A qualitative comparative analysis of blockchain-based P2P power trading platforms

Naoufal Bouhorma Mouffak and Pau Solà Gallardo
Sustainable Energy Planning and Management
Aalborg University
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AALBORG UNIVERSITY
DENMARK

Department of Planning
MSc Sustainable Energy Planning and Management
Rendsburggade 14
9000 Aalborg
http://www.plan.aau.dk

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Louise Krog Elmegaard Mouritsen

Authors & Signature:

Naoufal Bouhorma Mouffak

Pau Solà Gallardo

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Synopsis:

In this thesis, a Qualitative Comparative Analysis (QCA) on blockchain-based P2P power trading platforms is done in order to identify the main conditions that characterise this type of platforms to be successfully implemented and deployed. To carry out the QCA, two theoretical approaches are considered: the Multi-Level Perspective (MLP) approach and the Disruptive Innovation approach. Next, various blockchain-based P2P power trading platforms are analysed and a total of ten platforms are used as case studies. Five conditions are later considered, which include whether a token is used or not; whether electricity prices are predetermined by a third-party or locally; whether there is some form of cooperation with the grid operator and/or the local power utility; whether the regulatory framework is friendly on P2P power trading; and whether P2P power trading is geographically limited to a local area. After analysing how these conditions are fulfilled by each case study, six different outcomes are identified. These outcomes range from a pilot project platform to a nation-wide implemented platform. Afterwards, an evaluation on whether the results obtained are acceptable is done by reviewing each case study and examining whether the theoretical approaches uphold. The results obtained in the QCA are deemed valid. Finally, the challenges and requirements for the success of these platforms are identified while carrying out the thesis.

Acknowledgments

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Preface

This thesis is completed by Naoufal Bouhorma Mouffak and Pau Solà Gallardo, master students in Sustainable Energy Planning and Management from Aalborg University.

Instructions for reading:

In order to gain the best understanding, the thesis should be read as follows: Chapter 1 (*Problem Analysis*), Chapter 2 (*Problem Formulation*), Chapter 5 (*Baseline of Blockchain Technology*), Chapter 6 (*Analysis*), Chapter 7 (*Discussion*), Chapter 8 (*Conclusion*) and Chapter 9 (*Reflections*).

Besides the backbone of the thesis, it is required to read Chapter 4 (*Methodology*) to fully understand the *Analysis* and part of the *Discussion*. Therefore, for a complete understanding of the *Discussion*, it is also required to reach Chapter 3 (*Theoretical Approach*).

Throughout the thesis, abbreviations are used according to the acronyms list on page vi.

Two appendixes are attached.

The picture on the front page is taken from [IRENA, 2019].

List of acronyms

AI Artificial Intelligence.

BMG Brooklyn Micro Grid.
BTC Bitcoin.

cs-QCA Crisp-Set Qualitative Comparative Analysis.

DSO Distribution System Operator.

ESCOs Energy Service Companies.
EU European Union.
EVs Electric Vehicles.

fs-QCA Fuzzy-Set Qualitative Comparative Analysis.

GDPR General Data Protection Regulation.
GHG Greenhouse Gases.

ICO Initial Coin Offering.
ICT Information and Communication Technologies.
IoT Internet-of-Things.

LEF Lokaal, Energie en Flexibiliteit.
LES Layered Energy System.
LIC Lugaggia Innovation Community.

M2M Machine-to-Machine.
MLP Multi-Level Perspective.

NYC New York City.

P2P Peer-to-Peer.
PBFT Practical Byzantine Fault Tolerance.
PoAu Proof-of-Authority.
PoS Proof-of-Stake.
PoW Proof-of-Work.
PV Photovoltaics.

QCA Qualitative Comparative Analysis.

RES Renewable Energy Sources.

S.F.O.E. Swiss Federal Office of Energy.
SDGs Sustainable Development Goals.

TSO Transmission System Operator.

USA United States of America.

ZKP Zero-Knowledge Proof.

Summary

The threat of the consequences of climate change has led many countries to adopt sustainable goals to avoid catastrophic scenarios. Goals such as the Sustainable Development Goals (SDGs) and the Paris Agreement have led to a process in which many industries are being changed. The energy industry is one of these industries and efforts are being made so that the future energy sector becomes more distributed, decentralised and digitalised. As a result, the idea of a blockchain-based P2P power trading platform is widely discussed in both the academia and the industry. As a result, several practical implementations of this idea can be found around the world. However, many of these are just at an experimental phase and there seems to be a lack of studies that analyses these projects and determines what conditions led to their implementation in the way they are designed. Thus, a Qualitative Comparative Analysis (QCA) has been done in which various blockchain-based P2P power trading platforms are analysed and compared one another to fill the literature gap just mentioned.

With a QCA, it is possible to determine what combination of met and/or unmet conditions need to take place for a blockchain-based P2P power trading platform to be successfully implemented and deployed depending on their own circumstances. The analysis is relied on already-implemented projects in order to have a study based on empirical evidence. Along with the QCA, several challenges and requirement to successfully implement a blockchain-based P2P power trading platform are also determined while performing the analysis.

For the QCA to be correctly implemented, it is important to have a theoretical approach to validate the results. Two theoretical approaches have been considered in this thesis: the Multi-Level Perspective (MLP) theoretical approach and the Disruptive Innovation theoretical approach. Both approaches try to explain the process by which a technological innovation goes from being an idea to eventually become a mainstream phenomena. The theoretical approaches selected for the QCA are considered to be a perfect fit for the topic of the thesis.

After determining the theoretical approaches, the methodology used in the thesis is presented. First, the QCA is presented as methodology which has an iterative process. The QCA starts by developing a theory of change (as just mentioned). Then, the case studies to be analysed are identified. Afterwards, the conditions to study are defined and each case study is analysed to see which one of these conditions they fulfil or not. Eventually, conclusions are developed by examining how these conditions affect the final outcome of the case studies and, finally, the findings are interpreted to check the validity of the results. Two other methodologies are used as well: the literature review and semi-structured interviews. Both methods are used to collect as much information as possible for each case study, but for some of them it has been possible to collect further data by interviewing one of their developers.

Before commencing the QCA, a brief explanation of how blockchain technology and its

applications on the power sector is done. Fundamental concepts such as *consensus models* and *architecture types* are explained to facilitate the points to be made when discussing the challenges and requirements for successfully implementing a blockchain-based P2P power trading platform. After that, practical applications of blockchain technology on the power sector are presented, ranging from macro levels (TSOs and DSOs) to P2P power trading at local levels.

The next step is the selection of the case studies to be analysed when performing the QCA. A total of ten studies are carefully identified so that they all revolve around the topic of blockchain-based P2P power trading. Additionally, the conditions to analyse these projects are also defined. These depend on the available information that is able to collect on each case study. As a result, these conditions include whether a token is used or not; whether electricity prices are pre-determined by a third-party or locally; whether there is some form of cooperation with the grid operator and/or the local power utility; whether the regulatory framework is friendly on P2P power trading; and whether P2P power trading is geographically limited to a local area. All cases studies are checked to see what conditions they fulfil. Afterwards, conclusions on the type of outcomes that these conditions can lead to are identified. A total of six outcomes are identified, which range from a pilot project platform to a nation-wide implemented platform.

The validation step is followed, in which each case study is reviewed to see if the outcomes obtained during the QCA can be considered valid. Additionally, the theoretical approaches previously selected are also reviewed to see if these uphold when comparing to the result of the analysis. The review of these elements result in the validation of the findings obtained in the analysis. Finally, some challenges and requirements are presented to add value to the research done in the thesis. These challenges and requirements are categorized in three groups: technical-economic, socio-economic and regulatory. The general view is that efforts are necessary to be made in all of these groups to create an environment where blockchain-based P2P power trading platforms can thrive. Special emphasis must be given to the regulatory side, as many consider it to be critical to reach a decentralized and socially-just energy future.

Contents

Problem Analysis 1

1.1 Threatened by climate change

The topic of climate change has become an urgent issue to tackle for all countries in this 21st century. The high concentration of greenhouse gases (GHG) in the atmosphere from the industrial revolution as a result of human-related activities is currently leading to a global warming which has a direct impact to all ecosystems worldwide [United Nations, 2018b]. As a consequence of such a rise of the global average temperature for the last decades, climatic disasters are occurring more often than ever and hence, are influencing negatively in both the nature and human beings [Bompard et al., 2020].

Therefore, many countries around the world have taken action to mitigate this climatic threat and focused their policies to reduce GHG emissions. For instance, many nations are trying to fulfil the Sustainable Development Goals (SDGs) established by the United Nations number 7 and 13, which consist of Affordable and Clean Energy Access, and Climate Action, respectively [United Nations, 2018a]. Furthermore, the Paris Agreement adopted by all United Nations Framework Convention on Climate Change Parties on December 2015 actually became the cornerstone for many countries to decarbonise their energy systems by 2050 in order to keep the global temperature to well below 2ºC in comparison with pre-industrial levels. However, the 2018 report of the Intergovernmental Panel on Climate Change called to keep the global temperature increase to well below 1.5ºC as it was expected to already overcome a critical point by 2028, according to the current trends [Bolwig et al., 2020].

1.2 Energy transition: towards a distributed, decentralised and digitalised energy sector

In order to accomplish such mentioned climate goals, a major transition to a fossil-free-based energy systems is required. Hence, such an energy transition is primarily addressed to decarbonising the global energy sector, which is comprised by the transport, heat and power (sub)sectors.

As technology has significantly improved during these last years, it has been playing a crucial role to reduce the carbon emissions during this transition. However, the main driver of the shift which has taken place from mid-1990s is about all the policies implemented by governmental institutions since they have been accelerating the change of the global energy mix. Indeed, the political will to achieve a carbon-free economy in 2050 is generally not only focused on the technological shift to reduce the carbon emissions. Also economic and social aspects are considered, such as subsidies to afford renewable energy sources (RES) or measures to avoid energy poverty, among others. Hence, this energy transition is addressed to maximise the social welfare of people in order to have a more sustainable, affordable, just and transparent energy future [Blázquez et al., 2020].

For that, the future energy sector is expected to be transformed, primarily characterised by three main features: it is aimed to be distributed, decentralised and digitalised. Firstly, the energy sector would become distributed due to the increasing integration of RES in many energy systems worldwide in recent years (especially photovoltaics (PV) and wind power due to their fallen marginal costs) as their acquisition has become more cost-effective. Indeed, this current affordability of RES has been boosted by financial incentives and energy policy initiatives. Thus, that fact would lead to a transformation of the energy sector where several new electricity production nodes would be spread/located throughout a geographical area [Andoni et al., 2019]. Secondly, the energy sector would become more decentralised as a consequence of such distribution feature because a whole range of new players (especially end-users) would enter and participate in the coming energy sector. Many individuals and utilities which used to only have the role of consumers would have the chance from now on to become prosumers (both producers and consumers simultaneously) by actively manage their own electricity production and consumption. Consequently, that fact would lead to a reorganisation of how the energy sector is structured, giving more authority and sovereignty to end-consumers [Burger et al., 2020]. Finally, information and communication technologies (ICT) and artificial intelligence (AI) are being broadly implemented in many sectors of our society. In fact, the energy sector has been one of the most remarkable sectors in the last years to be digitalised in order to, among other reasons, manage and accommodate optimally the increasing volumes of produced electricity from RES. As the power generation from RES presents intermittency since it depends on the weather conditions, smart meters, energy storage systems and many other digital devices are being widely deployed in many energy systems in order to obtain greater flexibility and increase their efficiency [Moret and Pinson, 2018].

1.3 P2P power trading model in the power sector transformation

Focusing on the power (sub)sector within the energy sector, as stated in the previous section, it is expected to undergo a major transformation marked by small-scale multi-node distributed power systems together with the development and deployment of digital technology. This future scenario becomes quite challenging for grid operators (transmission and distribution system operators, also known as TSOs and DSOs, respectively) as it may endanger the physical stability and safety of power grids and power systems, from both a technical and economic perspective. In order to manage all power transfers between consumers and prosumers from a grid operators' centralised standpoint, a reinforcement of the main upstream grids to increase their capacity as well as a huger computational power would be required. Thus, that would also imply a higher risk in terms of security and robustness of such grid operators in case a wide-system failure occurred [Laszka et al., 2018].

Therefore, it is convenient to find an alternative solution to properly manage the future power sector for the sake of all actors involved. As such, a peer-to-peer (P2P) model seems to be an interesting solution to tackle this challenge. The fundamental concept of a P2P architecture consists of a network of peer nodes which share to each other the same type of resource without the need of a central authority. In this network, all peers are interconnected to each other and perform the same functional task. In other terms, all peers are equally privileged without distinction of any kind [Schollmeier, 2001]. Thus, this P2P model concept applied to the power sector would create a digital/virtual marketplace where consumers and prosumers could trade electricity, without an intermediary, at their agreed price. If implemented at a local-level, this new model of trading electricity would have a very positive impact not only to citizens but also to the global power sector in many ways.

For instance, the primary contribution of P2P power trading to the future power sector would be about an increased RES deployment and flexibility due to consumers' and prosumers' empowerment. On one hand, it would foster the utilisation of distributed RES which is aligned with the global climate goals mentioned in Section 1.1. On the other hand, that would allow peers to have control over their electricity consumption and its price as well as to support their local communities by enabling them to consume power produced locally from RES and earn more from their distributed power production. As seen, that would create a social value around the locally produced and consumed electricity that never existed before [IRENA, 2020].

