applied to. As she argues next, creating a trustworthy environment is especially important when peer-to-peer is understood literally, i.e. from peer to peer without a platform in-between.
- **Tamper-proofiness**, due to the fact that the operation of a system based on blockchain is authorised by rules such as PoW or PoS (described in Paragraph 1.3.2).

Moreover, the integrity of a blockchain network can be also ensured by a system of incentives or rewards for a fair behaviour and collaboration of its participants which is motivating for being above-board [Konstantopoulos, 2017].

Even though blockchain seems to provide a lot of benefits for systems that it is implemented to, it cannot be determined as flawless. Some of the disadvantages of blockchain encountered during the project are described hereunder:

- **Low cost-effectiveness** which is related to management of distributed ledgers, but also to long and challenging implementation of the technology [World Energy Council, 2018a]. It is also related to high costs of blockchain implementation due to high bills for power required for mining [Barnard, 2018] as well as expensive human resources since the list of blockchain experts is shortened [de Bruin, 2019].
- **High energy consumption.** As described above, blockchain utilization requires relatively big amounts of electricity to be operated. This statement can be backed up according to the newest report *Quantification of energy and carbon costs for mining cryptocurrencies* evolved by researchers from the Oak Ridge Institute in Cincinnati, Ohio, energy needed for mining of a one-dollar-worth amount of Bitcoin is over twice as high as energy required while mining the same-worth amount of real metals, such as copper, gold or silver. Authors of the aforementioned research concludes also that 17 MJ of energy to mine is needed to produce a one dollar worth's bitcoins, while at the same time, only 5 MJ of energy need to be used to produce gold worth as much [Krause and Tolaymat, 2018]. This high energy consumption implicates from the demand for the process of mining since Bitcoin is base don PoW.
- **Hard to implement**, which is due to a very low level of knowledge about blockchain (see Figure 1.2 one more time) as well as the technology structure deviating from the well-known standards [Ratka, 2019; Boshell, 2019].

1.4 How can blockchain be utilized in the energy sector

Based on the research as well as interviews with energy and blockchain experts, the most popular and interesting ideas of blockchain utilization in the energy sector are described below:

- **Smart contracts**, which have already gotten a huge interest in the finance and lately are becoming more popular in the energy sector. A smart contract can be explained as a immutable and distributed program which enables for safe and long term storage of data related to the contract itself as well as interested parties. In case of energy solutions, it most importantly finds application in contracts between energy providers and energy consumers by enabling for controlling and demand-side management of energy consumption. There are several energy companies already investigating implementation of smart contracts, i.a. Tauron, PGE, Energa. [Kozar, 2019]
- **Cryptocurrencies for energy sector**, which in principle aim to support development of clean energy economy by implementation of award systems. There already exist cryptocurrencies intended for energy e.g. SolarCoin which is given to a solar installation owner in exchange for producing 1 MWh of energy coming from this

installation [Sonnet, 2018]. Furthermore, The Sun Exchange from South Africa is a blockchain-based platform which enables their participants to invest in solar cells, which are installed on rooftops in places where the solar potential is the highest, thus mostly in Africa. Potential investors then can earn their profit in local currency or in Bitcoin [Ratka, 2019; Boshell, 2019].

- **Improvement of energy efficiency.** According to Diasr [2018] from the Copenhagen Centre on Energy Efficiency, blockchain can be implemented to improve energy efficiency, e.g. for building up new systems issuing and trading energy assets such as energy conservation certificates. Blockchain can also be a source of crowd funding actions supporting development of energy efficiency. None of these ideas however has found examples in existing projects so far.
- **Establishment of new energy market places**, which enables for P2P energy trading, whereas it is mostly electricity. According to Eggleston [2018] from Australian company Power Ledger which is already involved in the business, it spreads and disseminates the idea of local energy markets which involve citizens in clean energy supply and therefore in energy transitions understood as a switch from centralized scheme to decentralised systems. Even though P2P energy trading is mostly associated to trading electricity between neighboring dwellings, Power Ledger developed solution which enables trading between batteries and electric vehicles. Besides the given example of Power Ledger, there are several other projects which focus on proving P2P energy trading within utilization of blockchain and these are for example: Adger Energi, which provides the service to small communities in Norway [Kozar, 2019] and enerchain - a project which associates various energy companies, such as E.ON, RWE, edp, Vattenfall, Neas Energy and more in P2P energy trading business [Kellerer, 2019].

Thus, there are various ways of implementation blockchain into the energy sector. However, as displayed in Figure 1.6, the most widely-used cases lay in the P2P business. Throughout several applications such as utilization of blockchain in trading systems of emissions or certificates or organizing financial support for energy projects, circa 45% of companies interested in blockchain for energy solutions and interviewed by World Energy Council [2018a] are currently trialling P2P projects which mainly aim to integrate Distributed Energy Resources (DER) and optimize the wear of existing grids.

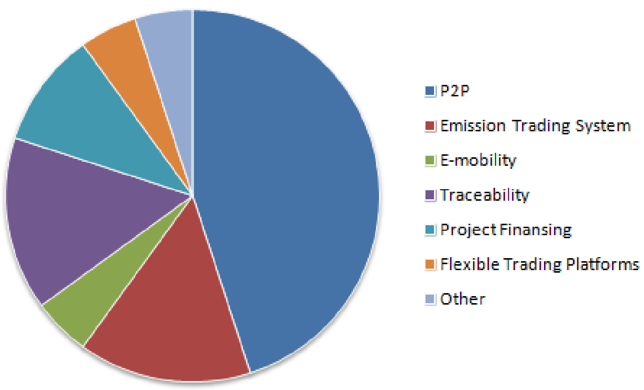

Figure 1.6. Use cases of blockchain in the energy sector [World Energy Council, 2018a]

Indeed, P2P energy trading which is vividly described in Chapter 5 requires specific environment to work properly as a service. It needs a digital system or a trading platform which has characteristics that are described in Figure 1.7. The figure also contains of evaluation on blockchain potential to fulfill these needs and my comments justifying why I think so. Blockchain potential can be rated as: "++" - very high, "+" - relatively high, "+/-" - unclear meaning that at that moment it is hard to define, "-" - low and "- -" - very low.

P2P energy trading needs	Blockchain potential	My comment
Providing solutions which lead to reduction of fossil fuel consumption and thus carbon footprint - P2P marketplaces are mainly introduced to integrate distributed RE sources	+/-	It is hard to decide after the literature research which outlines the issue of blockchain's energy consumption, however still blockchain helps in optimization of energy supply coming from RE
Conducting many transactions at the same time - participants of P2P energy trading tend to trade very frequently small amounts of energy	+	Blockchain can provide desirable solution, however when using the consensus of PoW only one transaction every 10 minutes can be done – that might be not sufficient
Tracing these transactions so it is clear who and how much of energy is sold to whom	++	Blockchain as a distributed ledger is a very good tool for register transaction
P2P platform managed by the trading bodies themselves, without a need to involve an intermediary - such as Distribution System Operator (DSO) to reduce their Operation & Management costs	++	Since blockchain is distributed among participants of a network and does not contain any centralized structure, it is definitely a good solution
Low costs of operation since P2P energy trading aims on providing economic benefits for community members	+/-	Probably blockchain is not the best solution because it is said to be expensive, however no reliable calculation on that has been found

++ Very high + High +/- Unclear - Low -- Very low

Figure 1.7. Needs of P2P energy trading systems vs. potential of blockchain to solve them [Murkin et al., 2016; Hvelplund, 2019]

1.5 Summary of uncertainties in Introduction

What we know	What we do not know
1. Blockchain is a distributed ledger which is able to transparently register transactions. **2.** Blockchain application in the energy sector is getting a lot of interest lately. **3.** The most popular application of blockchain in the energy sector is for P2P energy trading **4.** Blockchain is clearly able to fulfil some of the needs which occur in P2P energy trading and these are: conducting many transactions at the same time, traceability of the transactions and lack of intermediary.	**1.** It is not clear why blockchain is getting so much popularity since a lot of uncertainties are associated with it (see Figure 1.1 again). **2.** It leads to doubts how independent of intermediaries are trading parties, since they have to pay for the service somehow, thus they still might be using their bank accounts. **3.** It is hard to say if blockchain is able to provide a solution for P2P electricity trading which enables for reduction of fossil fuel consumption and thus carbon footprint. **4.** It cannot be stated at the moment if blockchain is cheap enough in its operation for P2P energy trading.

Figure 1.8. Uncertainties about the topic which occurred in Chapter 1

Research question 2

The following part provides a short summary of Chapter 1 which narrows down to the problem formulation. Thereafter, a specific research question is posed in order to evaluate which aspects of the problem are crucial in finding a desired solution.

2.1 Problem formulation

It can be concluded based on information from Chapter 1 that blockchain is getting a lot of attention lately, especially in the finance sector but also in more technology-focused applications like energy. The energy sector is experiencing entry of blockchain in several manners: as a tool enabling for more efficient processing of data such as energy production and consumption which lead to better optimization of it or a digital platform which is supposed to have a potential to answer the challenges appearing with currently strongly evolving shape of marketplaces while energy transitions are happening worldwide.

As it has been analyzed by World Energy Council [2018a], the most popular application of blockchain in the energy sector throughout energy start-ups and longstanding companies interested in the technology is by fostering P2P energy trading, whereas typically the traded type of energy is electricity. That is why the following Master thesis focuses on such a case.

At the same time, implementation of blockchain might raise a lot of questioning apropos its validity. Besides a lot of benefits that blockchain is supposed to provide for decentralized and distributed energy systems, such as security and transparency, it is also said to be very uncertain as an emerging innovation (see Figure 1.1), moreover energy intensive and hence expensive. This might lead to economic issues on the side of energy companies implementing such a solution as well as end users which actively participate in the system.

2.2 Research question followed by sub-questions

In the light of the paradox of blockchain utilization for P2P energy trading, the succeeding research question has been posted:

To what extend is blockchain application for peer-to-peer electricity trading purpose economically viable when taking into account its energy intensity?

which is assisted by sub-questions as below:

1. What kind of benefits can blockchain provide for peer-to-peer electricity trading?
2. How energy intensive is blockchain in application to peer-to-peer electricity trading?

3. How expensive is utilization of blockchain for peer-to-peer electricity trading when taking into account operation costs implicating from its energy consumption?

The sub-questions are here to help in structuring the project. Each sub-question plays a significant role in mapping out a path to answer the research question.

The answer for first sub-question is already outlined in Chapter 1 and then expanded in Chapter 5 while the second and the third question are analysed in Chapter 6. Altogether everything is wrapped up in the conclusion in Chapter 7 and parts of the analysis which were omitted are discussed in Chapter 8.

Theoretical framework 3

The following chapter presents theoretical framework used to fringe the Master thesis by choosing right theories which help in structuring both the research in general and the report as a summary of it. The Theory of Innovation Diffusion and a mix of theories attempting to draft a path between technological innovation and sustainable development are presented in context of blockchain in P2P electricity trading. Thereafter, the macro perspective of the problem is shown and then narrowed down to micro perspective which focuses specifically on the case study. This helps in a proper selection of stakeholders relevant for this project. Whereupon, the stakeholder analysis is carried out in Paragraph 3.2. Its main role is recognizing the most important actors and categorizing them into groups varying by the field of their knowledge and experience. Last but not the least, a short discussion about delimitations of the problem concludes the chapter.

3.1 Theories of science

3.1.1 Theory of Innovation Diffusion

The Theory of Innovation Diffusion is chosen as the leading theory in this project. The theory was developed by Rogers [1983] in 1962 and it is said to be one of the oldest theories in the field of social science. It explains how an idea or a product, which is associated as innovative, diffuses through a specific social system and becomes adopted.

Before digging into crucial aspects of aforementioned theory, there is a need to specify what is understood as *innovative.* While the definition of *innovation* might be hard to put into words, it is also dynamically changing over the times. Skillicorn [2016], Chief Editor, Founder & CEO at Improvides Innovation Consulting, asked 15 innovation experts what does it mean to them. The answers differed diametrically. Some experts emphasized that the core of innovation lays in executing a new idea into a new product, others that it should apply out-of-box way of thinking, still others that it should consist of a viable business model relevant either for its customers as well as the company. Eventually Skillicorn [2016] managed to formulate an ultimate definition of innovation based on these interviews, which is: *"executing an idea which addresses a specific challenge and achieves value for both the company and customer"*.

The theory of Rogers [1983] states that diffusion of innovation causes a lot of uncertainties which imply lack of predictability and of information. As a result, a number of alternative technologies occur to reduce this uncertainty and such an event can motivate for seeking relevant information which drives for a better adoption of the innovation.

According to the theory, any innovation needs a certain uncertainty that it can reduce, which is explained by an example of the innovation of solar panels. Rogers [1983] considers it to be a solution for reducing uncertainty about reliability of energy supply in the future as well as energy costs thereat.

There are four main elements that characterise an innovation diffusion and those are as following:

- characteristic of the innovation itself, which is consisting of 5 attributes of innovation:
  - relative advantage that it can provide
  - compatibility meaning integrity of the innovation and needs of its potential users
  - complexity which describes a level of difficulty over the comprehension of the innovation
  - trialability which is the extend to which innovation can be tested before being adopted
  - observability determining how tangible are results given by the innovation
- the nature of the communication channels where the idea standing behind innovation can be heard out
- the passage of time; according to Rogers [1983] any innovation diffusion is dependent on time in a couple of aspects, i.a. during the decision process over the implementation of innovation
- the social system that innovation diffuses through, since innovation can only occur inside specific social structure. [Rogers, 1983]

3.1.2 Technical innovations vs. sustainable development

Since 1990s more and more intensive focus on environmental aspects has been observed throughout policies all around the world. Thus, terms of *sustainability* and *environmental quality* appeared in the international narration, especially in the context of the energy sector. [Arts and Leroy, 2006]

This can be explained as a result of growing awareness of governing bodies as well as people themselves. As Wijesooriya [2018] noticed, nearly all of the most world-decisive innovations, such as light bulb, car or fossil fuels, that have been enforced during the last 300 years could be evaluated as heavily responsible for environmental issues that our population is facing currently.

In response to that Anadon et al. [2016] are proposing better actions for technological innovations to go along with Goals of Sustainable Development (aforementioned goals were defined by United Nations [2015] and these are: affordable and clean energy, sustainable cities and communities and climate actions among others). According to authors, implementation of technological innovation is a complicated and very individual adoption process that faces a lot of barriers. Moreover, sustainable development in mobilization for technological innovation can be possible only when a cross-sector approach is imposed, including e.g. socio-technical and environmental aspects. However, most importantly Anadon et al. [2016] recognize that existing institutions which are responsible for implementation of technological innovations are not adapted to goals of sustainable development. This is a result of a lack of economic and political force to adjust systems of innovations to such goals.

Proposed solutions for such a diagnosis are as following: establishing of learning channels which enable for cross-sector dialog, improvement of measures focusing on consumers' needs, both from highly developed as well as developing populations and last but not the least, reformation of institutions so technological innovations could be better oriented in the direction of sustainable development. [Anadon et al., 2016]

Taking into account findings of Arts and Leroy [2006], Wijesooriya [2018] and Anadon et al. [2016], it can be concluded that the aspects of sustainable development are often overlooked when introducing an innovation which is caused by the lack of communication between industries and institutions in effective enforcing. They all agree that actions should be taken to change that.

3.1.3 Theories in the context of utilization of blockchain for P2P energy trading

Blockchain is perceived as a groundbreaking innovation [Beck and Müller-Bloch, 2017], also in the application for P2P electricity trading [Andoni et al., 2019]. However, in the view of above, several questions arise: does this solution fit to the definition of innovation provided by Skillicorn [2016]?; does it own the specific characteristics of innovation determined by Rogers [1983], especially potential advantages that its utilization can provide?; does it go along with sustainable development?

Thus, the Theory of Innovation Diffusion is used in this case to uncover if blockchain for P2P electricity trading is able to provide measurable advantages for its users and companies implementing it in the specific social system. On the other hand, theories coping with outlining a connection between technological innovations and sustainable development are helpful to determine if blockchain is the best possible technology for P2P electricity trading when focusing on environmental and economic aspects.

3.2 Stakeholder analysis

Since investigating any innovation is associated with lack of information, interviews play a very important role in achieving knowledge and data. The following Paragraph provides a stakeholder analysis of the most crucial actors involved in the problem, who might be worth talking to. Afterwards, a delimitation to the most relevant stakeholders is done and justified.