This new power trading model would be much more decentralised because peers would have now the chance to be involved in the decision-making regarding the management of their electricity, participate in open public debates, decide about their own self-governance and have equal access to energy resources [Thombs, 2019]. In fact, that would lead to a severe reconfiguration of the current global power sector as it would become not only more decentralised but also more democratic. This feature of the P2P model actually fulfils the principles of the energy transition previously mentioned in Section 1.2.

Another contribution is that the P2P model in the power sector would have an impact on balancing and congestion management of the main grids through better operation of RES within the local network. If users' electricity demand and supply is matched locally, the transmission and distribution grids are not utilised [IRENA, 2020]. Hence, that would imply a reduction of electricity losses due to null or shorter transmission distances as well as a better utilisation of the current power network assets. Moreover, there would be a reduction of the peak demand, and power grid congestion and blackouts would be avoided [Hayes et al., 2020]. That fact could be translated into a reduction of long-term economic costs for the grid operators since further investments or expensive reinforcements of the upstream power grids would not be required.

However, despite the fact of all aforementioned positive contributions of P2P power trading to the future power sector, a new window opens up regarding how such P2P power networks should operate: whether they are profit-oriented or not; whether the local electricity price is linked to the wholesale electricity market or set independently; the need of a central authority like grid operators or not to monitor the local power trading; or whether the local power network is isolated from the main upstream power grid or not, among other considerations [Crespo-Vázquez et al., 2020].

1.4 Blockchain technology as a tool to implement P2P power trading

As previously mentioned in Section 1.2, the energy sector is undergoing a big transformation regarding its digitalisation. In fact, digital platforms and technologies have been proven to have a disruptive potential in the energy sector. Thus, a significant digital technology which is currently having a great impact to many sectors across all societies, especially in the energy sector, is blockchain technology. Briefly, this disruptive digital tool consists of a type of distributed ledger technology which allows peers of a digital network to record transactions between them in a transparent way, avoiding cyberattacks and tampering without the need of an intermediate entity to verify such transactions [Leeuwen et al., 2020]. Hence, blockchain technology has a huge potential in the future energy sector as it would be totally aligned with the principles regarding how the energy future is expected to look like. Furthermore, if implemented at a micro-level application in local power networks, it would allow for liberalisation and decentralisation of local electricity markets and key concepts such as decentralisation, democratic consensus, transparency, traceability or data security would be applied [Andoni et al., 2019]. Further information regarding blockchain technology and its potential in the energy sector is explained in Chapter 5.

1.5 Focus of this thesis

Even though blockchain technology is quite novel, there already exists so much research about its theoretical potential in P2P power networks. However, only virtual simulations and quantitative theoretical-based outcomes are performed. The truth is that nowadays, there are few practical implementations of P2P power trading platforms which operate with blockchain technology. Moreover, in all the literature found where already implemented blockchain-based platforms in P2P power networks are reviewed or explained, no discussions on the main aspects that characterise/tailor them are performed, neither the drivers that led these projects to take different shapes.

Because of the reasons mentioned above, a gap in the literature has been identified and it is aimed to be studied in this thesis. The future power sector is about to become much more distributed than it has ever been. That would lead to a situation where TSOs and DSOs would not be able to manage all the in- and outflows of electricity in the upstream power grid due to the complexity of so many integrated electricity production nodes. One solution to deal with this problem is to foster local P2P power networks where prosumers would just exchange power units with themselves, interacting only if necessary with the upstream power grid. Hence, blockchain technology would become a very suitable tool to implement P2P power trading platforms. There are still not so many studies that compare the practical implementation of blockchain technology for already-developed and implemented P2P power trading platforms. Hence, we believe that a comparative analysis of such operative power trading platforms is crucial and very useful to find out how future blockchain-based P2P power trading platforms can be successfully implemented.

Problem Formulation 2

2.1 The research question

As explained in Chapter 1, the implementation of blockchain technology in the global energy sector is becoming more and more extended. As the energy sector is still very centralised in many regions, blockchain technology presents a huge potential as a decentralised, distributed and democratic technology which also matches with how the energy future is aimed to be in 2050.

There are already implemented projects that use blockchain technology for P2P power trading and most of them are operated differently. However, due to a lack of studies that analyse the drivers and conditions that led P2P power trading platforms to be successful, **the object of this thesis** will be to identify the main conditions that characterise/tailor blockchain-based P2P power trading platforms in order to be successfully implemented and deployed. As such, general aspects regarding how the future power sector should be from a technical, economic, socio and legal perspective will also be considered in order to help future researches and businesses in their quest for a functional blockchain-based P2P power trading platform. Moreover, we hope that this thesis will fill a gap in the literature of this topic. For this, a Qualitative Comparative Analysis (QCA) of various blockchain-based P2P power trading platforms worldwide will be done by examining the different challenges and requirements that such platforms needed to tackle in order to be successfully implemented and how the end result was shaped as a result of these challenges and requirements taking place. Analysing these existing platforms will strengthen this study as it will be based on empirical evidence rather than only on theoretical studies.

Behind this motivation, the research question of this thesis will be the following:

What conditions can affect how blockchain-based P2P power trading platforms can be implemented and what are their final outcomes when these conditions take place or not?

In order to fully answer the research question, the following sub-questions are proposed:

1. How do some of the existing blockchain-based P2P power trading platforms operate in their respective circumstances?
2. How can these existing blockchain-based P2P power trading platforms be compared to analyse what are the conditions that had an impact on their implementation?
3. How do these conditions shape the final outcome of these blockchain-based P2P power trading platforms when they take place or not?
4. What are the main challenges and requirements to deploy a blockchain-based P2P power trading platform?

2.2 Limitations

For the sake of keeping the content of this thesis in the scope of the topic of the research question and avoiding unnecessary out-of-context analysis, the following limitations are declared:

- Only existing blockchain-based P2P power trading platforms are analysed. If the study is founded on empirical evidence, it allows for a more practical understanding on how these projects work. Therefore, theoretical-based studies are considered irrelevant when performing the QCA.
- Although blockchain technology can be used for many applications in the energy sector as it is explained in Section 5.3, only P2P power trading is analysed. This decision was made in order to avoid time and effort-consuming process in an already limited extension and time requirements for developing this master thesis.
- At the time of writing this thesis, there may be more projects developed and implemented around the world than the ones to be presented. Information on these projects may not be as available as other projects. As such, only projects with an acceptable amount of available information are selected.
- In order to remain on the scope of the research question, this thesis refrains from explaining how to technically implement a blockchain-based P2P power trading platform.

The previous limitations may expose some weaknesses of the study. However, it is hoped that by exposing them, it strengthens this study before these are discovered. Moreover, these can serve as a point of departure for future research on the topic to fill the gap left behind in this thesis.

Theoretical Approach 3

In this chapter, the theoretical approaches to which this thesis is based upon will be presented. Two approaches have been used and they are considered to fit well with the research question presented in Chapter 2. These are the Multi-Level Perspective (MLP) approach and the Disruptive Innovation approach. Both of them are considered to be transition theories. First, they will be briefly explained and later, both of them will be linked to the topic of the thesis.

3.1 The Multi-Level Perspective approach

The MLP approach helps to understand how the innovations in a society succeed and, therefore, how the different socio-technical systems gradually change. The understanding is done by analysing three levels of a socio-technical system and how these interact with each other to bring forward a transition in society. These levels are: the socio-technical landscape, the patchwork of regimes, and the niches. Figure 3.1 displays how these layers are organized between each other.

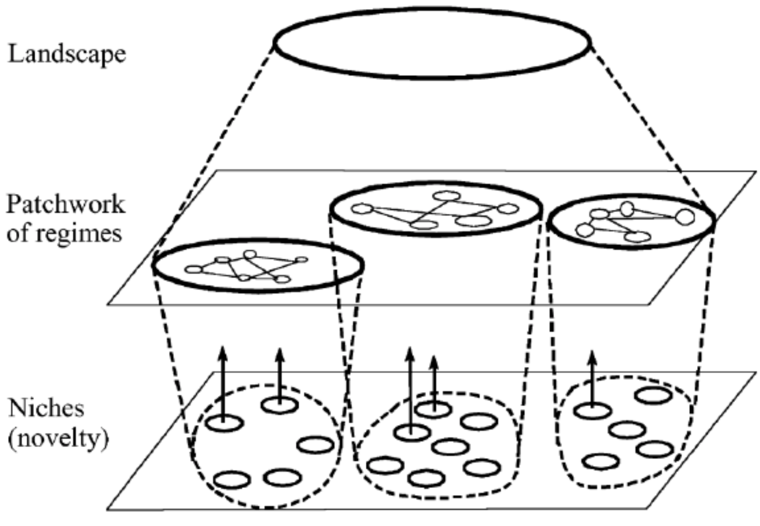

Figure 3.1. The multiple levels of society according to the MLP approach [Geels, 2006].

The first layer of the socio-technical system according to the MLP approach is the general **landscape**, also known as the macro-level, which corresponds to the external environment that influences all actors in the socio-technical system. It is compromised of trends and changes, which usually take place slowly, in the order of decades. For instance, it includes macro-economics and deep cultural patterns, societal values, political developments or demographic trends, among others.

The second layer of the socio-technical system, also known as the meso-level, is the **patchwork of regimes**. These are based on the mainstream operation of all the activities and structures that constitute a socio-technical system. It provides stability to the different pillars or sectors of a system (industry, science, culture, technology or consumer markets, among many others) as it is regulated by a set of rules which both the governing entities and citizens agree with. Moreover, regimes or sectors of a system tend to be stable by nature, leading to a "lock-in". Therefore, innovation and radical changes may present further difficulties to be implemented in such regimes.

At the third layer of the socio-technical system, also known as the micro-level, the so-called **niches** (or novelties) which consist of alternative ideas or technologies can be found, and these are usually developed in protected innovative spaces. Therefore, they are unstable and marginal as they initially deviate from the mainstream society trends. The niche actors aim to eventually integrate their novelties into the current regime which, as mentioned previously, is hard to happen due to the "lock-in" feature of the regime. However, niches are necessary for society as cornerstones to modernise and update the system. So, in case a niche achieves to expand its market, increases its demand and receives more support, it will not only change (or even replace) the regime, but also will influence the landscape.

So, the landscape of a system directly influences both the regime and the niches: by putting pressure to the existing regime due to the global changing trends, the landscape may allow niches to have room to emerge and be integrated in such current regime. Therefore, the regime adapts and assimilates these niches or otherwise, is taken over by such niches, which evolve into a very different new regime. This is what the transition dynamics of the MLP approach consists of (see Figure 3.2). As seen, transitions occur through interactions between processes at different levels, which are correlated since they influence each other [Schot and Geels, 2008; Geels, 2006].

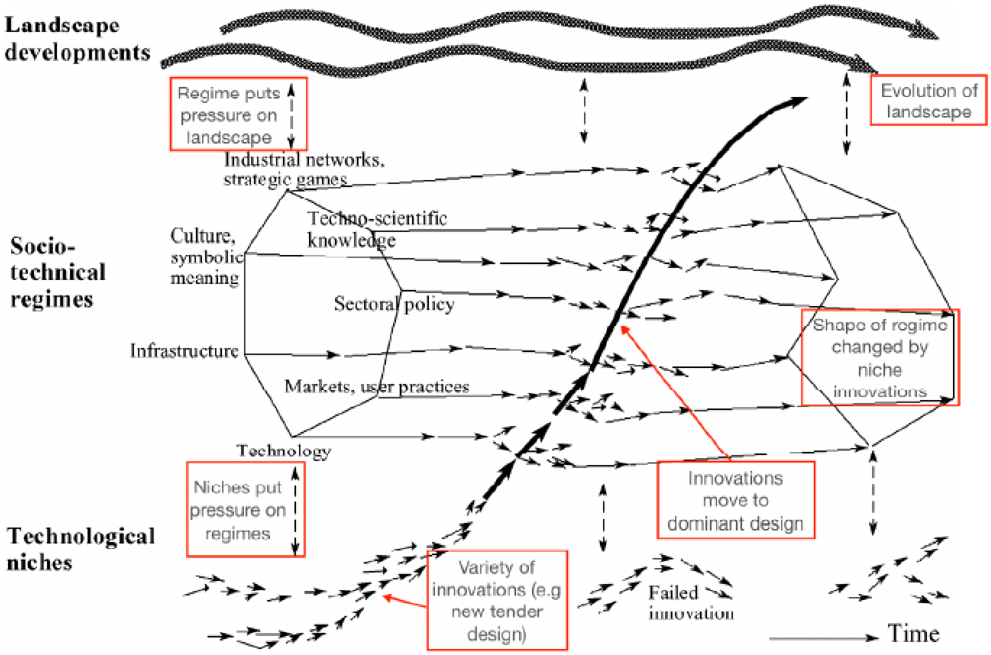

Figure 3.2. Niches evolution to become part of the regime and to the landscape [Geels, 2006].

3.2 The Disruptive Innovation approach

The Disruptive Innovation approach explains how new companies´ products become mainstream with their innovative solutions [Christensen, 2021].

The term was coined by Christensen in 1995 and it has been a very popular approach when studying innovation-driven growth. This approach argues that when a company is successful at providing a new product to a set of customers, the company will innovate new products over time to please the same customers while neglecting an unsatisfied demand. This type of innovation is referred to as the *incumbent´s sustaining trajectory*. The unsatisfied demand is then presented as a window of opportunity for small and new companies to develop a product that caters this demand. This time, the process is called the *entrant´s disruptive trajectory*, in which with its **disruptive innovation**, it will become a mainstream company. This new company, just like what the current mainstream company used to do, will innovate its products to satisfy its most demanding customers and eventually it will become a high-end market company, leaving behind a new window of opportunity for newer companies to innovate new products to provide for a neglected demand. Thus, the cycle continues over time. Figure 3.3 shows how the Disruptive Innovation approach works [Christensen et al., 2015; Hutt, 2016].

Figure 3.3. The Disruptive Innovation process [Hutt, 2016].

3.3 MLP and Disruptive Innovation in this thesis

Blockchain technology is, at the time of writing this thesis, still a novel technology. However, along with other sectors, it is expected that it gets more and more implemented in different applications in the energy sector in the coming years [Andoni et al., 2019]. Because of this phenomena, it is believed that the two theoretical approaches presented above fit very well and concord with the topic of this thesis.

First, the MLP approach explains how a novel technology goes from having a niche application to eventually becoming part of the regime and be integrated in the landscape of a socio-technical system. As of 2021 (the year when this thesis is performed), there are not many implemented platforms that use blockchain technology for P2P power trading. it is considered this stage to be a **niche state** in the MLP approach as it can be seen in Figure 3.4. So, the general potential applications of blockchain technology in the energy sector in 2021 are still in the early stages (further information can be found in Section 5.3). Assuming that by 2050 the **landscape** of the energy sector is changed and many countries' energy systems have successfully been decarbonised where blockchain technology has contributed to this achievement. It can therefore be considered that blockchain technology will have become part of the **socio-technical regime**. Hence, the period between 2021 and 2050 will be marked by several blockchain-based energy applications. During this period, a huge development and big investments in this technology are expected to happen as the countries' energy and climate goals are becoming more achievable to be fulfilled. One of the applications of blockchain in the energy sector will be that of P2P power trading, and it will constitute part of the regime. For this future path to happen, blockchain technology needs to be more mature and regulated, and that is mainly what this research aims to contribute. For this reason, the MLP approach is considered to be very suitable for the topic of this thesis.

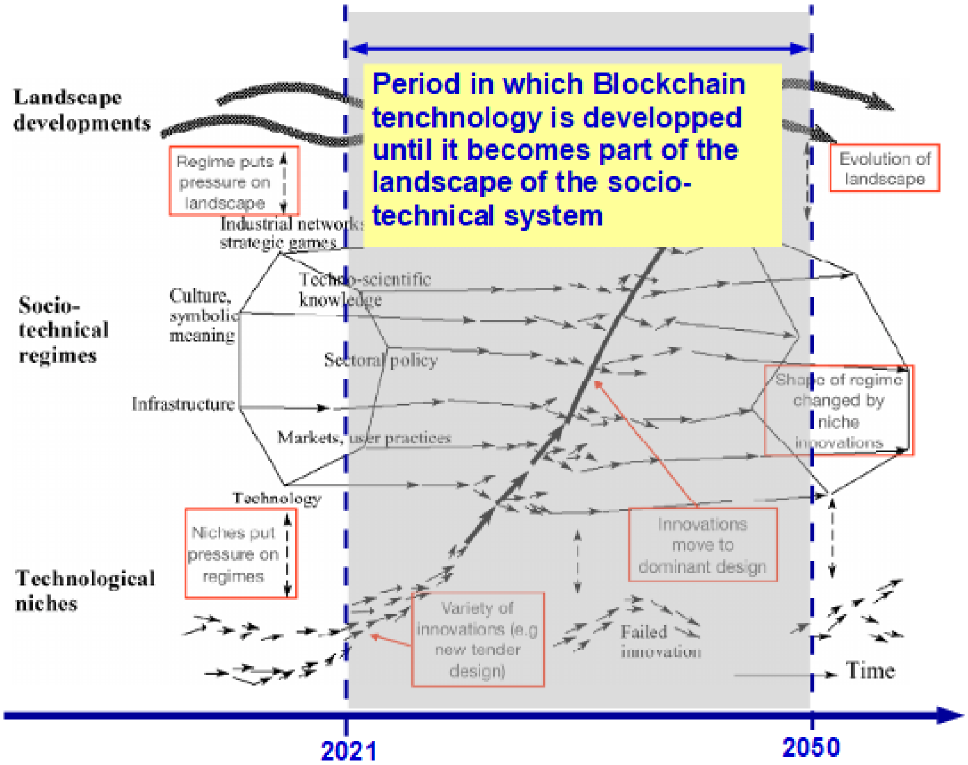

Figure 3.4. How the MLP approach can be applied for the topic of blockchain in the energy sector. Own elaboration based on [Geels, 2006].

As for the Disruptive Innovation approach, the main idea behind this way of thinking is that companies and startups which work with blockchain technology in a P2P power trading application take advantage to fill the gap in the market in areas where incumbent companies failed to do so. New business opportunities and business strategies can result successful by leveraging the potential of such a disruptive technology like blockchain for the first time in the energy sector. This can be morphed to the topic of this thesis, as it can be seen that the large energy corporations around the world are betting on RES, but with the objective of delivering power the same way they did before: in a centralised manner and using the same market rules as when the energy market was only fossil fuel-based.

Methodology 4

This chapter introduces the four different methods which have been utilised during the performance of this thesis. The first one is the Qualitative Comparative Analysis (QCA), which is implemented and further explained on the topic of this thesis in Chapter 6. As such, it also pretends to co-answer along with Section 6.1 the second sub-question which can be found in Chapter 2. The second method is the literature review, fundamental and necessary to settle the foundations of this thesis and provide a reliable outcome. The third method consists of semi-structured interviews, key in this thesis to bring an added-value to the outcome of this thesis. Finally, a research design of this thesis is presented.

4.1 The Qualitative Comparative Analysis

In order to identify the main aspects that characterise blockchain-based P2P power trading platforms in order to be successfully implemented and deployed, it is necessary to use a methodology with which it is possible to *"establish causal relationships through systematic comparisons"* [Intrac, 2017]. A popular methodology that has been used for this purpose in the academic field is known as the **Qualitative Comparative Analysis (QCA)**. This method allows to determine which conditions are necessary and which are sufficient to produce a particular outcome. It can help in explaining why certain situations happen and why others do not [Roig-Tierno et al., 2017]. This tool is thought to be very useful in this thesis, as the product of using it can essentially answer the research question developed in Chapter 2.

The process to carry out a QCA is explained hereafter and can be seen in Figure 4.1:

1. Develop a theory of change: it is important to define an approach that can explain the change that is being analysed (in this case, the decentralisation, distribution and digitalisation of the power sector) and what factors are responsible for this change. In Section 3.3, the theory of change was already brought up, and it consisted of a combination of the MLP approach and the Disruptive Innovation approach.
2. Identify the cases to be analysed: a QCA aims at explaining what conditions led to a specific outcome. As such, a set of cases needs to be selected in order to carry out their analysis. It is important that all selected cases are consistent with one another and evolve around a common topic (in this case, the P2P power trading using blockchain technology). In Chapter 6, this step and the next ones are presented.
3. Identify a set of conditions: in this step of the QCA process, it is very important to develop a set of conditions in which their presence or absence can result in a particular outcome. The process to which these conditions are established should be a rational one and not arbitrary.
4. Calibration process: once the first three steps are carried out correctly, a process to decide whether a case satisfies the established conditions is performed. This is

usually done in a Data Matrix. There are two popular ways to do this:

- Using Boolean logic, that is, whether the condition is fully met or it is not fully met. This type of scoring is typical in what is known as crisp-set QCA (cs-QCA). The advantage of the cs-QCA is its practical applicability in real situations. It does not, however, take into account partial conditions.
- Using a gradual score from 0 (not fully met) through 0.5 (partially met) to 1 (fully met). When a QCA uses this method, it is considered to be a fuzzy-set QCA (fs-QCA). The main advantage of this method over the cs-QCA is that it takes into account the degree in which a condition presents itself in a case. However, using this method makes it very difficult, if not impossible, to detect contradictions in the conditions. A solution to overcome this issue is to do again the scoring of the conditions in each case or deleting and adding cases and conditions.

Over the years, fs-QCA has been chosen over the cs-QCA in QCA-based research over its gradual scoring advantage. However, due to the previously explained difficulties that fs-QCA presents, and the high expected time and effort that the fs-QCA analysis has, this thesis will make usage of the cs-QCA method of scoring.

5. Analyse the dataset: after all cases have been scored for each condition, the process of identifying which conditions are necessary, which are sufficient and which must be absent for an outcome to emerge is performed. While a necessary condition is one that appears in all cases with the same outcome, a sufficient condition is one that if it presents itself in a case, a particular outcome appears. When different conditions lead to the same outcome, it is said that this particular outcome has multiple sufficient conditions. When using the cs-QCA, this process is also known as *Boolean minimisation*, and it consists of detecting irrelevant conditions to make simpler the reason why an outcome emerges. An irrelevant condition is one that has no effect on an outcome whether it appears or not. This step is usually done with a software.
6. The final step involves arguing whether the results obtained from performing the previous steps make sense. For this, the findings will be used to explain each individual case and argue whether these makes sense for all cases. Additionally, it is necessary to judge whether these findings concord with the theory of change established in Step 1. In case the findings do not make sense, the whole process should be re-analysed in order to identify what is the cause of these results. This can range from analysing whether the study cases are consistent with each other, whether the established conditions make sense, whether the scoring process is done correctly and whether there was an error during Step 5. Hence, this makes the QCA an iterative process [Intrac, 2017].

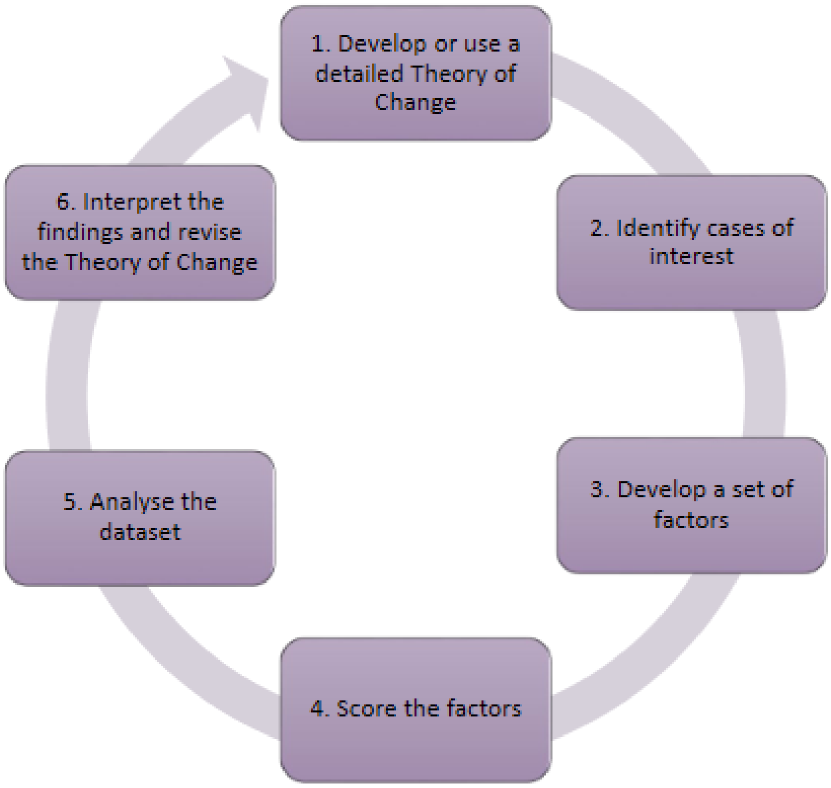

Figure 4.1. Steps when performing a QCA analysis [Intrac, 2017].

4.2 Literature review

As this thesis presents a qualitative outcome, a thorough literature review of all analysed case studies is of importance to make sure that suitable, proper data is sourced.

The primary search strategy has been articles from scientific databases, reports from big entities, white papers and news articles. Consequently, this has also been followed by chain search, which means that references from already found articles have also been checked. When checking sources of validity, some criteria has been followed depending on the type of content which was aimed to obtain, such as the publisher, the year of publication or the potential bias. That makes total sense in a thesis where a novel technology like blockchain is chosen. Thus, it is very relevant for the sake of this thesis to rely on sources with recent information and from trustworthy publishers. Moreover, the purpose of this thesis is at the same time to fill a literature gap which has been identified as no similar research has been found. Thus, it is expected that the findings of this thesis will also be meaningful and useful for future research, complementing the research of this specific topic.

4.3 Semi-structured interviews

Different implemented blockchain-based P2P power trading platforms within the energy sector are the subject of study of this thesis. In order to obtain a wider knowledge of each one of them, semi-structured interviews are included as fundamental data source.

The semi-structured interview method is used because, on one hand, it allows to have a minimum amount of essential information of each case to perform the QCA. On the other hand, it also offers the possibility to obtain further information which may be considered relevant for the final outcome of thesis but was not considered as such in the beginning. Therefore, the purpose of collecting information by conducting semi-structured interviews is evident: by interviewing people with expertise on blockchain applications for P2P power trading, not only we obtain an added-value information of each specific case study to be afterwards analysed, but we also get a wiser and more holistic perspective and understanding of this specific topic, especially applied in the industry.

Technically, a qualitative research-interview is semi-structured because it presents a set of premeditated questions (or interview guide), but at the same time, it also allows the interviewer to explore further into new knowledge while the interview is being conducted. Thus, the interviewer is at liberty to deviate from the predetermined questions and sequence of the interview as long as the new developed questions remain within the scope of the interview. To sum it up, a semi-structured interview is neither a free conversation nor a highly structured questionnaire [Wünderlich, 2009].