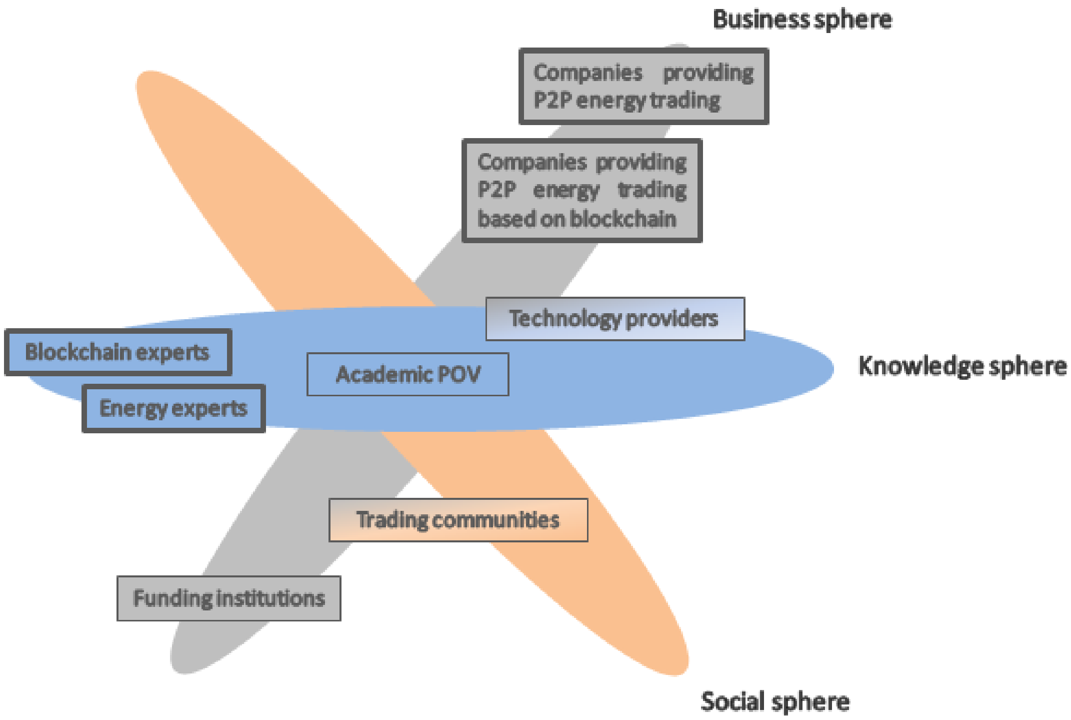

Figure 3.1. Stakeholder analysis of important actors involved in the problem

There are four main spheres which describe stakeholders in a typical stakeholder analysis and these are: knowledge, business, regulatory and social [Gimmler, 2017]. However, in the view of this specific problem, the regulatory sphere is not investigated due to lack of time and means. Thus, it is not included in the Figure 3.1.

The knowledge sphere represents stakeholders who own relevant expertise as well as theoretical and practical understanding of scientific areas related to the topic. The sphere includes experts in the field of energy systems, energy trading and energy intensity who are called as Energy experts here in simplification. Farther, experts with comprehension of blockchain technology and its potential applications among industries are an important part of the knowledge sphere. These experts seem to be very crucial since blockchain is an emerging technology and a lack of information and data appears when investigating it.

Stakeholders who belong to the business sphere are most importantly companies which provide P2P electricity trading, here including companies which use blockchain-based solutions and companies which utilize other technologies to operate their P2P trading platforms. Moreover, institutions (i.a. research institutes or private organizations) which fund research and implementation of P2P electricity trading systems and blockchain projects play a vital role.

Stakeholders called as Technology providers are understood as specialists who own abilities to create and maintain P2P electricity trading platforms, and these are for example IT specialists and engineers. Technology providers first of all have knowledge in fields of commodity trading, IT systems etc. Yet they also belong to the business sphere since they are providing technological solutions for companies.

The social sphere include primarily communities which are end-users and at the same time active parts of P2P electricity trading systems. However, due to lack of time and the fact that this Master thesis is an individual work, the social sphere despite its importance is not a focus of the project. The trading communities might also be considered as a part of the business sphere. It is because they are supposed to perceive benefits within P2P electricity trading. These benefits can be, among others, financial.

The stakeholder analysis leads to delimitation of the actors. As decided and marked in Figure 3.1 above, most important groups of stakeholders are therefore: blockchain & energy experts, while it should be noticed that some experts specialize in blockchain utilization in energy sector thus are both blockchain and energy experts, and companies providing P2P electricity trading, both utilizing and not utilizing blockchain. It can be concluded that this Master thesis focus on conjugation of two spheres: knowledge and business, however it is done from an academic point of view (POV).

3.2.1 From macro to micro perspective of the topic

Blockchain projects in P2P electricity trading could be observed in various locations all around the world. There are also several institutions which focus on research on blockchain potential in utilization for such a purpose.

The map in Figure 3.2 below shows selected companies as well as researching institutions.

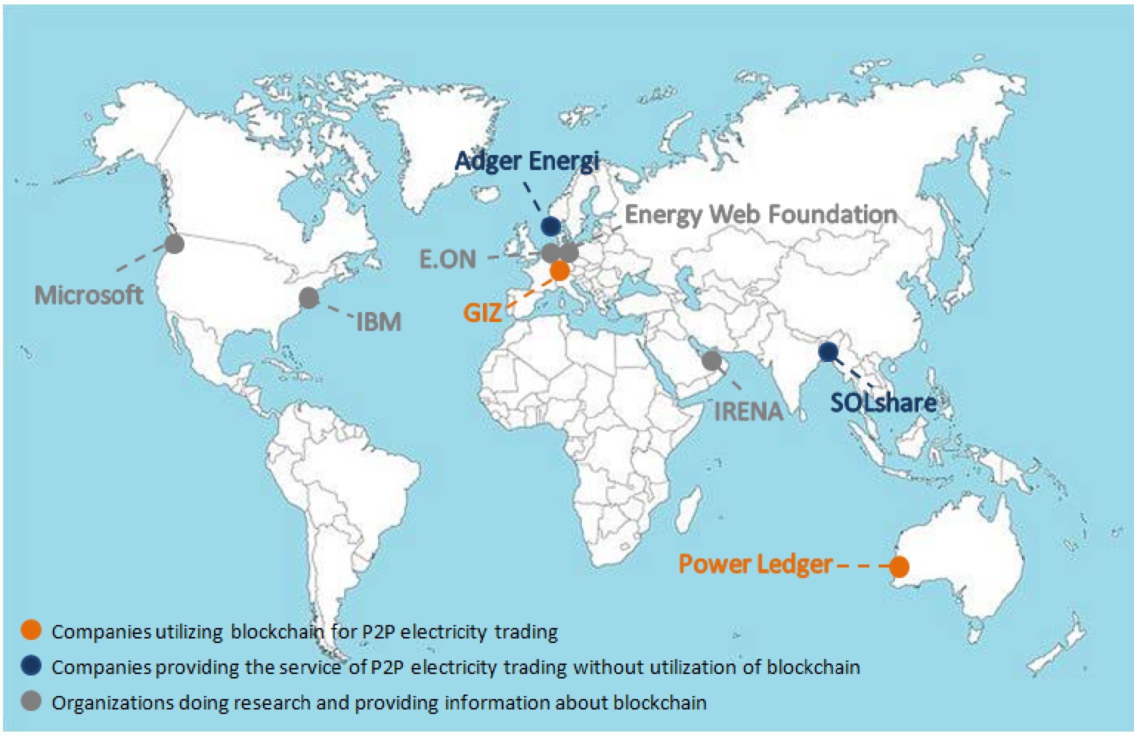

Figure 3.2. Companies and institutions involved in blockchain for P2P electricity trading

It can be concluded that mostly developed countries investigate the technology, for instance a lot of pilot projects of blockchain-based platforms for P2P energy trading in general could be observed in Germany. However, very often these solutions are implemented in developing countries, such as an example of GIZ [Peter, 2018].

The macro context had to be narrowed down to a micro context. Thus, throughout organizations which can provide information about blockchain in general as well as blockchain for P2P electricity trading the following ones have been chosen: E.ON (Appendix A) and IRENA (Appendix B). Companies such as Microsoft (Appendix F) and IBM (Appendix E) are however a good source of knowledge, practices as well as data. These stakeholders belong to the knowledge sphere.

Furthermore, among the most important stakeholders from the business sphere two companies has been chosen. Power Ledger (Appendix C) is picked as representative of the companies which utilize blockchain for P2P electricity trading. In contrary, ME SOLshare (Appendix D), located in Bangladesh but developed from a German practise, is embodying the group of companies which does not use blockchain.

3.3 Delimitation of the problem

Since the topic is very comprehensive and it involves a lot of aspects I decided to clearly outline the area of interest here.

3.3.1 Delimitation to community level

When talking about blockchain a lot of questions might arise regarding the way the technology works. The same relates to P2P electricity trading. Any community which is P2P-trading of electricity is a part of a bigger system. The system contains of many actors, but most importantly these are Transmission System Operator (TSO) and Distribution System Operator (DSO).

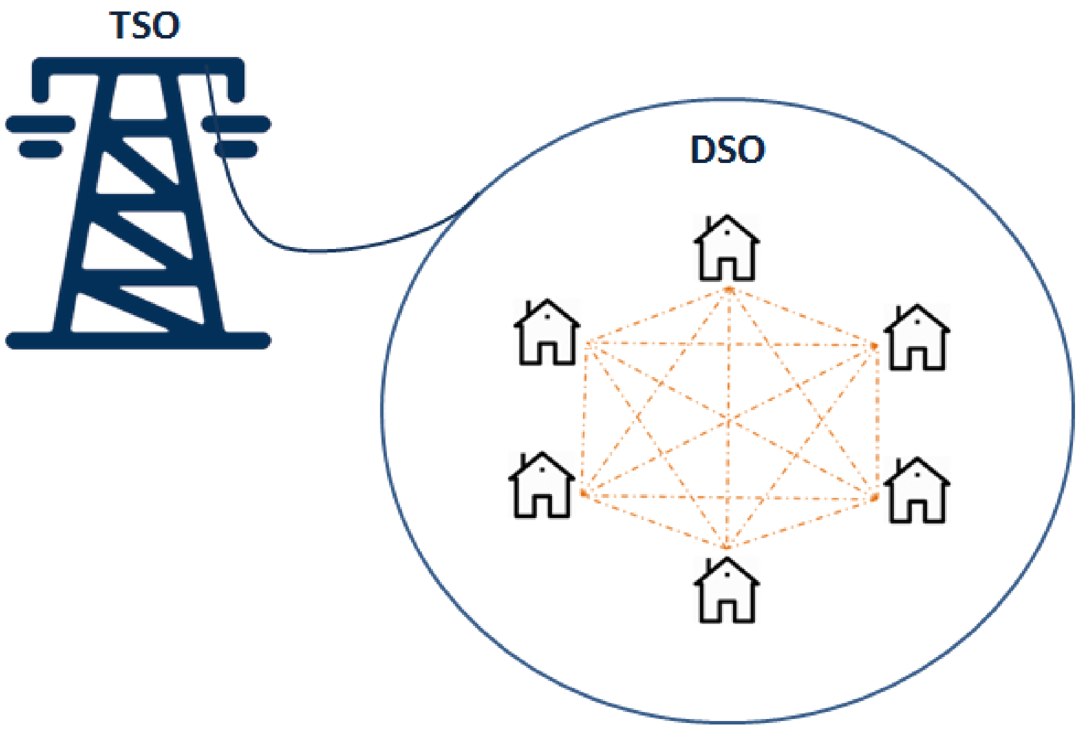

Figure 3.3. Energy system of TSO, DSO and P2P electricity trading community

When a community members are trading electricity between each other, they utilize electric grid being operated by their DSO. They also indirectly utilize the transmission grid. It happens when there is not enough excess energy produced within the community to sustain needs of its inhabitants. Then energy has to be transported from another part of the region, thus utilization of TSO grid.

The aforementioned is briefly mentioned here since there are issues associated to the use of DSO and TSO grids by members of P2P electricity trading systems which are described in Chapter 5. However, already at this point it needs to be emphasized that consideration over P2P electricity trading impact on DSO and TSO are not included in the Master thesis. Focus lays only in P2P electricity trading inside the investigated community.

The technical impact on TSO and DSO is not considered, however these actors play important role when talking about trading from the economic point of view. It is due to the fact that electricity bill for a private household in Germany consist of segments which address payments for TSO and DSO for their services. Therefore, it is important to define the relationship between trading peers, TSO and DSO. This relationship, including all the assumptions done to set it up, is however very precisely described in Paragraph 6.4.

3.3.2 Germany as my location

When talking about community I also want to outline that the case study being analyzed here is located in Germany and it is for threefold reasons:

1. My internship was done in Germany thus the third semester project was elaborating on a community in Germany. I decided to use some data from the previous project.
2. While doing internship in Germany I observed a lot of interest about blockchain utilization in the energy sector. What is more, I got in touch with some experts being involved in the field. Some of them are interviewed for the purpose of this project.
3. I noticed that a lot of companies implementing pilot projects of blockchain in P2P electricity trading are drawn from Germany.

3.3.3 Analyzed problem areas

There is a need to mention one more time that this Master thesis investigates only two aspects of the problem of blockchain utilization for P2P energy trading. These are as following:

- environmental, which focus on energy intensity of blockchain utilization for P2P electricity trading and thus sustainability of such a solution
- economic, which focus on expenditures implicating from the aforementioned energy intensity of blockchain and consider potential benefits provided by the technology in the range of sufficiency to compensate these costs.

Problem could be analyzed also in the light of social or regulative aspects, e.g. examining if properties of blockchain are actually desired by end-users of P2P electricity trading platforms. This is however part of discussion in Chapter 8.

3.4 Interplay of Theoretical Framework to Methodology

The theories described in this Chapter 3.1 have significant role in shaping the research done in this project. They represent my concerns about blockchain as an innovation which is getting popular and widespread extremely quickly. Due to this fast expansion, blockchain might not go along with goals of sustainable development. This potential lack of sustainability can be displayed through blockchain's consumption of power. Thus, the theories constitute a basic framework of the research question and subquestions which has been posed in Chapter 2.

Connection between problem statement, theoretical framework and methodology is shown in Figure 3.4 below.

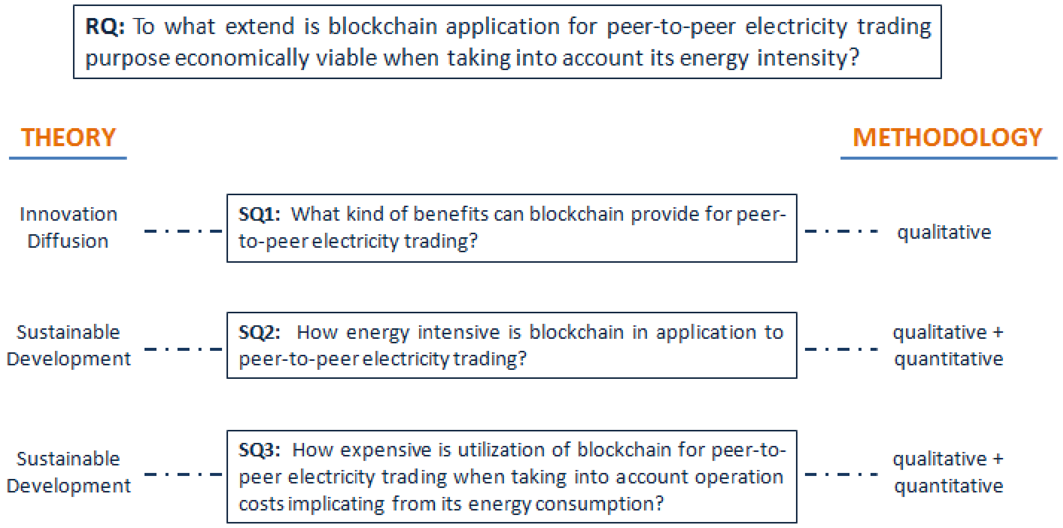

Figure 3.4. Connection between theoretical framework and methodology

Providing answers for all of the questions is challenging due to low maturity of blockchain and its applications (see Figure 1.2 again) and lack of data. That is why consultations with experts are so crucial in my project, thus I put a lot of emphasis on qualitative method of research. The stakeholder analysis is done then to wisely choose relevant actors that might be reliable sources of knowledge about blockchain for P2P electricity trading. Methodology standing behind interviewing of these stakeholders is described in the next chapter.

Methodology 4

The following chapter is providing information about the way research is done with pointing out implications that lead to the specific case study that is analysed later. Moreover, based on The Theory of Innovation Diffusion described in Chapter 3 awareness about lack of data that might occur during the project has increased. Thus, the whole process of data accessibility including faced challenges related to that is described.