In order to get at the meaning of the collected information from the interview, it is necessary to follow six steps, which consist of: organising the data by grouping questions in separated topics; finding and organising ideas and concepts from the answers; building general themes in the gathered data; ensuring reliability and validity in the data analysis in the findings in order to identify inconsistencies and biased content; finding possible and plausible explanations for findings by making a summary of the findings and themes; and finally, have an overview of the final steps to think about the implications of the responses in regards with the purposes of the research [O'Connor and Gibson, 2003].

Once the interviews have been done and its content transcribed, the previous steps have been put into practice to properly sort all gathered information. In general, the useful content from each interview could be divided into three different themes, which are: principles of each case study which are shared with the other cases, unique characteristics of each case study, and general content regarding the topic of this thesis (out of the scope of each particular case study). Thus, the first two are addressed to Chapter 6 (*Analysis*), and the latter to Chapter 7 (*Discussion*) of this thesis.

Finally, just to point out that all included interviews in this thesis have been conducted through video-calls. Moreover, a video or audio recorder have also been utilised with the permission of each interviewee in order to review and seize to the maximum the information obtained. Moreover, the predetermined questions guide utilised in the interviews can be found in Appendix A and the transcribed interviews in Appendix B.

4.4 Research design

The structure of the research done in this thesis is illustrated in Figure 4.2

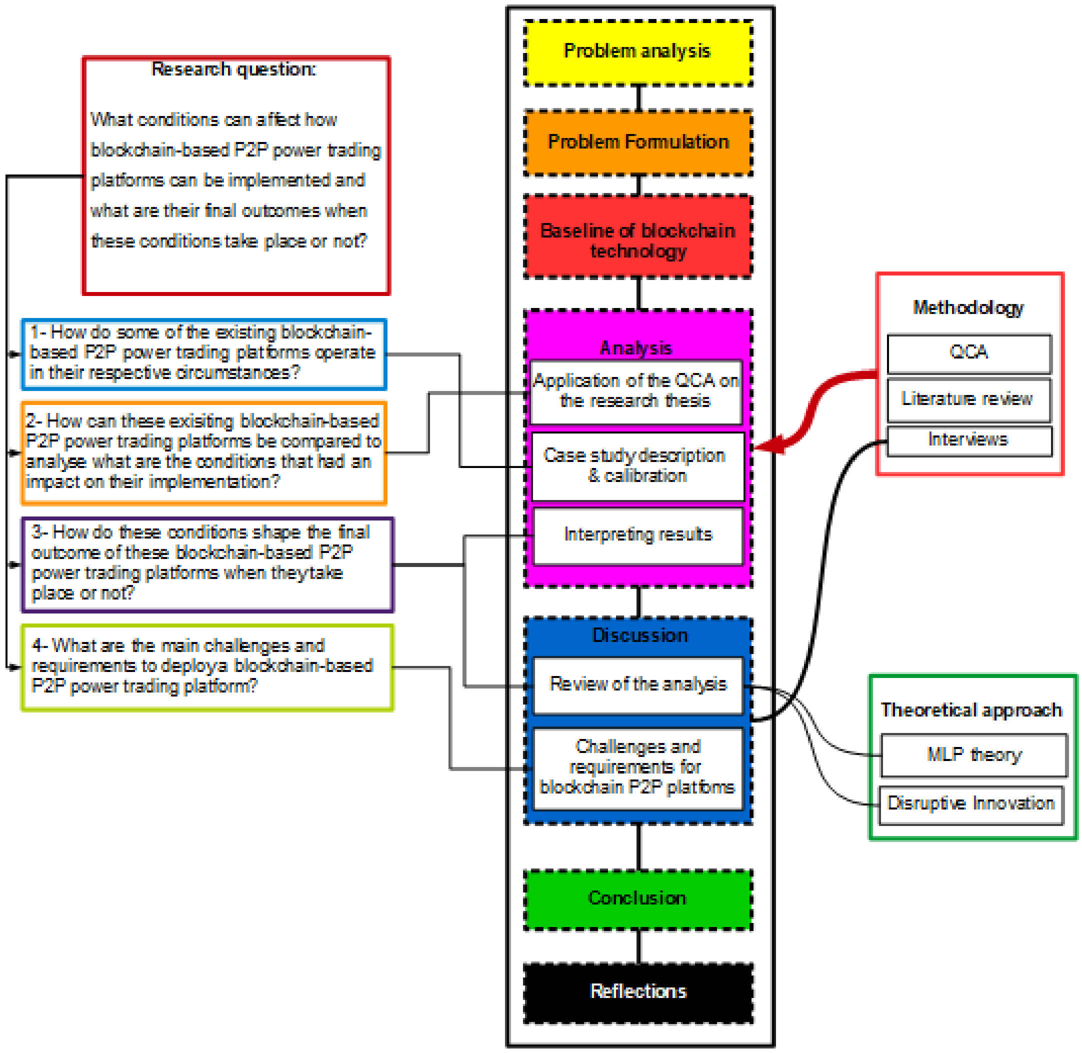

Figure 4.2. The research design of this thesis.

The research design has the purpose of showing and describing the structure of this thesis, as well as to give an overview of which methods and theories are used during the research.

On the left side of Figure 4.2, four sub-questions have the purpose to partially answer the main research question. All sub-questions are aimed to be answered in different sections of Chapters 6 and 7 (*Analysis* and *Discussion*, respectively) in order to provide more complete and holistic arguments to answer the main research question.

On the right side of Figure 4.2, three methods and two theories are included in this thesis in Chapters 3 and 4 (*Theoretical Approach* and *Methodology*, respectively). Regarding the methods, while the QCA is mainly utilised in the *Analysis*, the content from the semi-structured interviews done to some of the case studies of this thesis is utilised in both the *Analysis* and *Discussion*. Regarding the two theories, these are primarily employed in the *Discussion* to conduct for a better understanding the different themes that aim to reflect the topic of this thesis.

Focusing on the backbone of the thesis, the problem which is identified and aimed to be answered during this research is developed in Chapter 1 and presented in the Chapter 2 (*Problem Analysis* and *Problem Formulation*, respectively). Then, as a cornerstone of this research, Chapter 5 (*Baseline of Blockchain Technology*) introduces the concept of blockchain technology and its potential in the energy sector. This chapter is followed by the *Analysis*, where the collected data of each case study is presented, treated and therefore, some resulting outcomes are obtained. Furthermore, such results are extensively expounded from different perspectives in the *Discussion*. Then, a recapitulation of the findings of this thesis is exposed in Chapter 8 (*Conclusion*). And finally, few thoughts from the authors regarding the topic of this research and future work to be done is concluded in Chapter 9 (*Reflections*).

Baseline of Blockchain Technology 5

This chapter pretends to briefly introduce what blockchain technology consists of, how it was launched and what is its potential in the energy sector, especially in a P2P application.

5.1 Origin of blockchain technology

On 31st of October of 2008, a person or group of people under the nickname of Satoshi Nakamoto shared a white paper called *"Bitcoin: A Peer-to-Peer Electronic Cash System"*. The main purpose of this paper was to create a system which would let assets be transferred between people without the necessity to regulate or verify such a transaction through a middleman. This system would consist of a chain of blocks, where each block would store in a tamper-proof way all data related to all transfers performed.

Initially, the idea was to have a payment system that would work on the Internet and would not undergo all the disadvantages about trusting a third party (banks), such as transfer costs or the uncertainty about how personal data is managed. Therefore, Nakamoto suggested that the only solution that could solve this issue would be to have an electronic payment system based on cryptographic proof instead of trust. Moreover, Nakamoto also explained how transactions would work out within such a decentralised P2P net and how these would be recorded in a distributed time-stamped database to let all participants verify each transaction. The asset that Nakamoto released to operate in such a platform was called Bitcoin (BTC), and is currently the cryptocurrency with the highest value worldwide. Finally, participants would be incentivised to be honest with the system and ensure the security of the net through an inherent Proof-of-Work (PoW) mechanism where they would earn BTC as a reward. However, Nakamoto also proved mathematically how the security of the net would keep safe while at least 50% of the participants which control computational power behave honestly [Nakamoto, 2009].

5.2 Fundamental concepts of blockchain technology

A blockchain is a digital, shared, distributed database that can continuously store transactions and their chronological order in a secure way without using a central point of authority. The database is, in other terms, a data structure or a ledger. Thus, the transactions which the ledger contains are aggregated in larger formations or blocks. These blocks are cryptographically and time-stamped linked to previous blocks, and therefore, they form a chain of records that determines the sequencing order of events or the "blockchain".

The main reason why blockchain technology has a huge potential in the industry lies on the fact that it removes the need of intermediaries or third parties to verify any transaction of any asset. It redefines digital trust and hence, aims to replace traditional forms of top-down governance with distributed consensus among network members or peers in a tamper-proof and transparent way.

In order to get a clearer idea of its disruptive nature and underlying philosophy, the main features of blockchain technology will be briefly explained.

Distributed: as mentioned, the fact that it does not exist a central authority in a blockchain network leads the verification process of the transactions to the network members. Each one of them that integrates the network possesses a copy of the ledger and therefore, have access to the historical transactions record to verify their validity. Hence, blockchain technology is a decentralised P2P system where authority is distributed among its members.

Consensus-driven: every single block is verified independently via consensus models (or consensus algorithms). These consensus models are validation mechanisms that allow network members to ensure that each block is legitimate. Therefore, there exist different consensus models to accept a block depending on the architecture of the blockchain, where some incentives or rewards are established in order to ensure collaboration and honest behaviour from the network members. The two main consensus models which can be found in the literature are shortly introduced hereafter. These are the Proof-of-Work (PoW) and Proof-of-Stake (PoS).

- PoW: suggested by Nakamoto as previously mentioned, this consensus model consists of a hard-cryptographic puzzle which must be solved by some particular network members called miners. When a new block is ready to be embedded into the chain, miners are warned. Through a huge computational power, they try to be the first ones within the network to find out such a "puzzle" and thus, get rewarded for that. Finally, other miners double-check that the new block is correctly added to the chain. Otherwise, in case there is some contradiction, the competition of validation process starts again. This type of lottery-based approach is usually applied to public blockchain platforms used by most cryptocurrency systems like Bitcoin or Ethereum.
- PoS: in this other consensus model, the validating capacity depends on the stake within the network (the more stake/cryptocurrencies, the more validating capacity). In this case, network members who are also validators do not receive a reward but collect the transaction fee. Hence, it is much more cost-effective and less energy intensive than PoW. As it presents a voting-based approach, it is usually applied to private or hybrid blockchain platforms.

Moreover, other consensus models which can also be found in the literature are the Practical Byzantine Fault Tolerance (PBFT), the Proof-of-Authority (PoAu), or the Zero-Knowledge Proof (ZKP), among others.

Architecture: as seen, depending on the specific use case of the blockchain network, different rules in consensus models are followed. However, it also really matters the type of architecture of such network, which can be public, private or hybrid.

- Public: open-source blockchain networks where all Internet users can join. They can conduct and validate transactions as well as participate in open consensus processes, but they remain anonymous to each other. Therefore, public blockchain networks are completely transparent distributed permissionless ledgers, and aim to grow the network by providing incentives.
- Private: closed-source blockchain networks where the access is restricted only to authorised members. All the rules of the system operation are decided in private. Therefore, as permissioned ledgers, only certain validators (usually the owners) hold access rights to carry out modifications of the system. Hence, there are no incentives nor targets to grow the network.
- Consortium: hybrid blockchain networks as a combination of both public and private blockchain systems. Some processes are kept private and others public. In this case, transparency depends on how the owners agreed to set the rules. Hence, there exists the possibility to incentivise the network members to grow and maintain operative the system.

Furthermore, both the resulting type of architecture and consensus model of a blockchain platform are responsible of key performance features of the system, such as speed of transactions, scalability and efficiency of the resources spent.

Immutable: a blockchain, as a ledger, is a permanent record of transactions. Such records keep immutable, permanent, time-stamped and tamper-proof once they are validated in the system, and is computationally impossible to modify a single record after its registration. Every time a new transaction occurs on the blockchain, a record of that transaction is added to each network member's ledger with an immutable signature called hash. Transactions of varying lengths are run through a hash algorithm which gives a fixed-length unique alphanumeric code called hash. Therefore, hashes are the link between blocks, and in case the information that a block contains is modified, the hash will completely change. That is the reason why is so difficult to tamper a blockchain platform, since the corrupt network member should possess at least the 51% of the recorded transaction to not be caught. As the system is so decentralised, that is almost impossible. Moreover, all network members of a blockchain platform possess two alphanumeric keys to execute transactions: a public one to identify each member, and a private one to send or receive transactions. In few words, a transaction processed with one's public key will only be able to be decrypted by the intended recipient which holds a secret private key.

Programmable: in newer versions of blockchain technology, it is possible to embed smart contracts. A smart contract is a set of logic rules in the form of a coded script which is executed autonomously and is integrated into the system in order to regulate a transaction. All the pieces of code that a smart contract included had to be previously agreed by the network members. Somehow, smart contracts replaces the third party functionality, which is key in such a decentralised ecosystem [Sultan et al., 2018].