4.1 Research design

The idea of elaborating on blockchain in utilization for P2P electricity trading in this Master thesis spread out of observations of the energy industry. It could be clearly noticed that several energy businesses are interested in the technology of blockchain and that this interest is constantly growing. Moreover, frequency of international conferences (such as Innovation Week organized by IRENA [2018]) or discourses (e.g. Webinar described in Appendix G or Lecture summarized in Appendix F) dealing on the topic knocked up recently.

Both research and analysis arising from that are structured according to three pillars of institutions wrought by Scott [1995] which are: normative, cognitive and regulative. The meaning standing behind each pillar is translated for the needs of the research.

Even though the Scott's three pillars are originally related to institutional analysis which is not a subject of elaboration in this project, they can be translated to other cases. During one of the lectures of The Socio-Technical Context of Planning, Ramirez [2018] explained in what ways these pillars could create a basis for scientific research.

Thus, normative pillar which typically describes norms and habits or expectations of an institution can be used as a path which helps in determining the purpose of the project by answering the question "what do I want to achieve?". Cognitive pillar originally responsible for evaluation of values and beliefs can be used to describe what is the background which frames the problem by answering the question "how do I see it?". While defining the aforementioned framework, it is important to remember that the result of the project is strongly dependent on assumptions made at the same time. Last but not the least, regulative pillar which according to Scott's theory is defining rules, such as laws or policies for example, makes a helpful link in searching for a solution of the problem by posing questions "what can I do?" or "what kind of actions do I propose?". Foregoing with a specific reference to this project is precisely explained in Table 4.1 herein.

Pillar	Translation	Interplay to the research	Related chapters
normative - *what do I want?*	helpful in defining the purpose of this project	the purpose is to examine if blockchain is the appropriate technology for P2P electricity trading by applying an academic perspective and focusing on environmental aspects which therefore implicate economic expenses	the overall problem is described in Chapter 1 - Introduction, however specific information regarding blockchain and P2P electricity trading can be found in Chapter 1 and Chapter 5 respectively
cognitive - *how do I see it?*	helpful in determining of the relevant framework for the project by deciding on delimitations and assumptions	the project gains a relevant sense by posing a research question which is as specific as possible; the framework of the project is focusing on describing the aspects of blockchain and P2P electricity trading and pointing out important actors involved in the problem	research question backed up with three subquestions can be found in Chapter 2 while the Theoretical Framework with all the delimitations in Chapter 3
regulative - *what kind of actions do I propose?*	helpful in pinpointing actions that need to be taken in order to provide a sufficient answer for the research question	the research question can be answered when analysing results from an economic study of blockchain used for P2P electricity trading which is backed up by calculations of its energy consumption	the analysis is done in Chapter 6; a short conclusion of the results is given in Chapter 7 and a short discussion in Chapter 8

Table 4.1. Translation of the original definitions of three pillars of institutions for the perspective of this project

4.2 Accessing data related to the problem

As described in Chapter 3, any innovation at its early stage of adoption is associated with lack of information and data. This is going along with The Theory of Innovation Diffusion by Rogers [1983], which also has been outlined before. The lack of information relates also to blockchain and its potential applications in the energy sector. Thus, the following paragraph aims on describing the process of obtaining data essential to answer the research question.

First of all, during a pre-research phase of the project it was noticed that topic of blockchain is not very popular among literature sources such as books. On the other hand, a lot of scientific articles spread over the last couple of years, usually between 2016 and present. The articles elaborate on the technology, focusing however most often on explaining how does blockchain work rather than on potential challenges related to its implementation.

When talking about blockchain utilization in the energy sector or, more specifically, in P2P electricity trading, even more difficulties related to data accessibility could be encountered. The topic is quite popular among various Internet portals, but not much of reliable sources could be found.

In the light of previous, it has been decided that the most relevant method in accessing such information or data is by interviewing stakeholders who are exposed to the topic in their professional work. This approach is backed up by Valentine [2005] who convinces in the study that interviews can be very often the most appropriate research methodology, especially when using mixed research of both qualitative and quantitative methods which is a case in this project. According to Johnson et al. [2007] mixed research methodology occurs when qualitative conclusions, which are very often results of interviewing, are endorsed with quantitative study. The mixed method used for data collection is described in-depth in the following paragraph.

4.3 Data collection

As described before, both qualitative and quantitative methods are used here, thus both qualitative and quantitative data is required for this report.

4.3.1 Qualitative data

In order to obtain qualitative data, a lot of consultations and meetings were arranged. These consultations involved researchers from Aalborg University as well as other experts involved in the field. The whole process of interviewing is described below.

Interviewing

Interviewing used as a part of methodology is said to provide good overview during the phase of outlining the problem but also in accessing specific data about the problem [Jamshed, 2014]. Five interviews with experts have been conducted during the project. Interviews are either structured, in case of mailings, or semi-structured, in case of phone interviews.

Two interviews were conducted in the early stage of the project. These interviews resulted in mapping out area of interest around blockchain in the energy sector. The first stakeholders were encountered in November, 2018 while doing the third-semester internship in Bonn, Germany. Boshell [2019] - Renewable Energy Markets and Standards Analyst, Ratka [2019] - Associate Professional and Anisie [2018] - Associate Program Officer who are employees of Innovation and Technology Center at International Renewable Energy Agency (IRENA) therein agreed to participate in a meeting with me. Later Boshell [2019] and Ratka [2019] answered a couple of questions regarding the topic. The whole summary of my contacts with IRENA can be found in Appendix B. The second interview mentioned in the paragraph is conducted with Kellerer [2019] who is a Venture Manager and Data Scientist at E.ON in Munich, Germany. She was also approached in November, 2018. The interview with Kellerer [2019] can be found in Appendix A. These interviews had a significant role in narrowing down the macro perspective, which could have been identified based on literature research and observations as already mentioned, into micro perspective.

In the next stage of the project, when the core topic together with micro perspective are defined, three additional interviews are conducted. The aim of this interviews is to access specified information regarding blockchain utilization for P2P electricity trading, which includes data of blockchain's energy consumption in the application and costs which implicate from it.

Two interviews are carried out with companies which provide the service of P2P electricity trading, whilst one of them - Power Ledger - utilizes blockchain for the purpose and the another one - ME SOLshare - does not. This approach of interviewing two companies is undertaken in order to stay objective and be able to compare opinions of two totally opposite sides. Bedwell [2019] is a representative of Power Ledger and he works as a Contractor therein. Among others, his duties include working with the marketing team to develop product materials and respond to media and support Power Ledger community in general. The interview is attached in Appendix C. At the same time Tamhane [2019] is interviewed to give an overview of activities of ME SOLshare. He works as a Product Manager who makes a connection between technical and operation teams. As he mentions, he also specializes in a field of recognizing users' needs and expectations from their solution. The transcript from the meeting with Tamhane [2019] is in Appendix D.

The last interview is conducted with Barend de Bruin, employed as an Account Executive at SAS who however used to work on blockchain applications at IBM. He presents me data regarding costs related to implementation of blockchain projects. These information can be found in Appendix E.

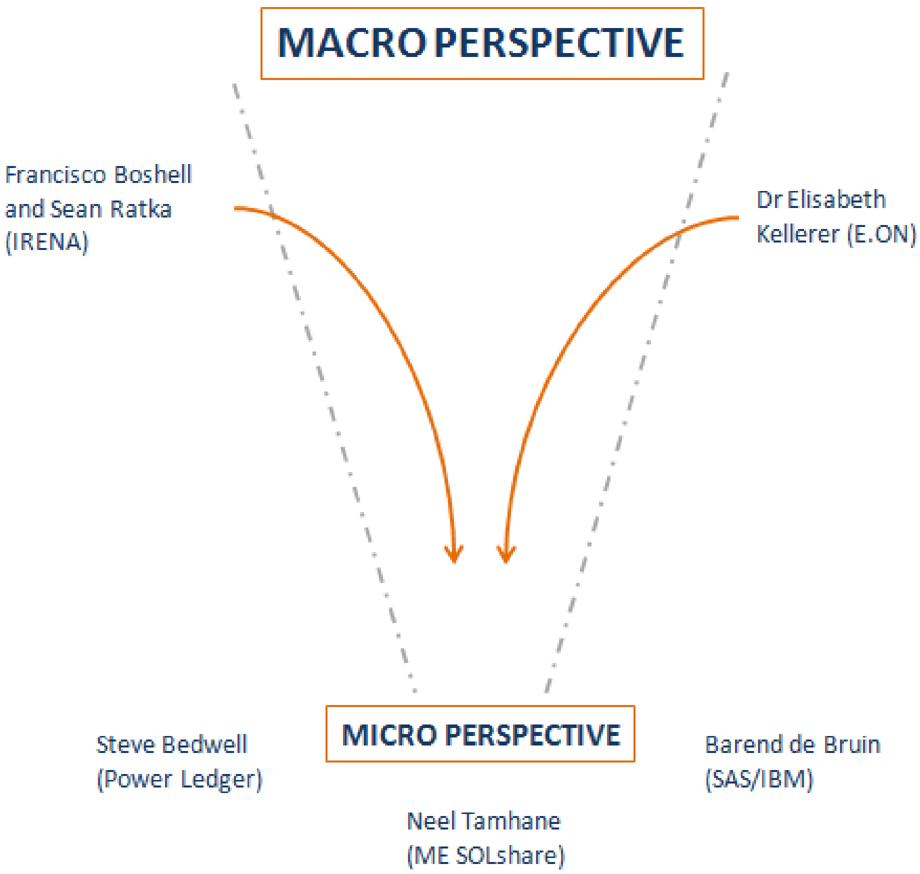

Figure 4.1. Interviewing as a tool to narrow down project perspective to the micro world

It is also worth mentioning that during the project a lot more experts have been approached. It happened most often to obtain a very specific data or to gain endorsement of opinions or assumptions. These experts are: Maciej Ziółkowski - blockchain entrepreneur at Coinfirm, Bartosz Trzciński previously working on blockchain solutions in the energy sector who helped me with obtaining information about the topic by providing reliable sources and Krystian Kowalewski who as an Executive Director of World Energy Council Poland shared with me studies about blockchain in the energy sector done by the organization.

Bias of the interviewed stakeholders

Since, as already described any access to objective sources of data related to blockchain for P2P electricity trading is hindered, most of the information is provided in other ways, i.a. during interviews or meetings with experts. Therefore, it is needed to emphasize that the objectivity of mentioned information is strongly connected with objectivity of interviewed stakeholders and it might significantly influence the results.

Moreover, the analysis is of an economic nature and it is important to be aware that some companies are not eager to share data related to their expenditures. It might be because of twofold reasons - companies are afraid that the data breach would potentially strengthen their competitors or the solution is innovative and they believe it might be prospective in the future, thus they rather keep it confidential.

During one of consultancies with Maciej Ziolkowski who is an expert in the cryptocurriences field, when asked about energy consumption of blockchain he provides the following answer: "I work in the field [bitcoin mining] for 8 years already and I have never even considered blockchain's energy consumption. It it possible that companies cannot provide you with relevant data because simply they do not know how high the consumption is". This occurs as another challenge that must be faced during the project - the topic of the Master thesis is relatively new which means that interviewed experts might not be fully aware of the issue or might not be able to answer specific questions related to that.

4.3.2 Quantitative data

In order to answer the second and third subquestion, a proper quantitative investigation has to be carried out. As described already, the research and collection of quantitative data could not be completely based on scientific sources, such as books or technical reports. Thus, a lot of data is accessed through articles. However, every time reliability of the article could appear questionable, it is confirmed by one of the experts or consultants mentioned in Paragraph 4.3.1.

Two computer programs are used during this project and these are EnergyPRO and Excel. EnergyPRO is a simulation tool that enables for calculating the optimal operation of energy plants or systems [EMD International A/S, 2019]. Here it is utilized in order to define how much electricity is traded between community members. Excel is utilized in order to do calculations such as costs of electricity incurred by community members.

Peer-to-peer electricity trading 5

The following chapter explains the idea of P2P electricity trading by pointing out its purpose and elaborating on the way it could resolve issues which are likely to occur during transitions from centralized structure to decentralized energy systems.

5.1 Background of new energy marketplaces

According to Ratka [2019] and Boshell [2019] one of the most crucial challenges facing energy systems while several attempts of their decarbonization and decentralization are made is of a structural character. As they emphasize the current "top-down" approach of energy sector will most probably be unable for efficient integration of high shares of Distributed Energy Resources (DER) which are instantly growing.

The aforementioned increasing penetration of DER worldwide is a fact - e.g. according to Australian Renewable Energy Agency [2018] over 40% of Australian energy users are expected to rely on DERs by 2027 and that number is said to rise up to 60% by 2050. DERs are understood as production and storage units which, besides their main purpose of energy generating and storing, are also able for managing and optimising the use of energy [Pollitt, 2018]. The examples of DER units could be diesel generation facilities as well as rooftop solar panels and wind turbines or even electric vehicles [Pollitt, 2018]. As a result of this upsurge, new innovations at the grid edge are needed, perhaps including a new grid architectures placing these DER units as the most important parts of energy systems and their owners, called prosumers, as the most important participants of the systems [Ratka, 2019; Boshell, 2019].

The word *prosumer* used above is associated with an exact definition. It is a blend of two words: producer and consumer, meaning that prosumer is a person who both produce and consume [Cambridge Dictionary, 2019]. In energy sector specifically the idea of prosumers boils down to technology that enables to build independent energy networks so participants of these networks are more self-sufficient thus less reliable on existing systems [Hwang et al., 2017]. According to the concept of *energy democracy*, which assumes energy, climate and environmental justice among other, prosumer is introduced as a proactive citizen who is aware about the importance of and is ready to locally contribute to energy transitions [Szulecki, 2018].

The popularity of prosumerism is thus instantly growing along with raise of public awareness [Szulecki, 2018] as well as increasing shares of DERs [Sousa et al., 2019]. Prosumers own their units, typically renewable DERs, which enable them to create small marketplaces together with neighboring consumers that are based on P2P energy trading [Sousa et al., 2019]. The idea of creating local network on a community level is displayed in Figure 5.1 below.

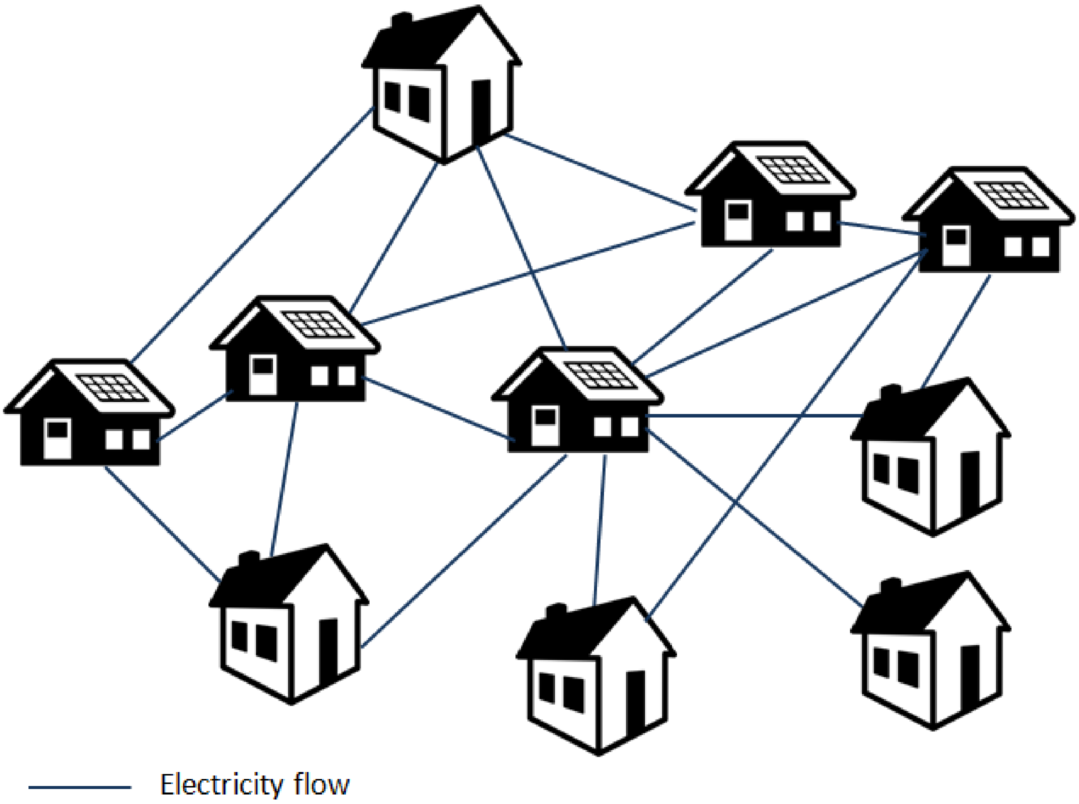

Figure 5.1. P2P electricity trading on a community level [Park and Yong, 2017]

According to Zhang et al. [2018], P2P electricity trading systems between prosumers on a national as well as regional or community scales emerged for the first time in the second decade of 21^{st} century with its main focus aiming on providing financial savings for the users.

5.2 Concept of P2P electricity trading

The core of P2P electricity trading lays in the possibility of bilateral power flow. Prosumers can either use produced electricity straightaway for their needs, trade it to their neighbouring consumers or feed in to the grid. There occur thus benefits in twofold ways - prosumers can sell their excess electricity, while consumers can buy electricity at a possibly more attractive price. The concept is displayed in Figure 5.2 below.

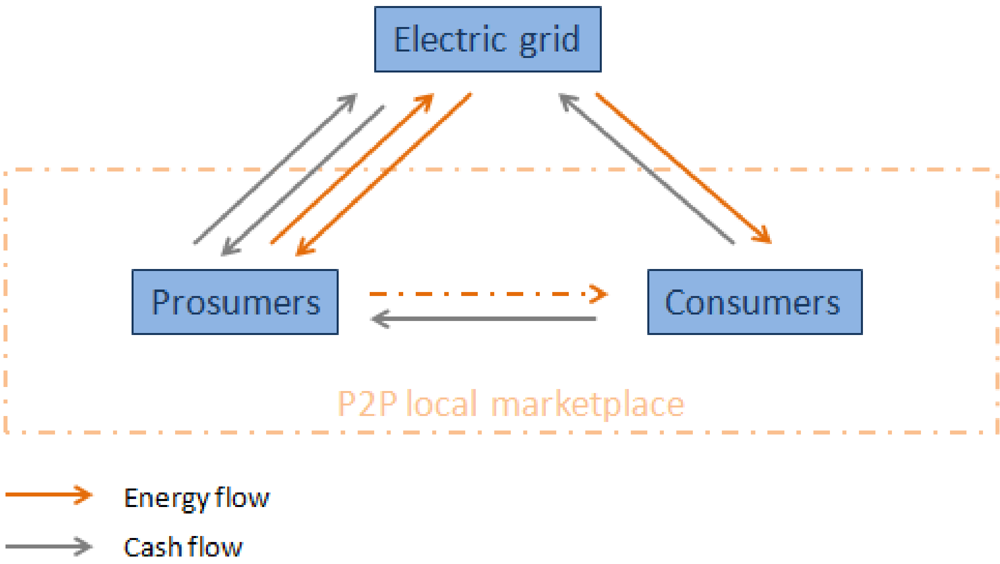

Figure 5.2. Model of P2P electricity trading marketplace [Sia Partners, 2018]

The Figure 5.2 shows electricity and cash flows between prosumers and consumers who together create a community-based local P2P marketplace. Prosumers have a possibility to sell their excess electricity within the local market as well as feed it to the electric grid operated by DSO. At the same time consumers can buy required energy locally at the P2P marketplace from other peers of the network but also from the DSO.

The arrow standing behind flow of energy produced by prosumers and delivered to consumers is deliberately dashed. It is very important to remember that the P2P marketplace has a symbolic meaning and from the physical point of view any electricity flow between peers can only happen through the distribution grid. The P2P marketplace is however supporting in optimizing and balancing of the flows by enabling for trading within the community. [Park and Yong, 2017]

The solution of trading electricity between peers of the network is said to provide numerous benefits for its users. However, it does also provide some challenges. The most important ones are described below.

Benefits resulting from P2P electricity trading are as following:

- Marketplaces based on P2P electricity trading enable for a better optimization of energy flows when a lot of DERs are implemented locally [Boshell, 2019; Ratka, 2019].
- As already mentioned before, the solution can provide financial savings both for producing and consuming peers of a network [Murkin et al., 2016].
- The idea of P2P electricity trading can be also treated as motivating factor for local communities in encouraging to actively participate in green energy production and supply. This implicate from the previous point as well as growing awareness on energy and environmental issues.

Challenges in operation of P2P electricity marketplaces are pin-pointed in what follows:

- According to Leberer [2018] who as a student of Sustainable Energy Planning and Management developed a Master thesis entitled *Impact of P2P power trading on rooftop PV in Alberta*, utilization of P2P electricity trading platform among community members makes sense in case when only part of them own DERs. As he concluded, the optimal share of DERs which enables for maximum amount of electricity traded equals for 30%. Also worth mentioning that the type of DERs that he analyzed are rooftop solar PVs.
- Utilization of P2P electricity trading as well as the idea of prosumerism itself can provide difficulties for DSOs since the capacity of distribution grids must be adjusted for more frequent flows [Bell and Gill, 2018].

5.3 Blockchain in utilization for P2P electricity trading

As already described in Chapter 1, utilization of blockchain gains a lot of popularity in P2P electricity trading systems. Some examples of the application are provided herein.

Energy Web Foundation is a non-profit organization originally based in Germany which focus on unleashing the potential of blockchain among the energy sector. Kellerer [2019] who works at a future lab at E.ON, which is at the same time an affiliate of the Energy Web Foundation, explains an idea of their product called *enerchain*. *Enerchain* is a trading platform which enables concerned organizations to anonymously commit orders for electricity to a decentralized order book. These orders are visible for other trading companies and thus can by lifted by any. This results in a trade which is confirmed for both parties and reveals the counterparties' identities to each other by placing an auditable manifestation. As she explains next, their solution can make a significant use because nowadays energy wholesale traders can either trade on a broker platform or on an energy exchange. Both of them involve a third party as an intermediary between the counterparties. The aim of introducing *enerchain* was therefore to change that through a blockchain-based order book which disintermediates the third parties and provides a new way of facilitating a deal between the interested parties. [Kellerer, 2019]

A more community-based approach is presented by Australian company Power Ledger. The company offers two main products - xGrid and uGrid [Bedwell, 2019]. The first one is "in front of the meter" meaning that the electricity trading occurs across the grid. The second solution is utilizing an island mode and it works totally "behind the meter" meaning beyond the grid. [Power Ledger, 2018]

Both Kellerer [2019] and Bedwell [2019] who are interviewed for the purpose of this Master thesis, claim that blockchain is the most appropriate technology for P2P electricity trading.

According to Bedwell [2019] blockchain offers properties that cannot be replicated by traditional ledger technologies. As he argues, when taking an apartment block operating a microgrid utilising solar and battery storage as an example, there might be hundreds of tenants sharing these DER units and each is entitled to use or trade their share between each other. Here blockchain enables for immediate settlement between tenants to be performed securely without a trusted intermediary. This ability becomes even more important when considering the number of entities that could be trading across the grid. [Bedwell, 2019]

On the other hand, Kellerer [2019] significantly emphasizes on blockchain characteristic of transparency. As she says, the ability to digitally foster trust between self-serving parties is the most important advantage of blockchain utilized for this solution. She however admits that the application of this technology is costly and it implicates from development of blockchain since it is not a very popular technology. [Kellerer, 2019]

All-in-all, according to experts, blockchain finds it utilization for P2P electricity trading thanks for its abilities which can be found in Table 5.1 below. The table contains also my comments about experts' opinions.

Advantages pointed out by experts	**My opinion**
Transparency which is provided with the idea of digital ledgers that are distributed to each participant	I am not convinced if transparency is so vital in community-based P2P electricity trading systems. I can however see that it is important to have a platform which enables for clear detecting of information about transactions, such as trading parties and amount of electricity traded
Lack of intermediary which is fostering trust among participants of a network	It is important to be able to manage such a P2P electricity trading system on a community level, thus not involving third parties, such as DSO
Maintaining numerous transactions in a safe way which is important in balancing and optimization of energy flows among communities or even on a wider level, e.g. regional or national	It is extremely important that the P2P-trading platform is able to quickly register the transactions which are made between parties. It is due to the fact that community-based trading systems tend to have a lot of transactions on a very frequent basis as already mentioned in Paragraph 1.4.

Table 5.1. Benefits of blockchain utilization for P2P electricity trading - experts' vs. my opinions

It is interesting to see that advantages of blockchain together with blockchain's characteristics crucial for P2P electricity trading that are pointed out by experts overlap only partly with needs of P2P electricity systems described in Figure 1.7 in Chapter 1. Experts do not mention anything about generally understood sustainability of as well as costs related to blockchain.

5.4 Summary of uncertainties in Chapter 5

What we know	What we do not know
1. It is clear how P2P electricity trading works, how it addresses challenges occurring to current energy systems and what kind of benefits it can provide to the end users.	**1.** Characteristics of blockchain that can fulfil needs of P2P electricity trading systems pointed out by experts partly overlap the needs described in Figure 1.7 and it is uncertain why. It is not clear why experts do not mention energy consumption of blockchain and its operational costs.

Figure 5.3. Uncertainties about the topic which occurred in Chapter 5

Analysis 6

6.1 Description of the collective case study

The case study that is a subject of elaboration in this Master thesis is a continuation of the semester project done during the third semester of the degree. The case study is located in Bonn, North-Rhine Westfalia, Germany and it is based on a community which is trading electricity between its members.

The case study is collective because it deals with a very new topic - relating to both blockchain and P2P electricity trading - and data has to be gathered from different case studies in order to formulate this one.

6.1.1 Assumptions

The amount of households of the community is assumed to be 100. The share of DERs - here rooftop solar PVs, among community members is 30%. This assumption goes along with the analysis of Leberer [2018] which says that when 30% of a community owns production units of solar PVs, the maximum amount of electricity can be traded within this community. It results from the fact that energy coming from solar characterises with the specific pattern of production - it is produced only during days. Therefore, the community consists of 30 prosumers, each owning rooftop solar PV installation and 70 consumers.

It was assumed that every household owned by a prosumer has installed 10 rooftop solar panels of following installed power: 315 W and dimensions: 65 x 39 in. After a literature research the efficiency of these panels is deduced as 18.7%, moreover when taking into account all the losses that might occur between modules and grid, the aggregated losses factor equals for 10% [Green Cells Energy, 2019].

At the consumption side it is assumed that average electricity consumption for typical German dwelling is at the level of 3,079 kWh annually [World Energy Council, 2016].

6.2 P2P-traded electricity

In order to calculate the energy intensity of a blockchain-based platform which enables trading between community members, two simple models of the community has been developed in EnergyPRO. Due to the fact that EnergyPRO is not able to analyze P2P electricity trading systems in sense of returning information of the amount of electricity traded between participants of P2P marketplaces, this electricity is calculated based on results from these two models. Both analyses are done using a partly island mode, meaning that the focus lays in covering own demand but there is also a possibility to exchange electricity at the market.

Model no. 1 shows prosumers grouped altogether. The electricity production from PV panels and electricity consumption is shown in Figure 6.1.

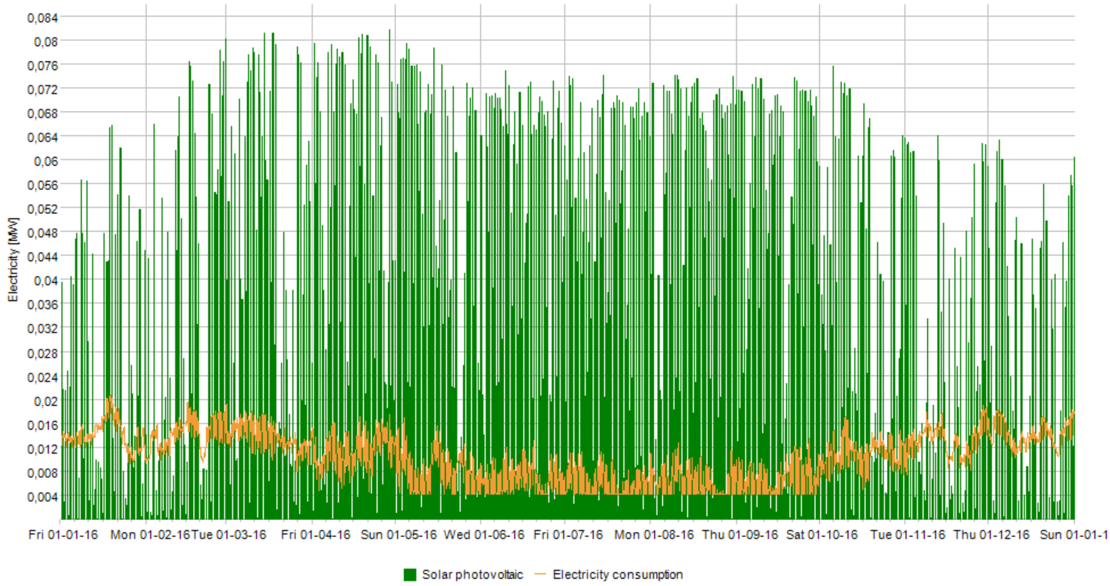

Figure 6.1. Electricity production and consumption of the prosumers grouped together

The amount of produced, exported and imported electricity needed to fulfill the demand of prosumers has been also generated from the program and it is displayed in Table 6.1 below.

PV production	125.8 MWh
Export	96.9 MWh
Import	63.5 MWh

Table 6.1. Electricity flow needed to cover annual demand of prosumers' dwellings

After analysing Figure 6.1 and Table 6.1, it can be noticed that prosumers produce a lot of excess electricity which has to be sold back to the grid. Subtraction of produced and exported electricity equals the amount of electricity actually used by prosumers. It is as following: 125.8 MWh - 96.9 MWh = 28.9 MWh.

Responding model no. 2 is developed for the whole community, meaning that electricity demand which can be fulfilled by PV production equals for 100% of community's consumption. The PV production and consumption of electricity in the second model is displayed in Figure 6.2 below.

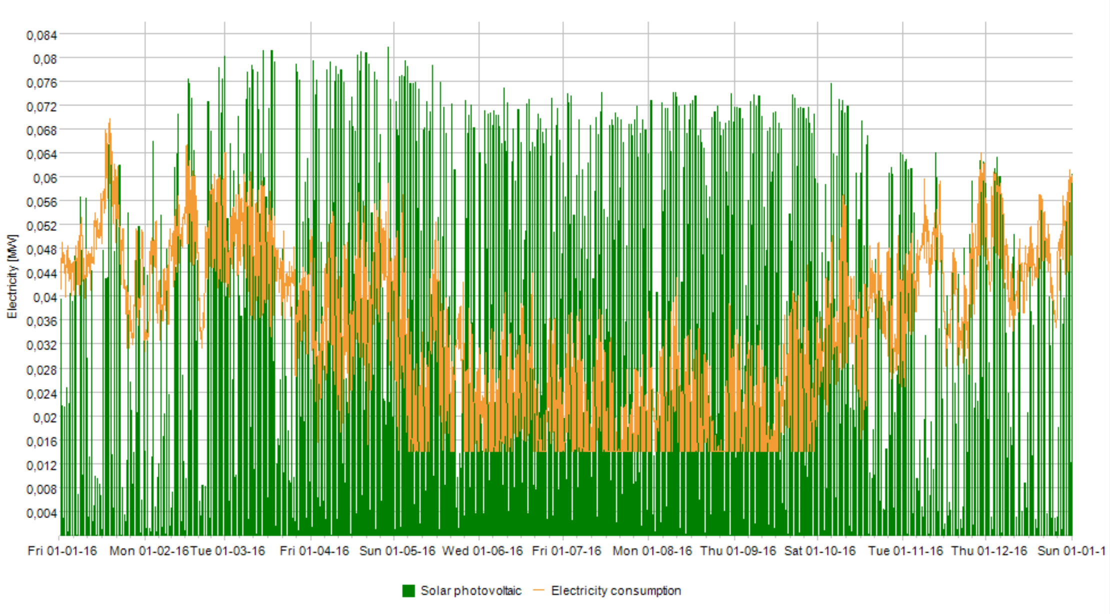

Figure 6.2. Electricity production and consumption of the community

Here the values of produced, exported and imported electricity are as following in Table 6.2.

PV production	125.8 MWh
Export	56.9 MWh
Import	239 MWh

Table 6.2. Electricity flow needed to cover annual demand of the whole community (prosumers + consumers)

Analogically subtraction of produced and exported electricity of the community equals for the amount of electricity used inside it. It is as following: 125.8 MWh - 56.9 MWh = 68.9 MWh.

It can be observed that amount of exported electricity dropped in comparison to the first model and it is due to the fact that some electricity has been traded within the community.

These electricity equals for subtraction of electricity traded when no P2P trading occurs and when P2P trading is introduced:

$$96.9 \text{ MWh} - 56.9 \text{ MWh} = \mathbf{40\ MWh}.$$

This means that 13% of electricity demand of the whole community can be provided by trading from prosumers to consumers. This result goes along with the outcome of Master thesis developed by Leberer [2018] which has already been mentioned in the report.