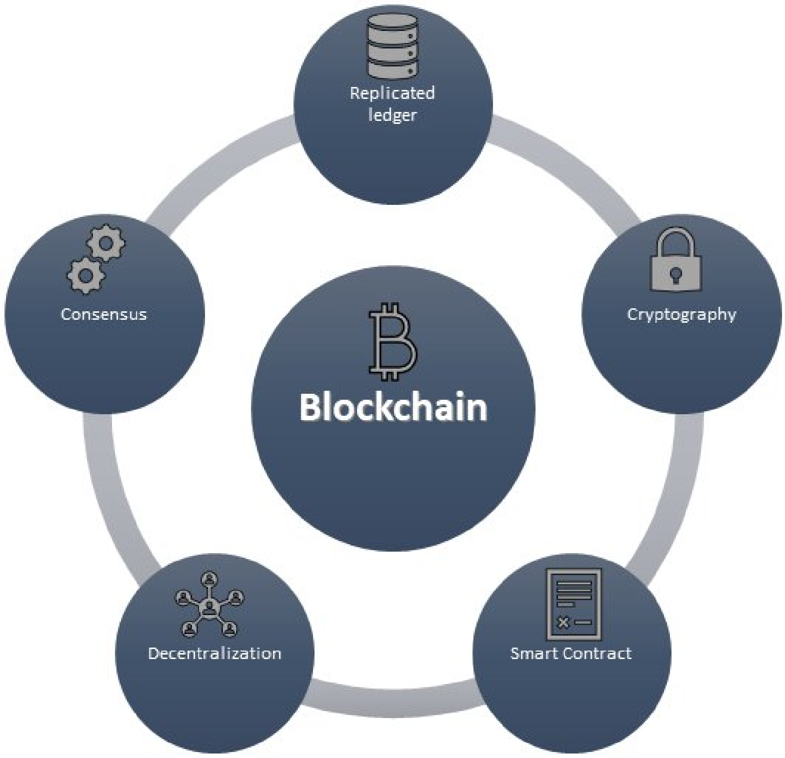

Figure 5.1. Important features of blockchain technology [Sultan et al., 2018].

5.3 Potential of blockchain technology in the power sector

Among many other sectors of our societies, the potential of blockchain technology in the energy industry is quite significant as it could provide solutions especially addressed to the future of the power sector. As developed in Chapter 1, the future power sector could be summarised in three main principles: distributed, decentralised and digitalised. Therefore, several energy service companies (ESCOs), startups and pilot projects have been keeping an eye on this digital technology as it fulfils the standards of the future power sector.

One example of the potential of blockchain technology in the power sector could be applied to the grid management and system operation. Blockchain technology could directly control network in- and outflows and flexibility options, avoiding curtailment of RES. If the number of transactions processed would scale up while remaining fast an secure, blockchain technology could help reduce the complexity of network operation of TSOs and DSOs [IRENA, 2019].

Another application could be focused on the management of renewable energy certificates, where electricity producers from RES could be awarded with such certificates in real time as their electricity is being generated. That would reduce costs to public agencies by optimising data verification and automating renewable energy certificates awarding [IRENA, 2019].

Moreover, ESCOs could also optimise their internal operations and business processes by using blockchain technology. Automated billing for consumers and distributed generators, faster communication between smart devices in the smart grids, or to secure privacy of data transactions and identity management are some of the aspects that could be simplified and enhanced. In a similar way, blockchain technology could also be applied to wholesale autonomous trading procedures, since current wholesale energy markets are composed of some complex operations that require several third-parties intermediaries such as trading agents, price reporters, logistic providers or even banks and regulators. Therefore, through a blockchain platform, it would be possible that any generating unit could be traded directly with a consumer or an energy retail supplier and thus, any further intermediate would be avoided in the trading operation [Andoni et al., 2019].

However, the most disruptive use case in the power sector where blockchain technology presents a huge potential is, as mentioned in Section 1.3, the P2P power trade, whether in micro power grids or regular bilateral transactions between individuals and/or businesses. Trusted third parties would play a much smaller role in a distributed P2P model as smart contracts would automate processes regarding the monitoring and redistribution of the electricity in local grids [IRENA, 2019]. In this particular context, blockchain technology could also provide solutions in demand-response service and therefore, it would affect revenues and tariffs for power grid use by avoiding expensive network upgrades [Andoni et al., 2019].

Many more applications could be considered as well, such as financing renewable energy through marketplaces in countries where people are lacking access to electricity, electrifying rural areas to increase their access to modern energy services, in the carbon tracking or in the deployment of electric vehicles (EVs), among others.

As seen, there currently exist a lot of applications in the power sector where blockchain technology could be widely deployed, from a national to a local-level. In Figure 5.2, it can be seen different applications of blockchain technology in the power sector and their percentage weight out of the total accounted applications as of July 2018.

Figure 5.2. Blockchain applications in the power sector [IRENA, 2019].

Analysis 6

The previous chapters had the purpose to introduce and present the foundations of this thesis. Therefore, in this chapter, the analysis of this research will carried out by following the six steps of the QCA method which are described in Section 4.1.

Firstly, in Section 6.1 it will be explained how Steps 1, 2, 3 and 4 of the QCA are done in this research. As mentioned in Chapter 4, this section (complemented with Section 4.1) aims to co-answer the second sub-question which can be found in Chapter 2. In addition, in Section 6.1 it is also developed the identification and justification of the set conditions (Step 3).

Secondly, an introductory description of all case studies (Step 2) as well as the calibration process or scoring of each one of them (Step 4) is performed in Section 6.2. Indeed, this section, especially when developing Step 2, aims to answer the first sub-question which is also found in Chapter 2. Lastly, such a section is complemented with a world map with all case studies' locations pinpointed.

Finally, an analysis of the dataset (Step 5) and a first interpretation of the results (partially Step 6) will be done and explained in Section 6.3. Therefore, this section pretends to co-answer along with Section 7.1 the third sub-question found in Chapter 2.

6.1 Application of the QCA on the research of this thesis

Local power networks and consumer-centred market places are expected to play a very important role in the future energy systems. Hence, blockchain technology could become a very suitable tool to make such local energy projects a reality. Indeed, it is already utilised in some enterprises of the private industry in the energy sector. For this reason, different companies and startups which are involved in blockchain-based P2P power trading platforms have been chosen in this thesis as case studies to perform the QCA. Their business strategies and purposes are aligned with the theory of change mentioned in Section 3.3, which is a combination of the MLP approach and the Disruptive Innovation approach. Therefore, that is what Step 1 of the QCA in this research is based on. Moreover, a first approach of what the case studies consist of is the the second step of the QCA, and that will be further developed in Section 6.2.

The third step of the QCA is to identify the conditions to which the selected case studies are going to be analysed on. The process to which the conditions are selected should be a rational one and not arbitrary. Due to the novelty of the topic, it can be expected to find a lack of practical information on the experience of the implementation of a blockchain-based P2P power trading platform. To circumnavigate this obstacle, an attempt to get an interview with the authors of the selected projects has been done. Although a fairly number of them accepted to conduct and interview, no response was obtained from the rest of them (case studies where further information could be obtained from an interview are marked with a *). Because of this, it was not possible to collect an equivalent amount of information for each case study as the information published on the Internet could be sometimes limited. As such, the following conditions are considered to carry out the QCA, and these were decided in order to consider all the selected case studies in the analysis, whether an interview was conducted with them or not:

- Condition 1 (C.1). Does the platform make use of a digital token to trade electricity?
- Condition 2 (C.2). Is the electricity price established by a third party?
- Condition 3 (C.3). Does any grid operator and/or any energy supplier actively cooperate in the platform in order to keep the grid balanced and/or supply the demand when needed to?
- Condition 4 (C.4). Is the current regulatory framework of the power sector of the country where the case study is implemented liberalised enough?
- Condition 5 (C.5). Are the peers of the blockchain platform only allowed to trade electricity within a local geographical area?

These conditions have been set according to different reasons. On one hand, the first two conditions are aimed to comply with the basic principles of blockchain technology applied to a P2P power trading application. The fact of using a token or not (C.1) and how the electricity price is established of each case study (by bids and asks processes between peers or by a third party) (C.2) already embrace different blockchain technology aspects of each analysed platform, such as the type of architecture, the consensus model or the purpose of the platform. On the other hand, the last three conditions are aimed to see the type of P2P power system of each case study and get to know them much deeper: the involvement of a DSO or energy supplier to enhance the proper operation of the local power network (C.3); the status of the current regulatory framework of the country where each platform is implemented (C.4); and the type of physical electrical grid which is used in each case study (C.5).

Following that, the process of calibration of each case study is the fourth step of the QCA. In order to do that, each case study is scored for each of the previously presented conditions. The score can be either 1 (if the condition in question is satisfied), or 0 (if the condition is not satisfied). In case of an ambiguity (if a condition is not fully satisfied nor not fully satisfied), the score given is the one closest to the state in which the case study is found for a condition. In Section 6.3, each scored condition of each case study will be explained and justified. It should be noted that the result of the calibration for each case study is presented on a two-row table. The first row is used as the headline and the second one as the result of the calibration process. Except the first column (where the name of the case study is written), each one of the conditions is allocated for the rest of the columns. For the sake of optimising the space of the page, each condition is abbreviated to **C.X**, where *C* stands for condition, and *X* is the number assigned for each condition as enumerated earlier. As a result, the table looks as follows (see Table 6.1):

Case ID	C.1	C.2	C.3	C.4	C.5
Project's name					

Table 6.1. Table structure where the calibration process is done for each project.

6.2 Case studies

6.2.1 *Electrify - SolarShare* project (Singapore)

Electrify is an energy company based in Singapore. In 2017, they became the first retail market place for electricity in the city-state (the market place was called *Electrify.SG*). In 2018, with the liberalisation of the energy market across Asia (C.4), they also became the first retail market place for P2P electricity trading (so-called *Electrify.ASIA*). In this new version of their market place, they utilise blockchain technology, AI and Internet-of-Things (IoT) to connect power producers and consumers on a P2P trading platform across city-wide power grids. Such a platform is called *Synergy*, and it allows customers to purchase electricity directly to small-scale prosumers, cutting intermediaries and transaction costs present in the current Singaporean energy system.

The platform is fueled using an Ethereum-based token called *ELEC* (C.1) and transactions can be automated using smart contracts. These tokens are paid by the producers to list their products in the *Electrify.ASIA* marketplace, and consumers are rewarded with them when buying electricity from the platform (C.2). Consumers, however, pay the electricity purchased in fiat currency to the retailers. With the current trend of liberalisation of the Asian electricity markets, it is hoped that this platform will be present in many countries in the region [Electrify, 2020a].

In July 2020, *Electrify* launched a one-year pilot project in collaboration with the electric utility company *Engie Factory* and the Singapore's largest and most established energy company, *Senoko Energy*. The Singapore-based pilot (C.5) is called *SolarShare* and has the aim of testing the potential of P2P power trading between residential and business clients of *Senoko Energy* (C.3). Moreover, it is built upon the *Synergy* platform. The pilot is targeting one hundred participants comprising consumers who wish to power their households and businesses with electricity from RES, as well as private houses and commercial properties (prosumers) with installed PV panels [Electrify, 2020b]. It is hoped that this project can serve as an initial establishment of the prosumer culture. From *Senoko Energy*, they ensure that this project will empower Singaporeans with greater choice in their electricity consumption. Furthermore, additional expected benefits of this project are to contribute to Singapore´s energy security as well as helping to meet the country's renewable energy goals [Electrify, 2020c]. In the *SolarShare* market place, on one hand, prosumers will be able to sell their surplus of electricity above wholesale price and enjoy higher returns on their investment. On the other hand, consumers will have a broader range of prosumers to choose from while enjoying savings from tariff rates [Senoko Energy, 2019].

Based on the previous information, the calibration for this particular case is the following (see Table 6.2):

Case ID	**C.1**	**C.2**	**C.3**	**C.4**	**C.5**
Electrify - SolarShare	1	0	1	1	0

Table 6.2. Calibration of the case study: Electrify - SolarShare project

6.2.2 * *Energy 21 - Layered Energy System* platform (Netherlands)

Energy 21 is a Dutch company with the headquarters in Utrecht. They develop and conduct sustainable energy data-driven strategies to different parties in the energy sector, from ESCOs and utilities to large energy-intensive industries from different European countries [Energy 21, 2021a].

Energy 21, along with the Dutch DSO *Stedin* and the companies *Quantoz*, *ABB* and *i.LECO*, have developed a solution to a variety of existing and future system problems due to the energy transition: an open market rather than a P2P energy supply. The pilot is called *Lokaal, Energie en Flexibiliteit (LEF)* and it is currently implemented in the district of Hoog Dalem, in Gorinchem (Netherlands), where forty houses are already trading electricity between them for almost a year [Energy 21, 2021b].

The developed blockchain-based platform is called *Layered Energy System (LES)* because not only end-users are encouraged to produce and consume local electricity from P2P connections, but also market players (wholesale traders, TSOs and DSOs) have given access to distributed flexibility to the local market [Energy 21, 2021b]. Focusing only on the end-users, they can trade electricity directly with their neighbours in the same residential area (C.2 and C.5). If necessary, electricity can also be bought from the local market as it has an open connection with traders on a wholesale-level (C.3). Smart contracts are also used to automatise the transactions in order to optimise the local power grid. According to a senior energy consultant at *Energy 21*, Michiel Dorresteijn, the Ethereum cryptocurrency is used (C.1), with an exchange rate of 1:1 with the fiat currency Euro. In addition, Dorresteijn also remarks that the current Dutch regulations do not allow for a pure P2P power trading (C.4), and that it is necessary to assign a responsibility to a party to manage and maintain the infrastructure [Dorresteijn, 2021].