Moreover, EnergyPRO tools are able to provide information about the amount of "turn ons" of PV panels. Since production units and respective demands are modelled separately in the program, EnergyPRO returns information how many times electricity is transported from production to consumption sides. This means that the program can proceed how many electricity transactions are conducted between the panels and end-users. The amount of "turn ons" between a single PV panel and its demand side equals 574, which thus gives 17,220 electricity transactions in total for the whole community.

Since the electricity produced from solar PVs and electricity traded from prosumers to consumers equal respectively 125.8 MWh and 40 MWh, it can be concluded that 32% of produced electricity is traded. Therefore it is assumed that 32% of transactions mentioned in the previous paragraph constitute to transactions between prosumers and consumers. This gives **5,475** transactions of traded electricity annually.

6.3 Energy intensity of blockchain-based P2P electricity trading platforms

As it has been already mentioned in Paragraph 1.3.2, energy consumption of blockchain-based trading platforms varies depending on the consensus of authorisation of transactions. Thus, the analysis is conducted for PoW as the most popular consensus throughput blockchain applications and for PoA since that consensus is mentioned by interviewed businesses which provide P2P electricity trading service with utilization of blockchain [Bedwell, 2019; Kellerer, 2019].

6.3.1 PoW

The values of energy consumption of transactions done via a blockchain platform utilizing PoW differ depending on the source. The Table 6.3 below shows an overview of these merits that could be found in the literature research or are based on interviews with stakeholders.

Energy consumption [kWh/tx] - overview
26 - 100+ [Malmo, 2017a]
45 [Malmo, 2017c]
77 - 215 [Malmo, 2017b]
95 [Kozar, 2019]
250 [Say, 2019]
1000 [Tamhane, 2019]
1005 [Stipp, 2018]

Table 6.3. Literature overview of power consumption per transaction done via blockchain platform utilizing PoW consensus

As it can be seen, values differ significantly starting from less than a hundred and ending with over thousand of kWh per transaction. It is even more interesting to see that the same author is providing varying numbers in three articles written in intervals of couple of months in 2017. It might be a proof that laboratory studies checking the energy consumption of blockchain have not been undertaken yet.

Based on the data provided in Table 6.3, it has been decided to examine the costs implicating from energy consumption for three values (minimum, medium and maximum) which are given in Table 6.4 below.

Energy consumption [kWh/tx] - analysis
26 - as a minimum
95 - as a medium
1005 - as a maximum

Table 6.4. Values of power consumption per transaction done via blockchain platform utilizing PoW consensus that are subjects of analysis

6.3.2 PoA

PoA is said to be as energy intensive as PoS [Achim, 2019]. The values of energy consumption used in this analysis are given for PoS, however it is assumed that these equal the same for PoA.

According to T [2019] consumption of power can be reduced to 1% when utilizing PoS instead of PoW for validation of transactions. Energy consumption of PoA is therefore as shown in Table 6.5.

Energy consumption [kWh/tx] - analysis
0.26 - as a minimum
0.95 - as a medium
10.15 - as a maximum

Table 6.5. Values of power consumption per transaction done via blockchain platform utilizing PoA consensus that are subjects of analysis

6.4 Electricity costs incurred by the community

First of all, the electricity price for households in Germany needs to be established.

6.4.1 Electricity bill of the community

General information

German households pay electricity bills which contain of a lot of segments. These are shown in Figure 6.3 and described herein.

Acquisition/sales fee (6.88 ct/kWh) stands for the price of electricity bought at the wholesale market and includes a payoff for TSO. Grid fee (7.39 ct/kWh) can be called a "DSO" fee since it equals for the amount of money user is paying for DSO for providing the electricity. Value-added tax (VAT) constitute for 4.83 ct/kWh. Electricity bill for a German household contains also of surcharges: for the state-guaranteed price for RE production units (6.41 ct/kWh) and combined heat and power plants (0.28 ct/kWh). There is also a concession levy (1,66 ct/kWh) that goes towards payments for utilization of public space for power transmission lines and electricity tax on power consumption which is also known in Germany as "ecological tax". Altogether it indicates electricity price at the level of 30.22 ct/kWh for a typical German household in 2019. [Thalman and Wehrmann, 2019]

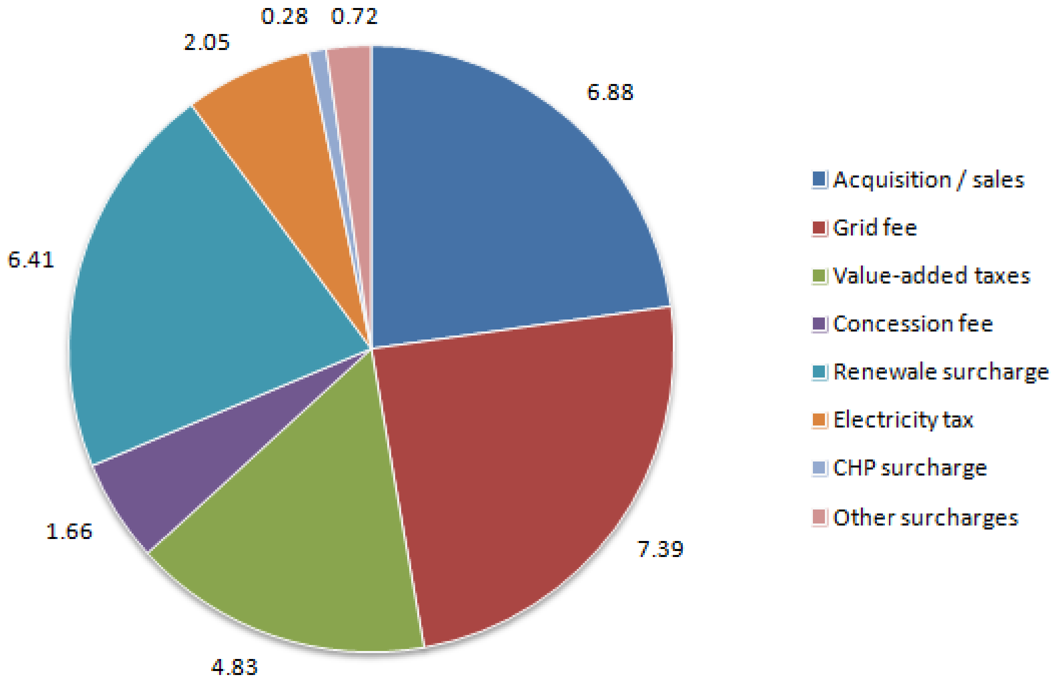

Figure 6.3. Segments of electricity bill for households in Germany [ct/kWh] [Thalman and Wehrmann, 2019]

At the same time it is important to mention that by law a special policy is applied for prosumers in Germany. The type of incentive for small RE plants (up to 100 kW) being in force therein is Feed-in Tariff (FiT) [European Commision, 2017]. FiT for rooftop solar PV installations of capacity lower than 10 kW equals for 10.79 ct/kWh in June 2019 [Photovoltaik4all, 2019]. Moreover, prosumers who own a RE production unit of installed power below 10 kW have a tax exception of renewable surcharge when buying electricity from their DSOs [European Commision, 2017].

Based on that knowledge, the analysis of potential savings done by introducing P2P electricity trading in the community is undertaken. First, the electricity bill of the whole community in case of no P2P trading is calculated and then compared with respective electricity bill when P2P electricity trading is utilized.

No P2P electricity trading

In that case, prices of electricity bought by prosumers and consumers from the electric grid or sold by prosumers to the electric grid are as following:

- Consumers buy electricity for the standard price which equals for 30.22 ct/kWh
- Prosumers have a tax exception of 6.41 ct/kWh when importing electricity from the grid, thus they pay 23.81 ct/kWh
- Prosumers export electricity to the grid with the granted price (FiT) of 10.79 ct/kWh.

The annual costs of electricity for the whole community are compared with earning of prosumers and altogether displayed in Table 6.6 below.

Community members	Electricity [kWh/a]	Cash [EUR]	Annual cost [EUR]
Consumers	215,530	65,133	65,133
Prosumers (import)	63,500	15,119	15,119
Prosumers (export)	96,900	10,456	-10,456

Table 6.6. Annual costs of electricity bill of the community when no P2P electricity trading occurs

Thus, it can be calculated that the annual cost of the whole community is as following:

$$63{,}113 + 15{,}119 - 10{,}456 = 69{,}797 \text{ EUR}.$$

P2P electricity trading

In case of introduction of P2P electricity trading, prices of electricity are a bit different and they are described in what follows:

- Consumers import electricity from the grid for the standard price which equals for 30.22 ct/kWh
- Consumers trade electricity from prosumers with a price falling within the range of values between FiT (10.79 ct/kWh) and electricity bill (30.22 ct/kWh). Since it is not known how exactly members of community can bid prices of electricity traded within local P2P marketplace, it is assumed that the price of electricity bought by consumers equals for 23.34 ct/kWh which is a subtraction of the electricity price from the grid and the acquisition/sales fee (6.88 ct/kWh). It is justified that consumers do not use the electricity provided within the wholesale market, thus there is no need for them to pay for that.
- Prosumers have a tax exception of 6.41 ct/kWh when importing electricity from the grid, thus they pay 23.81 ct/kWh.
- Prosumers export electricity to the grid with the granted price of 10.79 ct/kWh.
- Prosumers trade electricity to their neighbors with a price of 17.67 ct/kWh which is a sum of FiT (10.79 ct/kWh) and acquisition fee (6.88 ct/kWh). It is justified that prosumers save the transmission grid and thus the long-distance flow of electricity bought at the wholesale market therefore they should get this money as a reward.

The annual costs of electricity for the whole community are compared with earning of prosumers and altogether displayed in Table 6.6 below.

Community members	Electricity [kWh/a]	Cash [EUR]	Annual cost [EUR]
Consumers (import)	175,500	53,036	53,036
Consumers (trading)	40,000	9,336	9,336
Prosumers (import)	63,500	15,119	15,119
Prosumers (export)	56,900	6,140	-6,140
Prosumers (trading)	40,000	7,068	-7,068

Table 6.7. Annual costs of electricity bill of the community when P2P electricity trading is introduced

Thus, it can be calculated that the annual cost of the whole community is as following:

53,036 + 9,336 + 15,119 - 6,140 - 7,068 = 64,284 EUR.

Community savings

It is thus concluded that community can save 69,797 EUR - 64,284 EUR = 5,513 EUR annually on their electricity expenses when introducing P2P electricity trading.

6.4.2 Costs resulting from energy intensity

A miner in case of PoW or a validator when using PoA is going to incur losses of electricity required to authorize a transaction. This means that he needs to hold a payment of the adequate amount of electricity. This electricity can be bought either within the P2P local marketplace or from the electric grid. Then differences in electricity prices might be significant.

There also occurs a possibility that the authorizing person is a prosumer and he is not going to pay for electricity when excess electricity is produced at the same time. This however implicates in lower income resulting from prosumerism.

Depending on the person who is going to incur these costs and the source of electricity consumed (either electric grid or local marketplace), three scenarios are developed for each type of consensus:

1. Electricity consumed to authorise a transaction has to be bought from the electric grid with a price of 30.22 ct/kWh in case of authorisation done by consumer.
2. Electricity consumed to authorise a transaction has to be bought from the electric grid with a price of 23.81 ct/kWh in case of authorisation done by prosumer.
3. The electricity is delivered within P2P local marketplace with a price 23.34 ct/kWh.

6.4.3 PoW

The results of costs implicating from energy consumption of blockchain-based platform for P2P electricity trading in all of the three scenarios are presented in Table 6.8. The values given below stands for one transaction.

Electricity consumption [kWh/tx]	Ad. 1 [EUR/tx]	Ad. 2 [EUR/tx]	Ad. 3 [EUR/tx]
26	7.86	6.19	4.59
95	28.71	22.62	16.79
1005	303.71	239.29	177.58

Table 6.8. Costs implicating from energy consumption of blockchain-based trading platform utilizing PoW as a consensus

The costs are ridiculously high, thus PoW as a consensus for authorisation of electricity transactions is out of consideration. Taking into account that there are 5,475 transactions during a year, the annual costs start from circa 37,000 EUR.

6.4.4 PoA

The respective results of costs per transaction in case of utilization of PoA consensus of validation are displayed in Table 6.9 below.

Electricity consumption [kWh/tx]	Ad. 1 [EUR/tx]	Ad. 2 [EUR/tx]	Ad. 3 [EUR/tx]
0.26	0.08	0.06	0.05
0.95	0.29	0.23	0.17
10.15	3.04	2.39	1.78

Table 6.9. Costs implicating from electricity consumption of blockchain-based trading platform utilizing PoA as a consensus

Since it cannot be evaluated how many transaction throughout 5,475 during a year are authorised by prosumers and how many by consumers, it is hard to calculated annual costs implicating from electricity consumption of platform utilizing this kind of consensus. Thus, in order to do so, several assumption are done:

- both prosumers and consumers can become a validator and the likelihood of that is equal for both groups thus 30% of validators are assumed to be prosumers and 70% to be consumers, just as their respective share among community members
- respectively, 30% of electricity needed for validation is bought by prosumers and 70% is bought by consumers
- accordingly, 30% of electricity is bought with the price of 23.81 ct/kWh (price for prosumers which includes tax exception)
- as concluded in Paragraph 6.2, 13% of electricity demand of community is traded from prosumers to consumers, thus 13% of electricity needed for validation is delivered within the P2P marketplace with the assumed price of 17.67 ct/kWh
- the rest of electricity (57%) is bought by consumers from the grid with the standard price of 30.22 ct/kWh.

Thus, when taking into account the aforementioned, the annual costs of 5,475 electricity transaction are as shown in Table below:

Electricity consumption [kWh/tx]	Anual costs of transactions [EUR]
0.26	380
0.95	1,387
10.15	14,673

Table 6.10. Annual costs implicating from electricity consumption of blockchain-based trading platform utilizing PoA as a consensus

The costs of transactions, even though that much lower than in case of PoW still remain high in comparison to potential community savings on electricity bill. If the electricity consumption of the blockchain-based platform was minimal (0.26 kWh/tx), the implementation of such a platform sounds reasonable. In that case the community savings equal for 5,133 EUR. In case of the medium electricity consumption (0.95 kWh/tx), the community savings decline to 4,126 EUR. The results for maximal electricity consumption of 10.15 kWh/tx are definitely unacceptable.

6.4.5 Short summary of the results

As already concluded in Paragraph 6.4.3, both the energy consumption and costs resulting from that of PoW consensus are way to high to be dealt by communities.

When talking about consensus of PoA, the values seem to be more reasonable for the lower limit of electricity consumption. The upper limit is still way too expensive. In order to still generate savings for the community, the electricity consumption should vary between the minimal value up to approximately 1 kWh/tx. In case the energy consumption of the platform is at the level of 1 kWh/tx, the community savings equal for 4,053 EUR/a.

6.5 Short discussion of the results

I am aware that the results of the analysis conducted here and summarized in Paragraph 6.4.5 are strongly dependent on my assumptions and delimitations. These are for example: no trading between prosumers but only from prosumers to consumers, price of electricity sold at the P2P market at the level of 17.67 ct/kWh, price of electricity bought through the market for 23.34 ct/kWh, amount of transaction between prosumers and consumers at the level of 5,475 and way more.

At the same time, it is worth mentioning that several numbers used in this analysis are valid in June 2019 and most probably are going to change in the future. This relates to the electricity bill for a German household and its segments. It has been actually changing significantly during the last 10 years as it is displayed in Figure 6.4

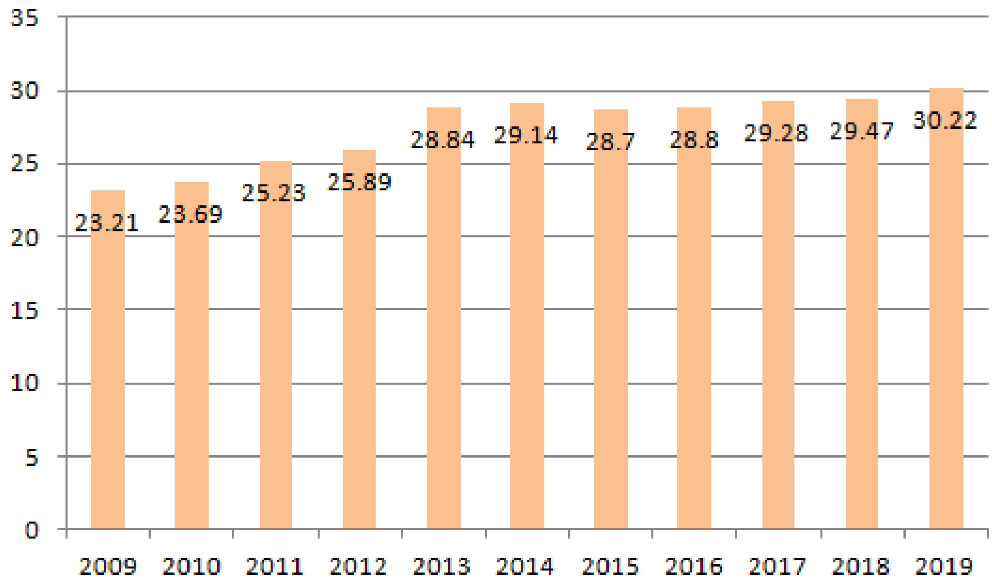

Figure 6.4. Variation of values of electricity bill for households in Germany during the past 10 years [ct/kWh] [Thalman and Wehrmann, 2019]

Moreover, the amount of state-granted FiT is permanently changing in Germany. Since January 2019 it has decreased from 11.47 ct/kWh to 10.79 ct/kWh as shown in Figure 6.5. It is also planned to keep decreasing in the future, e.g. in July it is expected to equal 10.64 ct/kWh.