Based on the previous information, the calibration for this particular case is the following (see Table 6.3):

Case ID	**C.1**	**C.2**	**C.3**	**C.4**	**C.5**
Energy 21 - LES	1	0	1	0	1

Table 6.3. Calibration of the case study: Energy 21 - Layered Energy System platform

(*) The complete interview to Mr. Dorresteijn can be found in Appendix B.1.

6.2.3 * *Hero Energy & Engineering* - Research project (Canada)

Hero Energy & Engineering is a Canadian consulting firm settled in Vaughan (Ontario), which is specialised in the design, development and implementation of integrated systems related to the renewable energy field and electric power grids [Hero Energy and Engineering, 2021].

With the support of the *York University* and the *Toronto and Region Conservation Authority*, the company successfully implemented in 2019 in the city of Vaughan a P2P platform where electricity was traded using blockchain technology. It consisted of a research project which was merely focused on what aspects were going to create net zero energy contributions. In fact, the President of the company, Shivam Saxena, says that depending on the price of electricity in the grid and the price that buyers submit in each time slot (C.2), the micro power grid could switch on and off the upstream power grid (C.3). Thus, the electricity retail price was a result of the equilibrium between supply and demand for each time slot, and that was determined using smart-contract capability [Saxena, 2021]. Moreover, the project showed successful results when practically implementing such platform in a four-houses micro power grid (C.5), shaving off the peak load considerably (almost by 46%) while reducing a 6% the electricity bill [Saxena et al., 2019].

Furthermore, a particularity of this pilot is that it did not use the token functionality (C.1). The reason for that is that the project focused more on studying the P2P capabilities that blockchain offers rather than designing a reward-giving system. Because of this, as Saxena states, the pilot was designed to be a private blockchain platform, where all participants were involved in the functioning of the system. Furthermore, the regulatory framework of the power grid that was connected to the micro power grid is yet to be updated to include regulations for RES [Saxena, 2021]. In addition, there is not a real push from the public to become prosumers unless they are economically incentivised. It is believed that implementing a carbon tax may raise the chances for P2P power trading to be established. As such, P2P energy technology is unlikely to be implemented in the near future in Canada (C.4). It is hoped that the performance displayed in this project could also contribute to accelerate its implementation in the Canadian power system [Saxena et al., 2019].

Based on the previous information, the calibration for this particular case is the following (see Table 6.4):

Case ID	**C.1**	**C.2**	**C.3**	**C.4**	**C.5**
Hero E&E - Research project	0	0	0	0	1

Table 6.4. Calibration of the case study: Hero Energy & Engineering - Research project

(*) The complete interview to Mr. Saxena can be found in Appendix B.2.

6.2.4 * *Hive Power - Lugaggia Innovation Community* project (Switzerland)

Settled in the city of Manno, in the Canton of Ticino, in Switzerland, the company *Hive Power* is oriented to smart grids and energy analytics. They developed a blockchain-based platform which is mainly addressed to energy suppliers and grid operators to improve their operation by using data-driven and AI-powered solutions. Their platform offers several modules depending on the user's preferences, and one of these is the so-called "*community manager*" module. This module uses a blockchain-automated local flexibility market to integrate different electric grids layers. Thus, this module simplifies the grid management for energy operators and retailers and improves the community self-consumption [Hive Power, 2020].

In collaboration with the *University of Applied Sciences and Arts of Italian Switzerland*, *AEM* (a Swiss DSO) and the companies *Optimatik*, and *Landis+Gyr*, *Hive Power* is involved in the ongoing *Lugaggia Innovation Community (LIC)* project, carried out by the Municipality of Capriasca. The *LIC* project started to be operative on 1st of October 2020. It was implemented to test and verify the capability of *AEM* to provide new power services to its customers. Thus, two different platforms were launched: a centralised energy management platform for sensing and actuation; and a decentralised blockchain-based platform.

Focusing on the latter, this platform consists of, on one hand, a 30 kWp PV plant on the roof of the local kindergarten in the village of Lugaggia. On the other hand, the kindergarten building is located on the edge of a residential area and connected with up to eighteen households (C.5) which are equipped with PV panels and a community battery. By creating this pilot energy community, the *LIC* project aims to improve the factor of self-consumption of electricity produced locally by the sun in order to manage the relationship between supply and demand, based on blockchain technology and AI (C.2) [Lugaggia Innovation Community, 2019].

In this project, no tokens are needed, as the transactions accept fiat currencies (C.1). Additionally, several efforts are being made in order to make the blockchain-based trading platform as automated as possible, cutting all possible intermediaries. Nonetheless, *AEM* is needed in order to keep stability of the local grid in check (C.3). Furthermore, one of the reasons why the project is successful is because of the high degree of freedom that the Swiss regulatory framework allow when it comes to self-consumption at the community level (C.4). Finally, in order to be as independent as possible, battery systems are installed in order to provide electricity to the community when power generation levels are low. However, according to the COO and co-founder of *Hive Power*, Davide Rivola, it is hard to reach this level of independence from the main grid at all times [Rivola, 2021].

Based on the previous information, the calibration for this particular case is the following (see Table 6.5):

Case ID	**C.1**	**C.2**	**C.3**	**C.4**	**C.5**
Hive Power - LIC	0	0	1	1	1

Table 6.5. Calibration of the case study: Hive Power - Lugaggia Innovation Community project

(*) The complete interview to Mr. Rivola can be found in Appendix B.3.

6.2.5 *Lition - Lition Solar Community* (Germany)

Settled in Berlin (Germany), *Lition* startup started in 2018 as a licensed energy supplier. In their digital platform, they connect consumers directly with prosumers who only produce from RES. In order to ensure that the transactions are done properly regardless of its complexity, blockchain technology along with the smart-contract capability is used.

Users can also decide their preferred suppliers, allowing full transparency as to where the electricity comes from [Lition, 2021].

From June 2020, *Lition* moved forward towards P2P power trading. They would not only purchase surplus of electricity from prosumers to ensure consumers supply their demand. In fact, along with a green-tech startup also from Berlin called *Eigensonne*, they created a *Lition Solar Community* where PV owners could become energy providers and sell their electricity through the blockchain-based market place. They would always receive a small additional remuneration per injected kWh regardless of the actual demand on the market place (C.2) [Lition, 2020].

The *Lition Solar Community* platform does not claim to use any token to effectuate the transactions (C.1). Their activities are limited to Germany, a country where the electricity market is relatively very liberalised (C.4). As the company is licensed as an energy supplier, it implies that they also monitor the transactions which are being recorded (C.3). Moreover, the *Lition Solar Community* platform is fully functional in more than 41 million households in Germany (C.5) [Lition, 2018].

Based on the previous information, the calibration for this particular case is the following (see Table 6.6):

Case ID	**C.1**	**C.2**	**C.3**	**C.4**	**C.5**
Lition Solar Community	0	1	1	1	0

Table 6.6. Calibration of the case study: Lition - Lition Solar Community

6.2.6 *LO3 Energy - Brooklyn Micro Grid* project (USA)

LO3 Energy is an American company with the headquarters in New York City (NYC) and two more offices in Portland (Orlando) and Chuo City (Japan). They are developing blockchain-based innovations to revolutionize local-level energy trading and management. They work with utilities and retailers to deliver configurable digital tools that meet the demands of modern energy customers [LO3 Energy, 2021].

LO3 Energy is involved in several projects worldwide. However, the most notorious one they were involved is the *Brooklyn Micro Grid (BMG)* project, along with other partners like *Consensys*, *Siemens* and *Centrica*. In early 2015, they created a partnership called *Transactive Grid* and developed the *Exergy* platform. This platform managed the first ever pilot project to use blockchain technology to conduct electricity transactions between prosumers. Located in the Gowanus and Park Slope communities in the district of Brooklyn, in NYC (C.5), the *BMG* project implemented a blockchain-based P2P electricity trading scheme in a real physical distribution grid. A micro power grid was also built in addition as a back-up to balance supply and demand of the existing distribution grid. In case of power outages, the micro power grid would operate in island mode. Hence, the mission of this pilot was to promote solar production and consumption throughout NYC by allowing consumers to trade manually surpluses of electricity between themselves in order to gain both financial and social benefits. Furthermore, the pilot did use tokens to trade electricity, which is a tool employed by the DSO to balance the grid (C.1, C.2 and C.3).

As the pilot resulted successfully operative during all next years, a simulated power marketplace was expected to be launched in 2019 with the aim of achieving automated power transactions and payments by self-executed smart contracts [Mengelkamp et al., 2018]. However, even it became a groundbreaking pilot in this specific application, no further news of its status have been published so far. Nor does it seem to have had a significant impact onto the regulatory framework of the energy sector in the USA (C.4).

Based on the previous information, the calibration for this particular case is the following (see Table 6.7):

Case ID	**C.1**	**C.2**	**C.3**	**C.4**	**C.5**
LO3 Energy - BMG	1	1	1	0	1

Table 6.7. Calibration of the case study: LO3 Energy - Brooklyn Micro Grid project

6.2.7 *Sonnen Group - sonnenCommunity* (Germany)

With the headquarters located at the village of Wildpoldsried, in the Allgäu (Germany), and other offices in Berlin, Great Britain, Italy, USA and Australia, the *Sonnen Group* has set up the world's largest platform for electricity sharing. And it is blockchain-based. They developed a power storage system so-called *sonnenBatterie*, but in 2015, they developed an intelligent platform so-called *sonnenCommunity* that connects all its users across Germany. Users may own a *sonnenBatterie*, but it is a must that they have a smart meter. Thus, the prosumer sets the price of his/her surplus of electricity, which is reported through the smart meter. Through a centralised company software, the power demand of any other consumer in the community is supplied (C.2). Users are able to choose between three tariffs depending on the fact whether they have a *sonnenBatterie* or not. The main purpose of this company is that everyone can afford cheap and clean electricity.

A special characteristic of the *sonnenCommunity* is that participants do not utilise tokens to trade electricity (C.1) even though they may be geographically very far from each other (C.5). This operation requires the collaboration of *TenneT* (the TSO) for maintaining the supply-demand balance in the network (C.3). Additionally, *TenneT* takes advantage of the blockchain platform and the *sonnenBatteries* to plan ahead using solar and wind forecast to maximise renewable energy usage [Sonnen Group, 2021]. Like the *Lition* case study in Subsection 6.2.5, the regulatory framework of the German market is very friendly and liberal with this type of P2P power trading platforms like the *sonnenCommunity* (C.4).

Based on the previous information, the calibration for this particular case is the following (see Table 6.8):

Case ID	**C.1**	**C.2**	**C.3**	**C.4**	**C.5**
sonnenCommunity	0	0	1	1	0

Table 6.8. Calibration of the case study: Sonnen Group - sonnenCommunity

6.2.8 *Spectral Energy - Jouliette* project (Netherlands)

Spectral Energy, settled in Amsterdam (Netherlands), is an end-to-end system integrator which is specialised in software development, smart grids and deployment of smart energy services. In autumn 2017, *Spectral Energy* in partnership with the Dutch DSO *Alliander* launched the pilot of its blockchain-based energy trading platform called *Jouliette*. The pilot was the first initiative of this type in the Netherlands and was settled in the community of De Ceuvel, in Amsterdam (C.5). Since 2012, De Ceuvel became a circular economy hotspot and thriving community of entrepreneurs. In addition, De Ceuvel already had its own micro power grid.

The *Jouliette* project was launched in 2017. It aimed to become a reference regarding how to harness the capabilities of blockchain technology to create social value and to support the energy transition with a more distributed, fair and transparent economy. Moreover, a token also called *Jouliette* was integrated, which aimed to empower community members to easily manage and share their locally produced electricity (C.1 and C.3). As the *Jouliette* tokens were only backed up by physical electricity production, community members were able to trade tokens with each other without any restrictions and avoiding market barriers and any type of speculation (C.2) [Spectral Energy, 2021].

In 2018, the project also incorporated new features such as new energy bill features and implementation of automated trading agents, among others [Spectral Energy and Alliander, 2021]. However, no further news regarding the status of the *Jouliette* project could be found as of today. In any case, as mentioned in Subsection 6.2.2 in the *Energy 21* case study, it is currently not legal to trade electricity in a fully-P2P way in the Netherlands (C.4).

Based on the previous information, the calibration for this particular case is the following (see Table 6.9):

Case ID	C.1	C.2	C.3	C.4	C.5
Spectral Energy - Jouliette	1	0	0	0	1

Table 6.9. Calibration of the case study: Spectral Energy - Jouliette project

6.2.9 *SunContract* (Slovenia)

SunContract, settled in Ljubljana (Slovenia), is a company that through their platform, aims to connect energy customers in an open marketplace. They offer a modern business model that allows renewable energy generators to sell their electricity at their desired price to consumers willing to pay that price, regardless of where these customers are located across the country of Slovenia (C.2 and C.5). Hence, the *SunContract* vision is to interconnect three main areas with enormous potential: electricity, blockchain technology and people. With such a synergy, their common interests are to save money and to create a decentralised, smart and clean energy future (C.3) [SunContract, 2020].

The *SunContract* platform is blockchain-based and is designed to connect electricity producers and consumers into an electricity pool based on smart contracts towards P2P electricity trading. Moreover, a token called *SNC* is also introduced in the platform in order to let participants trade (C.1). During the first half of 2021, the average price of 1 *SNC* token was around four cEUR. They can be obtained by producing electricity or purchased with fiat or cryptocurrencies [SunContract, 2017].