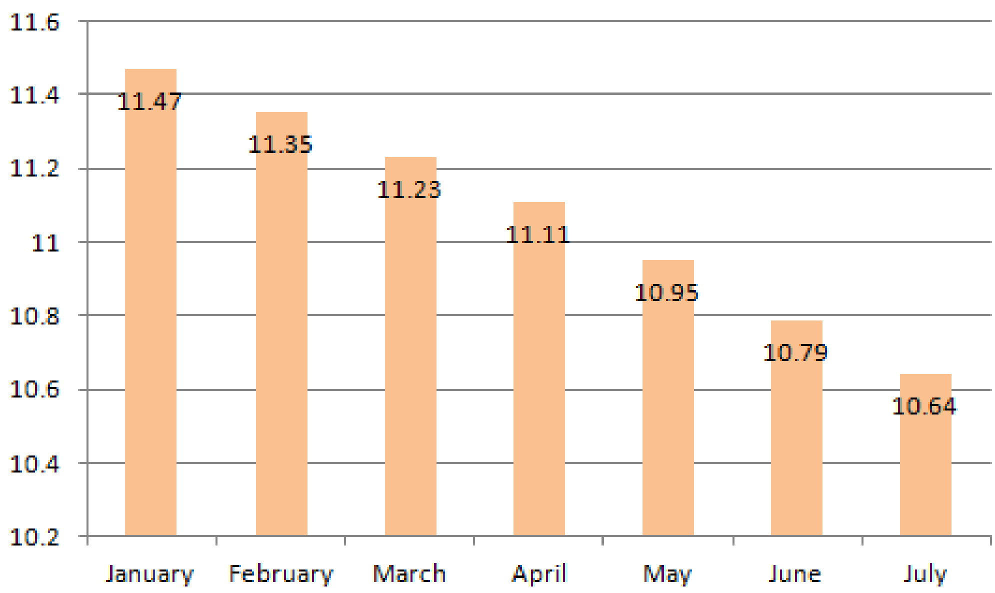

Figure 6.5. Variation of FiT for rooftop solar PV installations up to 10 kW in 2019 in Germany [ct/kWh] [Photovoltaik4all, 2019]

All in all, it is important to know that my results could have been much different if other assumptions have been done. This is however again discussed in Chapter 8.

6.6 Summary of uncertainties in Analysis

What we know	What we do not know
1. The amount of electricity traded within the P2P trading system is clearly determined. **2.** The results achieved in the analysis are valid for this particular case study and with the assumptions done.	**1.** It is not known how participants of P2P electricity trading system can bid prices of electricity sold within this system. **2.** The reliability of energy consumption (kWh/tx) for both PoW and PoA is questionable. **3.** It cannot be stated if results of this analysis can be generalized due to many uncertainties regarding data.

Figure 6.6. Uncertainties about the topic which occurred in Chapter 6

7 Conclusion

In order to wrap the project up, the conclusion is strongly related to Figure 1.7 in the very end of Chapter 1. Back then two needs of P2P energy trading - "providing solutions which lead to reduction of fossil fuel consumption and thus carbon footprint" and "low costs of operation" could not find a clear reflection in blockchain characteristics. Therefore blockchain was analyzed in the light of them.

After investigation it is easier to decide either blockchain has potential to fulfill these needs. This is summarized in Figure 7.1 below. Part with my comments changed according to findings from this project.

P2P energy trading needs	Blockchain potential	My comment
Providing solutions which lead to reduction of fossil fuel consumption and thus carbon footprint since P2P marketplaces mainly aim to integrate distributed RE sources	-	Blockchain is definitely very energy intensive, however some of its characteristics, such as described below, help in contributing to better implementation of DER of RE
Conducting many transactions at the same time - participants of P2P energy trading tend to trade very frequently small amounts of energy	+	Blockchain can provide desirable solution, however when using the consensus of PoW only one transaction every 10 minutes can be done – that might be not sufficient
Tracing these transactions so it is clear who and how much of energy is sold to whom	++	Blockchain as a distributed ledger is a very good tool for register transaction
P2P platform managed by the trading bodies themselves, without a necessity to involve any intermediaries such as Distribution System Operator (DSO) to reduce their Operation & Management costs	++	Since blockchain is distributed among participants of a network and does not contain any centralized structure, it is definitely a good solution
Low costs of operation since P2P energy trading is expected to provide economic benefits for community members	+	Operation of blockchain is very expensive when utilizing consensus of PoW, however in case of PoA the costs are way more reasonable; other operational costs are not analyzed in this project though

++ Very high   + High   +/- Unclear   - Low   -- Very low

Figure 7.1. Summary of P2P energy trading needs in the light of blockchain potential to fulfill them after the investigation

Discussion 8

During the project a lot of questions and dilemmas have arose. These are pinpointed and described below.

1. To what extend blockchain for P2P electricity trading can be called as an innovation

According to definition, innovation is "executing an idea which addresses a specific challenge and achieves value for both the company and customer" [Skillicorn, 2016]. In the light of that it can be said that blockchain is definitely a tool which addresses a challenge of managing P2P electricity trading platform on a community level. This platform has specific needs as shown in Figure 1.7 and 5.1 and some of them blockchain is able to fulfill. However it is questionable if it can provide *the value* for customers when this value is understood as economic benefits.

Moreover, throughout the four elements which characterise innovation diffusion (Theory of Innovation Diffusion described in Paragraph 3.1.1) there occur uncertainties over:

- characteristic of the innovation itself, which here is blockchain utilized for P2P electricity trading for communities, since the compactibility, trialability and observability are, in my opinion, lacking
- the passage of time, because the idea of blockchain applications in the energy sector is expending very fast, maybe even too fast
- the social system through which the innovation diffuses - definitely blockchain for energy is getting a lot of popularity in the business sphere of stakeholders which can be concluded from increasing interest among energy companies (see for example in World Energy Council [2018c]), however the actual end users of the solution are citizens living in communities, thus it should be addressed to their needs.

2. Properties of blockchain emphasized by experts such as transparency and security might not be the most crucial ones for communities which are interested in P2P electricity trading.

During one of the interviews Tamhane [2019] described the solution developed by the company he works at. ME SOLshare is providing a platform for P2P electricity trading within their own software, which is simply working like an app. It means that a person who is willing to trade excess electricity announces that to other community members. Then one of them can buy this excess electricity with an exact price. The whole transaction, including important information about trading parties, is thereafter saved in data storage - an online spreadsheet. Thus, there is no authorisation process likewise with blockchain.

Moreover, Tamhane [2019] works on defining needs of end users and he emphasizes that the main requirement regarding P2P electricity trading that he has encountered so far is generating economic savings for trading bodies.

In my opinion, an analysis about aforementioned must be conducted. It should be clear what are the needs towards platforms which enable for P2P electricity trading, but most importantly, it has to be investigated if blockchain in this application is actually working best for P2P electricity marketplace participants.

3. It can be clearly noticed that interviewed stakeholders are biased, very often unclear in their statements and not really eager to share data about their solution.

When interviewing Kellerer [2019] and Bedwell [2019] I very quickly realized that they are strongly biased. It can be understood since they are representing companies which are utilizing blockchain for P2P energy trading. However, their statements were often very general and unspecific.

For example, when asked about costs related to blockchain utilization for the purpose, Kellerer [2019] answers as following: "Our figures here are confidential, but development costs are at parity with other state of the art technologies in a green field approach. But could be significantly higher than an "off-shelf" product. In an established network, operation cost is strongly dependent on the number of transactions required and if applied the complexity and efficiency of the smart contracts."

It can be concluded from this answer that: blockchain might be more expensive than other respective technologies, operation costs are dependent on the number of transactions, however it is not specified why, and that E.ON's data regarding expenses is confidential.

Even though in the very beginning I was very positive about interviewing several stakeholders since I hoped they can share with me a lot of information about the technology and its application for P2P electricity trading, I must admit that it did not work out as I assumed. Due to the fact that companies are not eager to give access to their data, I was forced to do a lot of assumptions and decisions about how to delimit my research to actually be able to get a result.

4. Delimitation and assumptions done in this project most probably strongly influence its results.

The necessity to do a lot of assumptions implicates in uncertainty about generalisation of the results. For example my analysis was done on a collective case study located in Germany. There could be thus posed a question if the results are applicable for other case studies.

5. Lack of data results in uncertain values of energy consumption.

Indeed, big range of values of electricity consumption per transaction is a bit puzzling. Values for both PoW and PoA vary significantly - maximum values equal for over 3,500% of the minimum ones.

Having this in mind, the reliability of calculations done basing on these values can be uncertain. However, due to lack of data from the interviewed actors, I had to rely on the values provided within the research.

Another very interesting aspect is reason of such variations. I think that these values differ so much depending on the source because there is no scientific laboratory analysis which would aim to examine the energy intensity of blockchain. One should be done in the very near future, especially when taking into account the accelerating expansion of blockchain solutions in the energy sector, but also throughout other industries.

6. Proof-of-Authority as a consensus which is lacking the advantage of decentralization.

When investigating energy consumption and operation costs, PoA performs way better than PoW. However in contrary to PoW, blockchain-based platforms utilizing PoA can have only a limited number of validators. These validators should be but do not have to be democratically elected. This limited number of identified validators are then able to cooperate to censor particular types of transactions based on the identity of the user or the purpose of the transaction. Thus, they can control the network.

It is possible that in the aspect of P2P electricity trading the described problem is not an issue. However in general it sounds a bit contradictory to me - deciding for blockchain because of its characteristics such as security and transparency and then implementing authorisation consensus which excludes one of them.

7. Last but not the least - why are innovations being introduced if their sustainability is not even checked?

The main reason I wanted to focus on this specific topic is caused by concerns over connection between innovations and sustainability. When an innovation emerges, everyone seems to be so hyped about it even though it might be harmful for the environment. The question arises: why is that? I think that specific policies should determine a process of implementation of innovation which should include checking its impact, e.g. for the climate. It is relevant in light of current concerns about global warming.

Bibliography

Achim, 2019. Jo Achim. *The Proof of Authority Algorithm in the Energy Market.* Medium, 2019. URL https://medium.com/@joachim_21503/the-proof-of-authority-algorithm-in-the-energy-market-9535735d8f9c.

Anadon et al., 2016. Laura Diaz Anadon, Gabriel Chan, Alicia G. Harley, Kira Matus, Suerie Moon, Sharmila L. Murthy and William C. Clark. *Making technological innovation work for sustainable development.* Proceeding of the National Academy of Sciences of the United States of America, 2016. URL https://www.pnas.org/content/113/35/9682.

Andoni et al., 2019. Merlinda Andoni, Valentin Robu, David Flynn, Simone Abram, Dale Geach, David Jenkins, Peter McCallum and Andrew Peacock. *Blockchain technology in the energy sector: A systematic review of challenges and opportunities*, 2019. URL https://www.sciencedirect.com/science/article/pii/S1364032118307184.

Anisie, 2018. Arina Anisie. *Associate Program Officer at IRENA*, 2018.

Arts and Leroy, 2006. Bas Arts and Pieter Leroy. *Institutional Dynamics in Environmental Governance.* ISBN-13 978-1-4020-5078-7. Springer, 2006.

Atlamab and Willsa, 2018. Hany F. Atlamab and Gary B. Willsa. *Technical aspects of blockchain and IoT.* Advances in Computers, Elsevier, 2018. URL https://www.sciencedirect.com/science/article/pii/S0065245818300664.

Australian Renewable Energy Agency, 2018. Australian Renewable Energy Agency. *What are distributed energy resources and how do they work?* ARENAWIRE, 2018. URL https://arena.gov.au/blog/distributed-energy-resources/.

Barnard, 2018. Michael Barnard. *The Dark Side Of Blockchain: Electricity Consumption (Blockchain Report Excerpt).* Clean Technica, 2018. URL https://cleantechnica.com/2018/12/08/the-dark-side-of-blockchain-electricity-consumption-blockchain-report-excerpt/.

Beck and Müller-Bloch, 2017. Roman Beck and Christoph Müller-Bloch. *Blockchain as Radical Innovation: A Framework for Engaging with Distributed Ledgers as Incumbent Organization.* Conference: Hawaii International Conference on System Sciences, 2017. URL https://www.researchgate.net/publication/312166392_Blockchain_as_Radical_Innovation_A_Framework_for_Engaging_with_Distributed_Ledgers_as_Incumbent_Organization.

Bedwell, 2019. Steve Bedwell. *Contractor at Power Ledger*, 2019.

Bell and Gill, 2018. Keith Bell and Simon Gill. *Delivering a highly distributed electricity system: Technical, regulatory and policy challenges.* Energy Policy, Elsevier, 2018. URL
https://www.sciencedirect.com/science/article/pii/S0301421517307851.

Boshell, 2019. Francisco Boshell. *Renewable Energy Markets and Standards Analyst at IRENA*, 2019.

Boshell, 2018. Francisco Boshell. *Renewable Energy Markets and Standards Analyst at IRENA*, 2018.

Cambridge Dictionary, 2019. Cambridge Dictionary. *Meaning of prosumer in English.* https://dictionary.cambridge.org/dictionary/english/prosumer, 2019.

CoinMarketCap, 2019. CoinMarketCap. *All Cryptocurrencies.* 2019. URL
https://coinmarketcap.com/all/views/all/.

Copenhagen Centre on Energy Efficiency, 2018. Copenhagen Centre on Energy Efficiency. *Blockchain and sustainable energy in development and cooperation*, 2018. URL http://kms.energyefficiencycentre.org/elearning/blockchain-and-sustainable-energy-development-and-cooperation-webinar-16102018.

Creyts, 2018. Jon Creyts. *Managing Director at Rocky Mountain Institute*, 2018.

de Bruin, 2019. Barend de Bruin. *Account Executive at SAS*, 2019.

Decuyper, 2017. Xavier Decuyper. *How does a blockchain work.* Savjee Simply Explained, 2017.

Dhar, 2018. Rajdeep Dhar. *Public Vs Private Blockchain: What's Right For your Business?* Mobiloitte, 2018. URL https://www.mobiloitte.com/blog/public-vs-private-blockchain-whats-right-for-your-business/.

Diasr, 2018. Gabriela Prata Diasr. *Acting Head of the Copenhagen Centre on Energy Efficiency*, 2018.

Dowling, 2018. Richard Dowling. *Chief Economist and Global Government Affairs at The Faraday Grid*, 2018.

Eggleston, 2018. James Eggleston. *Senior Analyst at Power Ledger*, 2018.

EMD International A/S, 2019. EMD International A/S. *energyPRO*, 2019. URL
https://www.emd.dk/energypro/.

European Commision, 2017. European Commision. *Residential Prosumers in the European Energy Union*, 2017.

Gimmler, 2017. *Antje Gimmler*, 2017.

Green Cells Energy, 2019. Green Cells Energy. *PV Efficiency and Solar LCOE.* 2019. URL https://greycellsenergy.com/articles-analysis/pv-efficiency-and-solar-lcoe/.

Hvelplund, 2019. Frede Hvelplund. *Professor at the Planning Department of AAU*, 2019.

Hwang et al., 2017. Junyeon Hwang, Myeong in Choi, Tacklim Lee, Seonki Jeon, Seunghwan Kim, Sounghoan Park and Sehyun Park. *Energy Prosumer Business Model Using Blockchain to Ensure Transparency and Safety.* 4th International Conference on Power and Energy Systems Engineering, Energy Procedia, 2017.

International Renewable Energy Agency, 2019. International Renewable Energy Agency. *Innovation landscape for a renewable-powered future: Solutions to integrate variable renewables, International*, 2019. URL https://www.irena.org/publications/2019/Feb/Innovation-landscape-for-a-renewable-powered-future.

IRENA, 2018. IRENA. *Innovation Week 2018: Digital applications for the energy transition - Blockchain*, 2018.