Finally, Slovenia does support to buy and sell electricity directly between users, so it did not pose a problem when the platform had to be launched (C.4) [SunContract Community, 2018].

Based on the previous information, the calibration for this particular case is the following (see Table 6.10):

Case ID	C.1	C.2	C.3	C.4	C.5
SunContract platform	1	0	0	1	0

Table 6.10. Calibration of the case study: SunContract - SunContract platform

6.2.10 *Swiss Federal Office of Energy - Quartierstrom* project (Switzerland)

The *Quartierstrom* pilot project had the main target to examine a real-world P2P energy market. It was supported by the *Swiss Federal Office of Energy (S.F.O.E.)* and in close cooperation with the local utility company *EW Walenstadt*. It consisted of implementing the first P2P energy market blockchain-based with thirty seven participating households and a retirement home in the town of Walenstadt, in the Canton of St. Gallen (C.5). In case the local community could not manage the energy demand or supply, the utility *EW Walenstadt* served as a back-up (C.3). All prosumer households already had PV modules and therefore, could sell their surplus of electricity directly to their neighbours without an intermediaries in between. Both prosumers and consumers could set their bidding prices, and the transactions were automatically calculated, managed and stored on a blockchain platform (C.2) [Brenzikofer et al., 2019].

The pilot project was operative for a year, until January 2020. The main purpose was to investigate the technical feasibility of a blockchain-based community energy system, mainly focusing on the local utilisation of solar energy, the optimal market design and resulting prices over time, the user behaviour, and further aspects such as privacy, scalability, the regulatory framework and potential business models. No tokens were considered to trade electricity (C.1). The overall conclusions were that the pilot project successfully fulfilled its expectations from a technical, financial and social perspective. Furthermore, as mentioned in Subsection 6.2.4 regarding the *LIC* project, the Swiss legislation currently presents a higher degree for self-consumption energy communities to be really operative than in many European levels (C.4). However, the Swiss legislation still presented some legal hindrances for self-consumption energy communities when it was finished [Swiss Federal Office of Energy, 2020].

Based on the previous information, the calibration for this particular case is the following (see Table 6.11):

Case ID	C.1	C.2	C.3	C.4	C.5
S.F.O.E. - Quartierstrom	0	0	1	1	1

Table 6.11. Calibration of the case study: Swiss Federal Office of Energy - Quartierstrom project

6.2.11 Locations of all case studies

As it can be seen, the selected case studies stem from a wide variety of countries. This can help when analysing how these case studies were shaped according to their location. Figure 6.1 presents a map where the location of these platforms are.

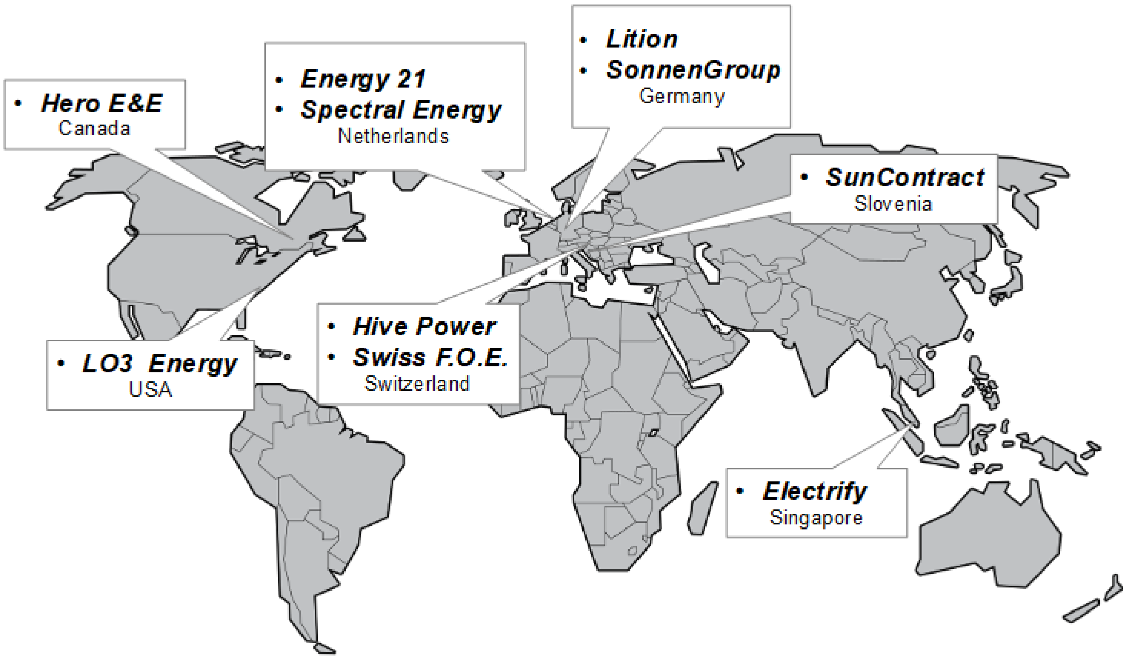

Figure 6.1. Location of selected case studies pinpointed in the map.

6.3 Analysis and interpretation of the results

Once the calibration of each particular case study has been done, it is time to proceed to fully develop Steps 5 and part of Step 6 of the QCA. Thus, this section will co-answer the third sub-question of this thesis

As can be seen in Table 6.12, the recompilation of the calibration of each case study is displayed. The table shown below is known as the Data Matrix, and it will be later used to create the Truth Table.

Case ID	C.1	C.2	C.3	C.4	C.5
Electrify - SolarShare	1	0	1	1	0
Energy 21 - LES	1	0	1	0	1
Hero E&E - Research project	0	0	0	0	1
Hive Power - LIC	0	0	1	1	1
Lition Solar Community	0	1	1	1	0
LO3 Energy - BMG	1	1	1	0	1
SonnenCommunity	0	0	1	1	0
Spectral Energy - Jouliette	1	0	0	0	1
SunContract platform	1	0	0	1	0
S.F.O.E. - Quartierstrom	0	0	1	1	1

Table 6.12. The Data Matrix as a result of the calibration done in Step 4 in Section 6.2.

The next step is to create the Truth Table that will be based on what is displayed in Table 6.12. For this, all case studies with the similar configuration of conditions will be grouped together. The maximum number of rows that can be created in the Truth Table is 2^k, where k is the number of conditions studied. In this case, the maximum number of rows is 32. However, since the number of the selected case studies is lower, that number will be the maximum number of rows in the Truth Table, i.e., 10 rows. With the previous condition taken into account, the Truth Table is shown in Table 6.13, with their respective outcomes classified into letters, all of which is hereafter explained in the (Table 6.14).

Case ID	C.1	C.2	C.3	C.4	C.5	Outcome
Hero E&E - Research project	0	0	0	0	1	A
SonnenCommunity	0	0	1	1	0	B
Lition Solar Community	0	1	1	1	0	
Hive Power - LIC	0	0	1	1	1	C
S.F.O.E. - Quartierstrom	0	1	1	1	1	
Spectral Energy - Jouliette	1	0	0	0	1	D
Energy 21 - LES	1	0	1	0	1	
SunContract platform	1	0	0	1	0	E
Electrify - SolarShare	1	0	1	1	0	
LO3 Energy - BMG	1	1	1	0	1	F

Table 6.13. The Truth Table as a result of the Data Matrix displayed in Table 6.12

Outcome (Letter)	Outcome description
A	A pilot project for research purposes in an environment where the regulation has yet to adapt to a decentralized power system.
B	A platform developed to integrate prosumers in the power system nation wide in a decentralized-friendly environment to compete with the existing players. Blockchain technology is used exclusively to track the power flow between the peers.
C	The platform is used by a community to trade electricity among its participants. The regulatory framework is friendly in allowing these kind of activities and local utilities help in balancing the grid.
D	The regulatory framework is not very keen in allowing a lot of decentralization. However, individuals in a community, as well as other key players (i.e. DSO) try to develop a token-based blockchain platform to empower themselves against the stance of the regulatory framework.
E	The platform is used nation-wide and efforts are being made so that the power sector becomes both highly decentralised and digitalised.
F	A platform developed in a environment that is yet to push for decentralization and citizen empowerment. The local utility can impact both the energy demand and the energy production of the individuals.

Table 6.14. Description of the outcomes presented in Table 6.13.

By analysing an interpreting the results, certain similarities can be observed in each group of projects. These similarities were considered to be the outcome when their respective configuration takes place.

The next step is the Boolean minimisation process, as explained in Section 4.1. However, given the low number of cases that are grouped in each outcome, an external software is not useful. As such, it has been considered that the results shown in Table 6.13 are already optimized, and cannot be further simplified. Thus, the following configurations can be extracted from the Truth Table.

- **Outcome A: Only Condition C.5 (related to trading electricity only in a local area) is necessary.** Pilot project are used as way to prove the viability of a project idea. They are usually implemented to later bring forth the project idea in a much larger scale. In this case, the project implemented by *Hero Energy & Engineering* is considered to be a pilot project where power trading between households using blockchain technology is tested to prove its feasibility in a Canadian context. As explained by Saxena in the interview, the regulation concerning decentralised systems in Canada is yet to be updated to incorporate this new practice.
- **Outcome B: Conditions C.3 and C.4 are necessary, while Condition C.2 is irrelevant.** Both of the projects that have outcome B are located in Germany, a country regarded as having a high degree of liberalization in their electricity market (this relates to Condition C.4). Moreover, a trend has been seen where companies that use blockchain technology for P2P power trading in their projects located in this country tend to work with the local utility as a way to balance the grid (this relates to Condition C.3). Furthermore, given that the trading is not limited to a local geographical area, the distribution and transportation cooperation is necessary to ensure that the project becomes successful. This was deemed a necessary condition if a blockchain-based P2P power trading platform was to be developed in Germany. Condition C.2, which relates to whether the electricity price is determined by a party that does not trade electricity in the blockchain platform, is irrelevant, since it does not impede the development of a blockchain-based P2P trading platform in Germany. Finally, the usage of a token is not encouraged if a blockchain-based P2P power trading platform is to be developed in Germany.
- **Outcome C: Conditions C.3, C.4 and C.5 are necessary.** Outcome C resembles outcome B in the sense that: no token is necessary to reach the outcome; the cooperation of the local utility, DSOs and TSOs is necessary; and the regulation is friendly towards P2P power transactions. However, the geographical area in which the P2P power trading blockchain-based platform is allowed to operate is limited to a local geographical area. As such, outcome C is the most likely outcome if a blockchain-based P2P power trading platform is to be developed in Switzerland, and Conditions C.3, C.4 and C.5 are necessary to be able to do so.
- **Outcome D: Conditions C.1 and C.5 are necessary, while Condition C.3 is irrelevant.** In this case, both of the projects analysed are located in the Netherlands. In the interview conducted to Dorresteijn, the Dutch regulation at the time of writing this thesis makes it complicated to implement large-scale blockchain-based P2P energy trading platforms, limiting it to only pilot projects for small residential areas. Moreover, some utilities can cooperate with these pilot projects in order to prove the viability of these. Additionally, a token can be used to track all power transactions that can happen in the blockchain platform. This is not a condition that it is believed to be necessary to implement these kind of projects in the Netherlands, but since the two case studies from the country employ it, it is highly recommended to

implement tokens when developing a blockchain-based P2P power trading platform in this country.

- **Outcome E: Conditions C.1 and C.4 are necessary, while Condition C.3 is irrelevant.** The projects that have outcome E have implemented a blockchain-based P2P power trading platform in which its participants can submit bids in cryptocurrency and the price is calculated as a result of the submitted bids in the blockchain platform. Moreover, the regulation of the country where these projects were implemented (Slovenia and Singapore) are highly liberalized and allow this kind of practices. In the case of the pilot project *SolarShare*, the cooperation of the local utility made the project viable. However, since no similar case is observed in Slovenia, the active cooperation of a utility or grid operator in the blockchain platform is not necessary to reach this outcome. As such, by having a token and highly liberalized regulation, outcome E can be reached.
- **Outcome F: Conditions C.1, C.2, C.3 and C.5 are necessary.** In this case, the regulation is not friendly to allow a blockchain-based P2P power trading platform to compete with current power sector players. As a result, a platform that uses tokens and to which the price per unit of electricity is determined by the grid operator. Moreover, in the case study that has this outcome (BMG), the grid operator manipulates the electricity prices to monitor the behaviour in terms of production and consumption of the participants that are connected to their blockchain platform (which results in Conditions C.2 and C.3 being fulfilled). Finally, because of the tight freedom of operation particular in this outcome, the power trading can only occur in a local geographical area.

In Figure 6.2, a visual representation of the combination of the conditions that result in the outcomes explained before is depicted.