Jamshed, 2014. Shazia Jamshed. *Qualitative research method-interviewing and observation.* J Basic Clin Pharm., 2014.

Jayachandran, 2017. Praveen Jayachandran. *The difference between public and private blockchain.* IBM, 2017. URL https://www.ibm.com/blogs/blockchain/2017/05/the-difference-between-public-and-private-blockchain/.

Johnson et al., 2007. R. Burke Johnson, Anthony J. Onwuegbuzie and Lisa A. Turner. *Toward a Definition of Mixed Methods Research.* Journal of Mixed Methods Research, 1, 112–133, 2007.

Kellerer, 2019. Dr Elisabeth Kellerer. *Venture Manager and Data Scientist at E.ON*, 2019.

Konstantopoulos, 2017. Georgios Konstantopoulos. *Understanding Blockchain Fundamentals, Part 2: Proof of Work and Proof of Stake.* Medium, 2017. URL https://medium.com/loom-network/understanding-blockchain-fundamentals-part-2-proof-of-work-proof-of-stake-b6ae907c7edb

Kozar, 2019. Tomasz Kozar. *Cloud Technology Strategist – Microsoft*, 2019.

Krause and Tolaymat, 2018. Max J. Krause and Thabet Tolaymat. *Quantification of energy and carbon costs for mining cryptocurrencies.* Nature Sustainability, 2018. URL https://www.nature.com/articles/s41893-018-0152-7.

Leberer, 2018. Philipp Leberer. *Impact of P2P power trading on rooftop PV in Alberta*, 2018.

Liua et al., 2019. Yikui Liua, Lei Wua and Jie Lib. *Peer-to-peer (P2P) electricity trading in distribution systems of the future.* The Electricity Journal, Elsevier, 2019. URL https://www.sciencedirect.com/science/article/pii/S1040619019300284.

Madsen, 2016. Henrik Madsen. *Probabilistic forecasting and its importance for energy systems.* Centre for IT-Intelligent Energy Systems (CITIES), Department of Applied Mathematics and Computer Science, DTU, 2016.

Malmo, 2017a. Christopher Malmo. *A Single Bitcoin Transaction Takes Thousands of Times More Energy Than a Credit Card Swipe.* Motherboard Tech by Vice, 2017. URL https://www.vice.com/en_us/article/ypkp3y/bitcoin-is-still-unsustainable.

Malmo, 2017b. Christopher Malmo. *One Bitcoin Transaction Consumes As Much Energy As Your House Uses in a Week.* Motherboard Tech by Vice, 2017. URL https://www.vice.com/en_us/article/ywbbpm/bitcoin-mining-electricity-consumption-ethereum-energy-climate-change?fbclid=IwAR1NsAaj0FRuzPDRzj_Apk6I3iySuiG_zdxW78NLhLSbM7Ahbo3L31lyc_E.

Malmo, 2017c. Christopher Malmo. *Ethereum Is Already Using a Small Country's Worth of Electricity.* BMotherboard Tech by Vice, 2017. URL https://www.vice.com/en_us/article/d3zn9a/ethereum-mining-transaction-electricity-consumption-bitcoin?fbclid=IwAR1NsAaj0FRuzPDRzj_Apk6I3iySuiG_zdxW78NLhLSbM7Ahbo3L31lyc_E.

Markets Insider, 2019. Markets Insider. *Bitcoin Price.* 2019. URL https://markets.businessinsider.com/currencies/btc-usd.

Mourdoukoutas, 2018. Panos Mourdoukoutas. *Bitcoin, Ethereum And Litecoin Are The Most Popular Cryptocurrency Investments Among Millennials.* Forbes, 2018. URL https://www.forbes.com/sites/panosmourdoukoutas/2018/03/25/bitcoin-ethereum-and-litecoin-are-the-most-popular-cryptocurrency-investments-among-millen
#20bbf25676dd.

Murkin et al., 2016. Jordan Murkin, Ruzanna Chitchyan and Alastair Byrne. *Enabling peer-to-peer electricity trading.* Proceedings of ICT for Sustainability 2016, 2016. URL https://www.atlantis-press.com/proceedings/ict4s-16/25860390.

Nace, 2019. Shaun Nace. *Bitcoin - Statistics and Facts.* Statista, 2019. URL https://www.statista.com/topics/2308/bitcoin/.

Park and Yong, 2017. Chankook Park and Taeseok Yong. *Comparative review and discussion on P2P electricity trading.* International Scientific Conference "Environmental and Climate Technologies", CONECT 2017, 10–12 May 2017, Riga, Latvia, Elsevier, 2017. URL https://www.researchgate.net/publication/320374197_Comparative_review_and_discussion_on_P2P_electricity_trading.

Parra et al., 2017. David Parra, Maciej Swierczynski, Daniel I. Stroe, Stuart A. Norman, Andreas Abdon, Jörg Worlitschek, Travis O'Doherty, Lucelia Rodrigues, Mark Gillott, Xiaojin Zhang, Christian Bauer and Martin K. Patel. *An interdisciplinary review of energy storage for communities: Challenges and perspectives.* Renewable and Sustainable Energy Review, Elsevier, 2017. URL https://www.sciencedirect.com/science/article/pii/S1364032117306263.

Peter, 2018. Viktor Peter. *Senior Blockchain Governance Expert at the GIZ Blockchain Lab*, 2018.

Photovoltaik4all, 2019. Photovoltaik4all. *Aktuelle EEG Vergütungssätze für Photovoltaikanlagen 2019.* 2019. URL https://www.photovoltaik4all.de/

aktuelle-eeg-verguetungssaetze-fuer-photovoltaikanlagen-2017?fbclid=IwAR3xVihjXvZ2_udT9zyUsw8VM_UzqlAjCy1cLjzrc5g9B6DTHtyH3OLMOcE.

Pollitt, 2018. Michael Pollitt. *Electricity network charging in the presence of distributed energy resources: principles, problems and solutions.* Economics of Energy and Environmental Policy, 2018. URL https://doi.org/10.5547/2160-5890.7.1.mpol.

Power Ledger, 2018. Power Ledger. *Whitepaper*, 2018.

Ramirez, 2018. Paulina Ramirez. *Institutional Analysis: Three Pillars, Socio-Technical Context of Planning, Aalborg University*, 2018.

Ratka, 2019. Sean Ratka. *Associate Professional at IRENA*, 2019.

Ratka, 2018. Sean Ratka. *Associate Professional at IRENA*, 2018.

Rogers, 1983. Everett M. Rogers. *Diffusion of Innovations - Third Edition.* ISBN 0-02-926650-5. The Free Press, 1983. URL https://teddykw2.files.wordpress.com/2012/07/everett-m-rogers-diffusion-of-innovations.pdf.

Say, 2019. Nicholas Say. *Crypto Energy Consumption: How Green is Blockchain Technology?* Blokonomi, 2019. URL https://www.statista.com/statistics/881541/bitcoin-energy-consumption-transaction-comparison-visa/.

Scott, 1995. W. Richard Scott. *Institutions and Organizations. Ideas, Interests and Identities.* ISBN: 978-142242224. Sage Publications, 1995.

Sia Partners, 2018. Sia Partners. *Peer-to-peer (P2P) energy: A threat or an opportunity for traditional suppliers?* 2018. URL http://energy.sia-partners.com/sites/default/files/20180910_sia_partners_p2penergy.pdf.

Skillicorn, 2016. Nick Skillicorn. *What is innovation?* Idea to Value, 2016. URL https://www.ideatovalue.com/inno/nickskillicorn/2016/03/innovation-15-experts-share-innovation-definition/.

Sonnet, 2018. Francois Sonnet. *Co Founder of ElectriCChain*, 2018.

Sousa et al., 2019. Tiago Sousa, Tiago Soares, Pierre Pinson, Fabio Moret, Thomas Baroche and Etienne Sorin. *Peer-to-peer and community-based markets: A comprehensive review.* Renewable and Sustainable Energy Reviews, Elsevier, 2019. URL https://www.sciencedirect.com/science/article/pii/S1364032119300462.

Stipp, 2018. Dr Horst Stipp. *Bitcoin network average energy consumption per transaction compared to VISA as of 2019 (in kilowatt-hours).* Statista, 2018. URL https://www.statista.com/statistics/881541/bitcoin-energy-consumption-transaction-comparison-visa/.

Stram, 2016. Bruce Stram. *Key challenges to expanding renewable energy.* Energy Policy 96, 2016.

Szulecki, 2018. Kacper Szulecki. *Conceptualizing energy democracy.* Environmental Politics, 2018.

T, **2019**. Alex T. *Inside Ethereum's Plan To Reduce Energy Consumption by 99%.* CCN, 2019. URL `https://www.ccn.com/inside-ethereums-plan-to-reduce-energy-consumption-by-99`.

Tamhane, **2019**. Neel Tamhane. *Product Manager at ME SOLshare*, 2019.

Thalman and Wehrmann, **2019**. Ellen Thalman and Benjamin Wehrmann. *What German households pay for power.* Clean Energy Wire, 2019. URL `https://www.cleanenergywire.org/factsheets/what-german-households-pay-power`.

The Intergovernmental Panel on Climate Change, **2018**. The Intergovernmental Panel on Climate Change. *Global Warming of 1.5 ºC*, 2018. URL `https://www.ipcc.ch/sr15/`.

United Nations, **2015**. United Nations. *Sustainable Development Goals*, 2015. URL `https://sustainabledevelopment.un.org/?menu=1300`.

Vacilescu, **2018**. Dumitru Vacilescu. *Policy Specialist/Innovation lead for UNDP Moldova*, 2018.

Valentine, **2005**. G Valentine. *Tell me About...: Using Interviews as a Research Methodology.* Pearson Education, 2005.

Wijesooriya, **2018**. Niranjika Wijesooriya. *Sustainability Needs Innovation, Innovation Needs Sustainability.* Sydney Environment Institute, 2018. URL `http://sydney.edu.au/environment-institute/blog/sustainability-needs-innovation-innovation-needs-sustainability/`.

World Energy Council, **2018a**. World Energy Council. *World Energy Insights Brief - Is blockchain in energy driving an evolution or a revolution?*, 2018a.

World Energy Council, **2018b**. World Energy Council. *World Energy Insights Brief - Blockchain: Evolution or revolution*, 2018b.

World Energy Council, **2018c**. World Energy Council. *The Developing Role of Blockchain*, 2018c.

World Energy Council, **2016**. World Energy Council. *Average electricity consumption per electrified household.* 2016. URL `https://wec-indicators.enerdata.net/household-electricity-use.html`.

Zhang et al., **2018**. Chenghua Zhang, Jianzhong Wu, Chao Long and Meng Cheng. *Review of Existing Peer-to-Peer Energy Trading Projects.* The 8th International Conference on Applied Energy – ICAE2016, Elsevier, 2018. URL `https://www.sciencedirect.com/science/article/pii/S1876610217308007`.

Interview - E.ON A

Interview with Kellerer [2019] who works as a Venture Manager and Data Scientist at E.ON in Munich, Germany.

Could you tell what do you do? What is your connection and experience with the technology of blockchain utilized in energy sector?

I am a venture manager and data scientist at E.ON's digital venture laboratory futurelab. We constantly scan the tech, customer and business space for new developments, explore their implications and combine them to new ventures which we then test. One of the tech developments we explored was blockchain technology.

In the initial exploration, the disintermediation potential of the technology draws our interest, especially its implications for our business: where do we depend on intermediaries? Where are we the intermediary? The first question brought us to whole sale energy trading as we use brokers to arrange deals for us – enerchain. The second, yielded in the community level P2P.

Subsequently, we broadened the space of interest to any transaction where the mistrust between the parties implies costs.

Could you described activities of E.ON related to blockchain for energy sector? I know that there is project called Enerchain – could you tell something about it?

We are affiliate of the Energy Web Foundation, developed our own prototypes and are still extending our solid knowledge base.

As mentioned before enerchain was our starting point. Since today, energy wholesale traders have two main choices: trade on a broker platform or on an energy exchange. Both involve a third party as an intermediary between the counterparties. For us enerchain was an aim to change that through a blockchain-based order book which disintermediates the third parties and provides a new way of facilitating a deal between the counterparties.

Enerchain allows trading organizations to anonymously commit orders to a decentralized order book which can be lifted by another energy trading company. Thereby, the trade is confirmed for both parties – revealing the counterparties' identities to each other and placing an auditable manifestation.

Since your company is working on utilization of blockchain - what kind of characteristics does blockchain have which make it an interesting technology for energy?

The technologies ability to digitally foster trust between self-serving parties. This is regardless of the field – energy, finance, supply chain,... .

Which blockchain characteristics could be helpful in providing peer-to-peer energy trading? Are these blockchain characteristics crucial for this purpose or maybe can they be provided within another technology/software? If yes, do you know any examples?

The digitalization of trust characteristic is key if peer-to-peer is understood literally, i.e. from peer to peer without a platform in-between. Since this network of peers needs to be self-contained and willing to share responsibility a trust base is essential. The more one weakens the interpretation of "peer to peer" the less important becomes the unique selling point of the blockchain technology and more platforms come into play, e.g. https://www.enyway.com/de.

What kind of expenses are related to blockchain for peer-to-peer energy trading? Do you have any knowledge how high are these expenses?

Our figures here are confidential, but development costs are at parity with other state of the art technologies in a green field approach. But could be significantly higher than an "off-shelf" product. In an established network, operation cost is strongly dependent on the number of transactions required and if applied the complexity and efficiency of the smart contracts.

Can these expenses be avoided by using another technology?

There is no free lunch – so reduced yes, avoided no.

Meeting & Interview - IRENA B

B.1 Meeting

The meeting with IRENA experts took place on December 5th, 2018 at Innovation and Technology Center of International Renewable Energy Agency (IRENA) in Bonn, Germany. The participating bodies of the meeting were: Boshell [2018], Ratka [2018] and Anisie [2018].

The main topic of the meeting were applications of blockchain in the energy sector. It was emphasized that blockchain is of an interest from IRENA's side and currently they work on a report "Innovation landscape for a renewable-powered future" which elaborates on digitalisation in the energy sector with a focus on blockchain besides other technologies. Moreover, it was stressed out that IRENA as an organisation is able to provide sources related to blockchain used for energy issues, e.g. from their previous conferences such as Innovation Week 2018.

All three of them work on the topic at IRENA. They mentioned interesting applications of blockchain that might have potential implementation in the energy sector in the future. It is for example electricity trading between users but also devices, e.g. batteries or electric vehicles. Here trading platforms based on blockchain can help in improving flexibility of energy supply. Another example is assigning smart contracts between distribution companies and energy consumers, which can be provided by blockchain's ability to reveal visibility of assets.

When focusing on energy trading, they gave examples of companies which are active in the area and these are: Power Ledger from Australia, The Sun Exchange from RPA and LO3 from the USA. They also mentioned Malta as an example of a blockchain-base P2P energy trading project on a national level. They also told me about ME SOLshare which is an example of a company which provides P2P electricity trading service without utilization of blockchain.

In the end, the topic was directed to economic challenges related to blockchain. Boshell [2019] said that blockchain is an interesting technology, however there are high costs related to its utilization. It is due to its energy consumption. He also mentioned that the energy consumption differs depending on the type of authorisation of transactions done within a blockchain platform. It varies significantly when using Proof of Work or Proof of Authority (these are described in Paragraph 1.3.2).

B.2 Interview

Interview with Boshell [2019] and Ratka [2019].

What are the main challenges for energy markets nowadays when we face several attempts of energy transitions towards decarbonised and decentralised systems worldwide?

- Regulatory - no room for failure in the energy sector, need private sector to innovate within sandboxes; regulations differ widely by market, hard for DLT solutions/start-ups to scale
- Structural - the current top-down energy sector approach will not be capable of efficiently integration high shares of DERs, new innovations at the grid edge are needed, and perhaps new grid architectures place prosumers at the top
- Social - lack of awareness
- Economic - transactions can still be more costly than centralised systems
- Technology - DLT technology still in its infancy, much more scalability needed for have an impact in the energy sector. Currently only seeing niche use cases (REC market on blockchain by Singapore Power).

What kind of characteristics does Blockchain have which make it an interesting technology for energy trading?

- Transparency
- Security through cryptography
- Potential to handle transactions at scale with minimal transaction fees (Scaling is ongoing, particularly for truly decentralised platforms like Ethereum. This is less of an issue for more centralised platforms like EWF which rely on PoA)
- Immutability – useful for registering green certificates
- Decentralised nature – useful for spurring increased investments in small-scale projects in developing countries without the need for money transfers or conversions
- Ability to have micropayments useful here as well (sending a few USD cents worth of a cryptocurrency). ...

Which blockchain characteristics could be helpful in providing peer-to-peer energy trading? Are these blockchain characteristics crucial for this purpose or maybe can they be provided within another technology/software?

- If the energy sector is able to transition to an LDO architecture (in order to accommodate the growing amount of DERs) blockchain can play a critical role in managing all of these data/transactions in a transparent way. Automation via smart contracts will be needed to manage all of the new smart devices (75bn IoT devices online by 2025).
- Increased grid complexity will require increased intelligence, automation and transparency; blockchain provides these tools.

What kind of expenses are related to blockchain for peer-to-peer energy trading?

- Consumers will need blockchain-enabled smart metres (provided by service providers such as PowerLedger).

- At the moment what we see are mainly PoCs, PowerLedger or LO3 would able to provide specifics in terms of exact costs to consumers where they are testing their platforms.

In case of blockchain applications for peer-to-peer energy trading for a community, what kind of activities are required from community members? To what extend do they have to adjust to this technology?

- What we've heard from our stakeholders, in a general sense, is that adoption will only become widespread once the underlying blockchain technology powering these solutions is hidden in the background and consumers no longer need to be tech savvy to adopt it (e.g. using the Uber app without having to know about TCP/IP). Allowing consumers to go about their lives, while smart contracts execute in the background and manage their energy usage/storage/generation based on price signals is the way to mass adoption.
- PowerLedger or LO3 would able to provide specifics.

In the end, could you tell what do you do? What is your connection and experience with the technology of blockchain?

- Innovation Week 2018 – Blockchain panel (session summaries below)
- Innovation Landscape report – Blockchain brief

Interview - Power Ledger C

Interview with Bedwell [2019] who is a Contractor at Power Ledger in Perth, Australia. Among others, his duties include working with the marketing team to develop product materials and respond to media and support Power Ledger community in general.

What is the experience of Power Ledger in utilization of blockchain for P2P energy trading? How many blockchain based P2P energy trading systems does the company operate?

Power Ledger was founded in May 2016 with the first demonstration of our P2P energy trading platform in December of that year. We now have 12 active projects, 11 of which are using either our xGrid (in front of the meter) or uGrid (behind the meter) P2P products.

We also have our C6/C6+ carbon credits, VPP 2.0 and Asset Germination products which make up our portfolio which you can read more about at our website.

Does the company operate any P2P energy trading platforms which are not based on blockchain?

No. Blockchain technology offers properties that cannot be replicated by traditional ledger technologies which we believe are important to P2P energy trading. Take an apartment block operating a microgrid utilising solar and battery storage as an example. You might have 200 tenants sharing the PV/storage and each is entitled to use or trade their share between each other. Blockchain enables immediate settlement between tenants to be performed securely without a trusted intermediary.

This becomes even more important when you consider the number of entities that could be trading across the grid. The trades might not only be between neighbours, but also between energy retailers, or between commercial and industrial customers and the network operator for providing grid stability without a trusted middleman.

Would you describe how energy intensive are your P2P systems based on blockchain (e.g. how much power do you need to operate a specific energy system in Wh if possible))?

Power Ledger's trading platform uses a Proof of Authority (PoA) consensus mechanism as opposed to Proof of Work (PoW) like Bitcoin does. The energy requirements for operating such a blockchain is far lower, in the region of a standard consumer laptop.

What kind of costs are related to utilization of blockchain for P2P energy trading? Which costs play the main role?

Power Ledger built and continually improves upon the platform and certainly the development is a fair portion of the financial costs. Being a new technology and as leaders in this space, we spend a lot of time educating the industry and regulators about P2P energy trading and the underlying blockchain technology and the problems its solving. As a result of this investment we are now having much more open dialog with energy companies and regulators than back in 2016 now that they have a greater understanding of the technology and its value.

How expensive is building up a P2P energy trading platform based on blockchain?

As a private company, we cannot share the development costs we've incurred on our platform. Having said that our platform is provided as a subscription model to our customers with very little upfront cost as we use data from existing smart meters. As most enterprises now prefer Opex versus Capex expenditure, they are looking to best of breed cloud, subscription based software providers rather than building and maintaining systems in-house.

How expensive is maintenance of such a platform?

As above. Power Ledger are wholly responsible for the maintenance of the platform.

Interview - SOLshare D

Interview with Tamhane [2019] who is a Product Manager at ME SOLshare in Dhaka, Bangladesh. ME SOLshare is a company which is providing P2P energy trading across Bangladesh within a self-developed platform.

What is your role in ME SOLshare?

I am a product manager and my job is based on walking across the teams – operations, technical as well as working with users of our solution themselves. I specialize in a field of recognizing what users want, what they need and what they expect from our solution. Then I work on know-how which helps in translating these needs to the technical side.

I have been working for SOLshare for 3 years. Before that I already had an experience in working with microgrids in India. However, that was more for consultancy kind of role.

How does your platform work? How big it is?

Just to give you more context and background first – during the last 15 years 5 million of small solar systems were installed in Bangladesh and power which is generated within these systems fulfils over 30% of electricity needs of households therein. Also nowadays people start to use more devices which require power, it is no more enough to just charge phones like it used to be a couple of years ago. People stepped up with their incomes, they use more appliances, such as fans, fridges and those cannot be powered with these long-distanced tiny solar systems which create microgrids. Thus, what SOLshare does is developing a network, which basically means that we interconnect these distributed solar systems physically, through cables, as well as create a digital marketplace which enables for energy trading among the users.

We do it by implementing our solution, called SOLbox, which works similarly to a phone – you can charge your phone with a specific amount of money and then spend it on electricity. Also if you have excess electricity and you do not utilize it, with just a "click" on your SOLbox you can sell it. Users are also able to control their balances (e.g. electricity production and consumption, amount of energy stored in batteries and so on) on a displayer placed on the SOLbox.

There must be a software which is managing your P2P energy trading service. What kind of software do you use? Did you develop your own solution or did you use a software which is available on the market?

We developed our own software. We buy hardware but the software is mostly made by our IT specialists.

How big are your P2P systems?

We do not install a new capacity of solar power like in microgrids, we rather connect existing solar home systems. The definition of a solar home system is simply having a tiny panel, having a tiny battery and a few loads that can be connected to that.

The power traded within a system depends on the area, condition of grid, if it is a market place or a household grid, number of people buying the energy etc. However, these systems are always under 5 kW. Now we operate around 25 systems but by the end of this year it is going to be nearly a hundred. We also plan on building up bigger than 5 kW systems but is all depends on users' needs.

But do you think your data base is able to manage bigger systems?

Yes, absolutely.

Blockchain is getting a lot of attention lately, especially in application for P2P energy trading. You decided to develop your own software. Why haven't you used blockchain for your P2P platform?

That is a very good question and it has a simple answer to begin with. First of all, blockchain is an extremely new technology and secondly – it is extremely energy intensive. Transfering a 1 Wh of energy requires spending 1 kWh on computing power. It is a very inefficient process. At this point, the technology itself has not gotten to a stage where it can be plugged in, played and started to be used without other systems. We [Bangladesh] are not blockchain exports and blockchain exports across the globe are very expensive. The whole idea of building a blockchain and maintaining it is not more complex than maintaining a log-in IoT data.

It is not that we are not interested in blockchain, we have definitely been in touch and have been talking with a lot of blockchain exporters, especially from Europe. We are exploring different opportunities but at this stage they are mostly at a "pilot and try" level.

How energy intensive is you platform? How much power do you need to operate it?

It is much less energy intensive than blockchain, because it works just like a simple data base. It is much more like storing a tiny Excel sheet online. We also try to filter the data thus we do not have to store everything. There are a lot of cloud and physical servers that we can access and that we used in the past. It is what enables us to do P2P in much more simple way and without creating one complex system to store data.

What generate the highest costs of your solution?

Costs of development of the SOLbox system itself, so people who are doing that. But also development of the tech side as well. We need to buy some parts, we need to assemble our solution and so on – which is mainly software and hardware. Another aspect is working with people – enabling them to understand how the system work and how they can benefit by using it.

How expensive is maintenance of your solution?

What we do is working on a B2B model which means training a local person in every grid, who therefore becomes our partner, to operate and maintain the system. This person is available to help SOLbox users in case of any issues.

How many specialists did you required to develop your solution?

We started with 10 people on board, but the team grew because the amount of projects is higher. Now we are 30 members in our team. It is a mix of people with different backgrounds – mostly power electronics, IT, buts also engineering or architecture.

Interview - SAS/IBM E

The interview is conducted with de Bruin [2019] who is currently employed at SAS as Account Executive, however previously he used to work at IBM. While working for IBM he was implementing blockchain technology through the Hyperledger project. The application aims on improving loyalty programs within the travel and transportation industry. As he argues, IBM which is a company specializing in both software and hardware, is said to be one of the world's leaders in fostering blockchain and Internet-of-Things (IoT) technologies into real practices.

He points out costs related to blockchain utilization which occur in any application, no matter what the field is. Accordingly it is:

- Expenses related to human resources, especially for hiring in IT and data science and analysis
- Costs implicating from mining, which are a result from requirements of high computer power
- Scalability
- Business development related

He also gives specific numbers based on the real project that he was involved to on behalf of IBM. Expenditures for controlling of the application equals to 150 EUR per hour which gives 24,000 EUR monthly, salaries for 2 coders which are at the level of 100 EUR/h give 32,000 EUR monthly and last but not the least, costs related to implementation of pilot software are rounded to 100,000 EUR, plus 20,000 EUR of amortisation.

He is not able to provide any numbers related to energy consumption of blockchain-based platforms, even though he is aware that this generates high costs.

Summary of lecture held by Tomasz Kozar F

Kozar [2019] is a Cloud Technology Strategist working at Microsoft Polska. Among others, he is leading a research in innovative projects implementing new technologies such as IoT, Machine Learning and blockchain to renewable energy solutions, such as wind turbine monitoring.

On February 21, 2019 Kozar [2019] held a lecture *Blockchain: from the idea to the new business model* (the lecture was conducted in Polish and its original name is as following - *Blockchain: od pomysłu do nowego modelu biznesowego*). The meeting with Microsoft employee was organized by the Academic Association of Power Engineers at Warsaw University of Technology.

The lecture's agenda included i.a. basics of how does blockchain work; evaluation on different scenarios of blockchain application in energy sector, escpecially by being used for smart contracts which are getting a lot popularity lately due to extended digitalisation in energetics; and a demonstration of a platform "Sandbox" which enables for initiating an own system based on blockchain.

In the very beginning Kozar [2019] emphasized that lately lots of new projects implementing blockchain to various industry sectors, also to energy, have been formed worldwide. He also gave examples of Polish companies which are involved in doing so and these are: Tauron, PGE, Energa and PGNiG Innowacje which developed an interesting project called Billon.

He also said that energy intensity of blockchain is a challenging aspect of its utilization. As he mentioned - a transaction of 1 Bitcoin between peers of a net requires 95 kWh to be executed. Moreover, he said that at the moment blockchain consumes up to 60 TWh of power annually.

Afterwords Kozar [2019] focused on blockchain and its technological aspects. He pointed out the most crucial characteristics of blockchain, which in his opinion makes the technology so desirable in several applications. According to him, the adjectives which describe blockchain the most are: secure (mainly due to the fact that administrator of a blockchain net, if existing, is not able to make any changes in a ledger), distributed, shared (since ledger is available for everyone participatng in a network) and transparent. Then he explained three ways to authorise blockchain's transactions which are the most interesting and popular among the world and these are: Proof of Work (PoW), Proof of Stake (PoS) and Proof of Authority (PoA).

He also introduced some energy related projects where blockchain is utilized. Most importantly he focused on smart contracts which are already widely known among industries and are being introduced in power sector. Smart contracts are said to play a very important role in the progress that is made in blockchain technology, consisting in the transition from the protocol of financial transactions to a universal tool that will automatically implement contract terms in an automated manner, minimizing the risk of error and manipulation. Smart contracts, like traditional paper ones, are a guarantee of trust. There are, however, some of their features. They are not a stack of paper filled with legal and difficult to understand language. Usually, it also happens that the lawyers spend a lot of time and verify the contracts legally. Smart contracts are digital versions of these traditional ones. These are simply programs that operate on the Ethereum platform as part of blockchain technology and have the same meaning: legally bind anyone who intends to participate in the contract. It's nothing but code lines written in Solidity language comparable to Java Script. This code is then converted into a byte code and released to the lock as a smart contract. Each contract has its own block address. This means that if one starts communicating with someone else, the contract will be created as a blockage and its address will be available to all interested parties. Then you can use it to interact with the smart contract and fulfill the commitment to start implementing it. These smart contracts can be implemented as contracts for electricity between a user and a company which provides the electricity. Besides smart contracts, blockchain can be also used for data processing in cases where there are a lot of input data. As an example Kozar [2019] gave wind turbines which typically have circa 25 sensors located on their parts. These sensors measure data such as ambient conditions or velocity of blades etc. Retrieval of the measurment data as well as its processing can be done more safely and quickly with a platform based on blockchain.

Moreover, he mentioned examples of companies which applied blockchain to their solutions and these are:

- Adger Energi Smart Grid based in Norway which specialises in providing peer-to-peer energy trading for small communities therein
- Centrica from the United Kingdom which utilizes blockchain to control heat consumption in smart homes that they operate
- Allego which is a emobility company based in Berlin, Germany and it uses blockchain to proceed transactions for charing of their electric vehicles.

Summary of webinar about blockchain G

Webinar *Blockchain and sustainable energy in development and cooperation* took place on October 16, 2018 within an e-learning platform. It was organized by Copenhagen Centre on Energy Efficiency in cooperation with United Nations Environmentent and program Sustainable Energy for All. During the webinar 5 experts - Diasr [2018], Peter [2018], Eggleston [2018], Vacilescu [2018] and Sonnet [2018] - took a stage and talked about their experience in different projects of blockchain utilization in the energy sector, especially focusing on sustainability issues.

First speaker - Diasr [2018] - is working as an Acting Head of the Copenhagen Centre on Energy Efficiency. She talked about potential applications of blockchain in solutions related to energy efficiency. She elaborated that blockchain could be used for issuing white certificates, crowdfunding loans for investments in energy efficiency and achieving flexible energy demand and supply by implementation of blockchain based smart meters and smart contracts. Moreover, she emphasized that blockchain can be used in other applications, e.g. for energy-as-a-service solutions, such as e-mobility, as well as peer-to-peer energy trading in energy systems based on renewables. Furthermore, Diasr [2018] mentioned a few obstacles blockchain could be facing and these are: market mechanisms, lack of funding for small-scale projects and changing role of grid operators in case of blockchain based neighbour or micro-grid peer-to-peer energy trading.

Second speaker - Peter [2018] - is a Senior Blockchain Governance Expert at the GIZ Blockchain Lab based in Berlin, Germany (GIZ - Deutsche Gesellschaft für Internationale Zusammenarbeit). He is working on blockchain utilization for energy systems in developing coutries, mainly in Africa. He mentioned a few projects where GIZ implemented blockchain to provide electricity coming from renewable energy sources.

Third speaker - Eggleston [2018] - is a Senior Analyst at Power Ledger. At his work, he specialises in project development of blockchain applications i.a. for renewable electricity trading, management of commodities and market optimization. Power Ledger as a company focuses on peer-to-peer energy trading within small-scale community networks, but also develops peer-to-peer trading between batteries and electric vehicles. They also operate virtual power plants. Virtual power plant's main idea is to concentrate small-scale electricity production units and operate it as a one power plant. Eggleston [2018] said that blockchain enables for development of local energy markets, which is going along with idea of switching from centralized systems to decentralized energy supply. However, in his opinion, this transitions leads to a shape of energy markets which are more dependent on consumers, or prosumers, and that might be a challenge in the future.

Forth speaker - Vacilescu [2018] - is a Policy Specialist/Innovation lead for UNDP Moldova. He has been actively involved in a project called Moldova's Solar Dilemma which focuses on promoting solar energy supply by engaging either public and private sector.

Fifth speaker - Sonnet [2018] - is a Co Founder of ElectriCChain. The idea of ElectricChain is to collect data about development of the solar energy sector, post information about solar production and consumption worldwide on an online basis and thus provide scientists, researchers as well as consumers with an access to the analytics and insights. This all is done within a blockchain-based platform. Moroever, Sonnet [2018] is an advisor in a project of SolarCoin Digital Assets which aims to develop blockchain tools to globally initiate the clean energy transition. SolarCoin is a solar currency which is meant for supporting solar energy economy by awarding producers for producing clean energy from solar installations. According to the idea, 1 SolarCoin is given in return for producing 1 MWh of solar energy. Later on, owner of the installation can trade the solar currency and financially benefit from it.

The whole webinar can be found at the official website of Copenhagen Centre on Energy Efficiency [2018].