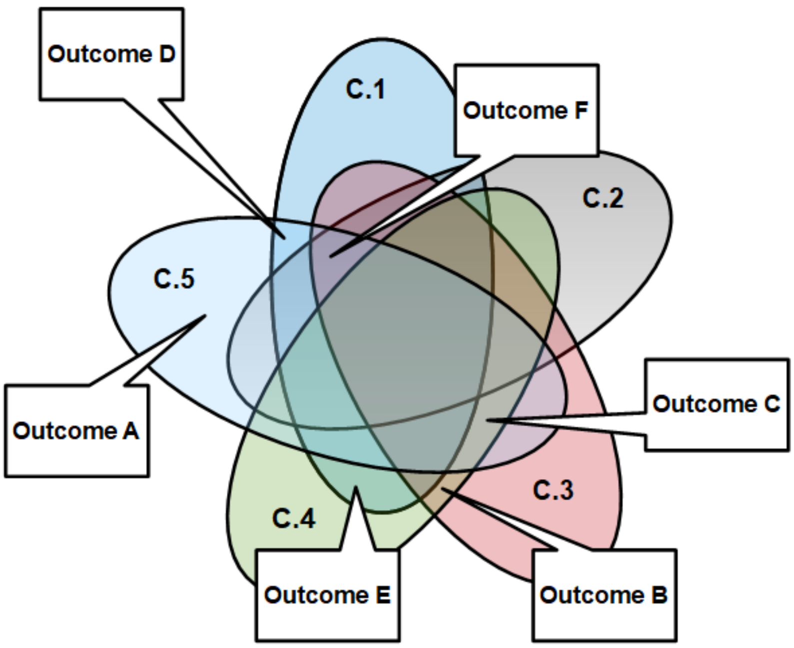

Figure 6.2. Venn diagram of the result of the analysis.

Discussion 7

This chapter aims to present a discussion on the findings obtained during the research of this thesis. Hence, an assessment of the different outcomes obtained from the set conditions from Section 6.3, as well as a meta-analysis on the methods performed during the analysis will be explained in Section 7.1 with the aim to co-answer the third sub-question found in Chapter 2. Secondly, Section 7.2 pretends to figure out the different challenges and requirements which have been identified in this research to successfully deploy blockchain-based P2P power trading platforms. Thus, the fourth (and last) sub-question found in Chapter 2 will be answered.

7.1 Reviewing the results and the methodology of the analysis

In Chapter 6, the QCA was performed and a final result has been determined. However, the QCA does not end there. As explained in Section 4.1, the final step of the QCA consists of reviewing whether the results obtained make sense and whether they concord with the theories of change selected in this thesis. An assessment on the whole process will be done as well to complete the QCA process.

7.1.1 Assessing the outcome for all case studies

A total of 6 different outcomes have been determined during the QCA. These outcomes are a result of the different configurations of conditions that were found when calibrating each individual case study.

For the research project performed by *Hero Energy & Engineering*, outcome A has been assigned. It denotes the fact that this case study is a pilot research project aimed to study the viability of using blockchain technology for power flow control and management for decentralised systems. Only Condition C.5 is satisfied, which makes sense as pilot research projects are often developed in a much smaller scale that full projects. Moreover, since the rest of the conditions are not fulfilled, it is hard for a profit-oriented company to implement a blockchain-based P2P power trading platform in a much larger scale [Hero Energy and Engineering, 2021; Saxena et al., 2019]. Saxena confirmed as well in the interview that the platform they developed in the province of Ontario is indeed a pilot project, making this result so far an acceptable one [Saxena, 2021].

The *SonnenCommunity* case study had outcome B, which is particular for companies that have used innovation to enter a competitive power market and that it can continue operate in it. Moreover, the participants involved in the project are considered a "community" since more emphasis is given in trading power between them rather than the rest of the power market. Given the decentralization-friendly regulation that Germany has (which is why Condition C.4 is 1) and thanks to the cooperation with the grid regulator (which is why Condition C.3 is 1 as well) power trading can be done across large distances (Condition C.5 is 0). The "community" feature that this case study presents also resulted in a lack of third party determining the prices at which the participants ought to trade (Condition C.2 is 0). Additionally, the lack of a token that forces these power transactions to be linked to a cryptocurrency makes blockchain technology a tool just for tracking the power flow and stabilize the power grid (and not for tracking the quantity of cryptocurrency of each participant in the network, which is a much popular way to use blockchain). The information presented in the *SonnenCommunity* website confirms the resulting outcome determined for this case study [Sonnen Group, 2021].

Similarly to the *SonnenCommunity* case study, the *Lition Solar Community* case study also has outcome B. Both of these case studies are located in Germany, which makes them have the same regulatory framework (which justifies Condition C.4 being 1). The rest of the conditions are similar to the case of the *SonnenCommunity*, with the exception of Condition C.2, where the participants in the *Lition Solar Community* do not have the option to determine their own power selling prices. Despite that, both of the projects are very similar, which is way these have the same outcome. The information found also does not contradict with the outcome determined for this case study [Lition, 2021, 2020, 2018].

The *LIC* case study by *Hive Power* has outcome C, which can be considered close to outcome B but the big difference is that the power trading that the participants can do is not nation-wide, contrary to outcome B. The regulation in Switzerland is also decentralization-friendly, and the grid operator also cooperates in these power transactions being performed (Conditions C.3 and C.4 are 1). In the interview done to Rivola, the projects developed by *Hive Power* are meant to test how blockchain can become useful to both grid operators and consumers and how blockchain can help in decentralized power production [Rivola, 2021]. With the information collected in the interview, as well as in the website, outcome C describes well the situation of the *LIC* case study [Hive Power, 2020; Lugaggia Innovation Community, 2019; Rivola, 2021].

Another case study with outcome C is the *Quartierstrom* case study developed by the *S.F.O.E.*. The location of the case study is in Switzerland, which means that the regulation is friendly when it comes to decentralization and energy communities like the *LIC* pilot. The aim of the pilot project was to test the technical-economic and social feasibility of the project, which again means that it has been not applied at a nation-wide scale (which is why Condition C.5 is 1). Tokens where not used, as in the *LIC* pilot, which means that blockchain technology was also not used to track the cryptocurrency ownership of its participants. The outcome assigned for this project concords with the public information available on the Internet [Brenzikofer et al., 2019; Swiss Federal Office of Energy, 2020].

When it comes to the case studies with outcome D, the first one is the *LES* case study. Located in the Netherlands, the regulatory framework of the country is complex and makes it difficult for this kind of projects to be quickly implemented (which is why Condition C.4 is 0) [Dorresteijn, 2021]. This fact makes it impossible for a blockchain-based P2P power trading platform to be implemented on a large scale (which is why Condition C.5 is 1). Additionally, the tokens are used in the *LES* case study to experiment their potential in bringing forth the practical implementation of a blockchain-based P2P power trading platform (which is why Condition C.1 is 1). According to Dorresteijn, the participants in their project can trade electricity directly with their neighbours at the price they want (which is why Condition C.2 is 0). Dorresteijn also confirms that any lack of electricity can be bought directly at the local power market from wholesale traders involved in the platform (which is why Condition C.3 is 1) [Dorresteijn, 2021]. With all the previous, the outcome D concords with the information obtained on the *LES* case study [Energy 21, 2021a,b; Energy 21 and Stedin, 2018; Dorresteijn, 2021].

The second case study with the outcome D is another project from the Netherlands: the *Jouliette* case study. The results of the actual project are very similar to the ones described for the *LES* case study. Aspects such as the utilization of tokens, the freedom of trading power among the participants of the network, the harsh regulatory framework and the similar size of the projects (Conditions C.1, C.2, C.4 and C.5 respectively) make these two projects very similar. The main difference is that no clear indication of the cooperation of a grid operator or an external electricity supplier was mentioned in their white paper (which is why Condition C.3 is 0). This, however, was considered to be an irrelevant condition for outcome D, since the final outcome does not differ much whether this condition is present or not. Thus, the outcome assigned to this case study is found to make sens by reviewing the information available on the *Jouliette* case study [Spectral Energy, 2021; Spectral Energy and Alliander, 2021].

As for the *SunContract* case study, outcome E was found to be the perfect fit for this case study. As detailed in their white paper, users of the platform located all over Slovenia can sell their power produced using tokens at the price they want [SunContract, 2017]. This is possible due to the government support for decentralized energy trading (which is why Conditions C.1 and C.4 are 1, and Conditions C.2 and C.5 are 0). According to their white paper, the platform can compete with the big energy suppliers to attract as many customers willing to become decentralized as possible (which is why Condition C.3 is 0) [SunContract, 2017]. The results were considered to be acceptable for this case since the information found on the *SunContract* case study concords with the outcome found for it [SunContract, 2020, 2017; SunContract Community, 2018].

The *SolarShare* case study also has outcome E. Based in Singapore, which is another location that is promoting a more liberalized power market, users can produce and sell their own electricity to other consumers in the same manner as the local utilities using tokens, all over the country (which is why Conditions C.1 and C.4 are 1, and Conditions C.2 and C.5 are 0). Additionally, the cooperation with the local utility has made this project to be carried out very smoothly (which is why Condition C.3 is 1). All of the information regarding this case study suggests that assigning outcome E to the project indeed makes sense [Electrify, 2020a,b,c; Senoko Energy, 2019].

Finally, the last outcome, outcome F, has been assigned to the *BMG* case study. The particularity of this project lies in the fact that the regulatory framework of the location of the project does not incentivise the decentralization of the power sector and, despite that, the grid operator actively participates in the operation of the platform. Moreover, the fact that a token is being used in this environment further sets apart this case study from the rest. After reviewing all available information regarding this project, it has been decided that putting the *BMG* case study apart from the rest is indeed a sensible choice

[LO3 Energy, 2021; Mengelkamp et al., 2018].

After reviewing the results and determining that the findings to make sense, it is worth seeing how these concord with the theories of change presented in Chapter 3. As mentioned in that chapter, the MLP approach and the Disruptive Innovation approach have been selected as the theories of change.

As for the MLP approach, it has been seen that some of the case studies analysed are more advanced in their development than others. For instance, the *Electrify.ASIA* platform has been implemented at a national scale and is supported by the current power sector players of the region, while the research project carried out by *Hero Energy & Engineering* is only a pilot at the academic level. Figure 3.2 in Section 3.3 shows the process in which a niche goes from becoming an idea to eventually be part of the regime. If the case studies analysed in this thesis were to be situated in one of the stages of the MLP approach, some of them will be at the first step of a niche (in the case of *Hero Energy & Engineering*), while others would have just become, or are in the brink of becoming part of the regime (such as *Electrify.ASIA* and *SunContract* platforms) (see Figure 7.1). This observation makes the obtained results concord with the MLP theoretical approach.

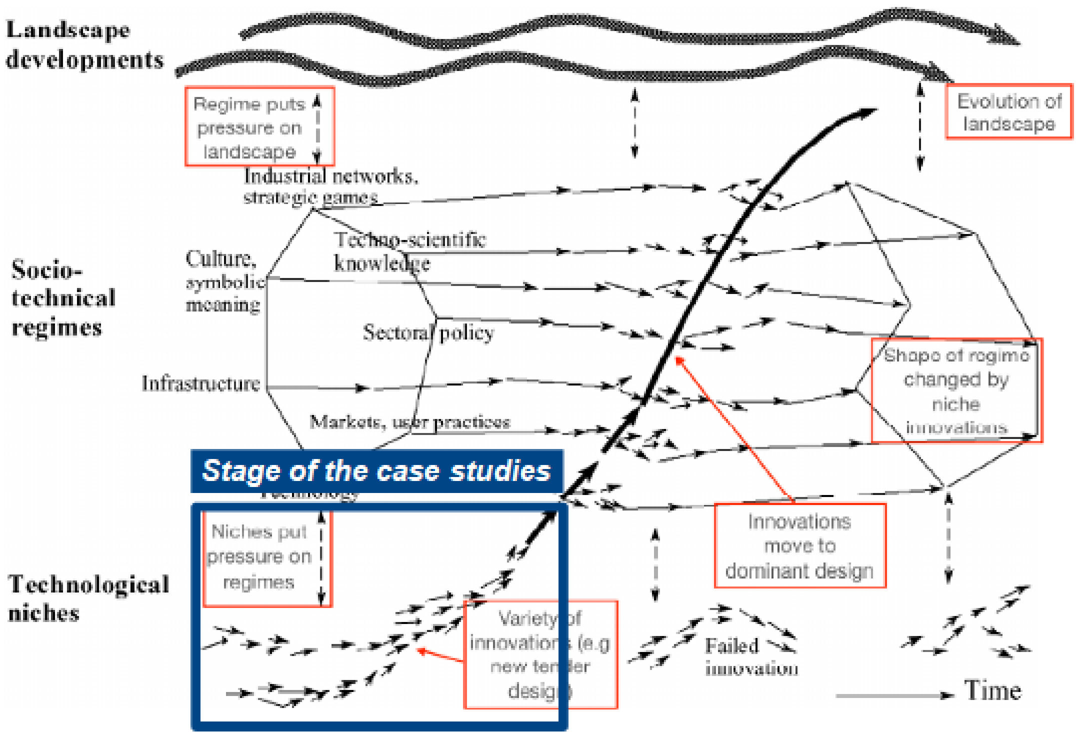

Figure 7.1. The range of stages in which the case studies analysed are according to the MLP theoretical approach. Own elaboration based on [Geels, 2006].

As for the Disruptive Innovation approach, Figure 3.3 in Section 3.2 shows the process in which an innovative product fills the vacuum of demand left by mainstream products and how it eventually becomes part of the mainstream market. The case studies analysed in this thesis, if they were to be situated in the aforementioned figure, some of them would just be at the initial stage of the *entrant's disruptive trajectory* (such as the *Lition Solar Community* platform), while others might just come out of it (such as the *Electrify.ASIA* and *SunContract* platforms). The case studies that are merely pilot projects have yet to enter the market, since some of them are just developed for a short period of time and are yet to appeal a demand that waits their type of product. As it can be seen in Figure 7.2, the blue box depicts the projects that are already competing in the market, while the blue ellipse corresponds to the pilot projects that are yet to enter the market. Because of the previous, the results obtained in the analysis do also concord with the Disruptive Innovation theoretical approach.

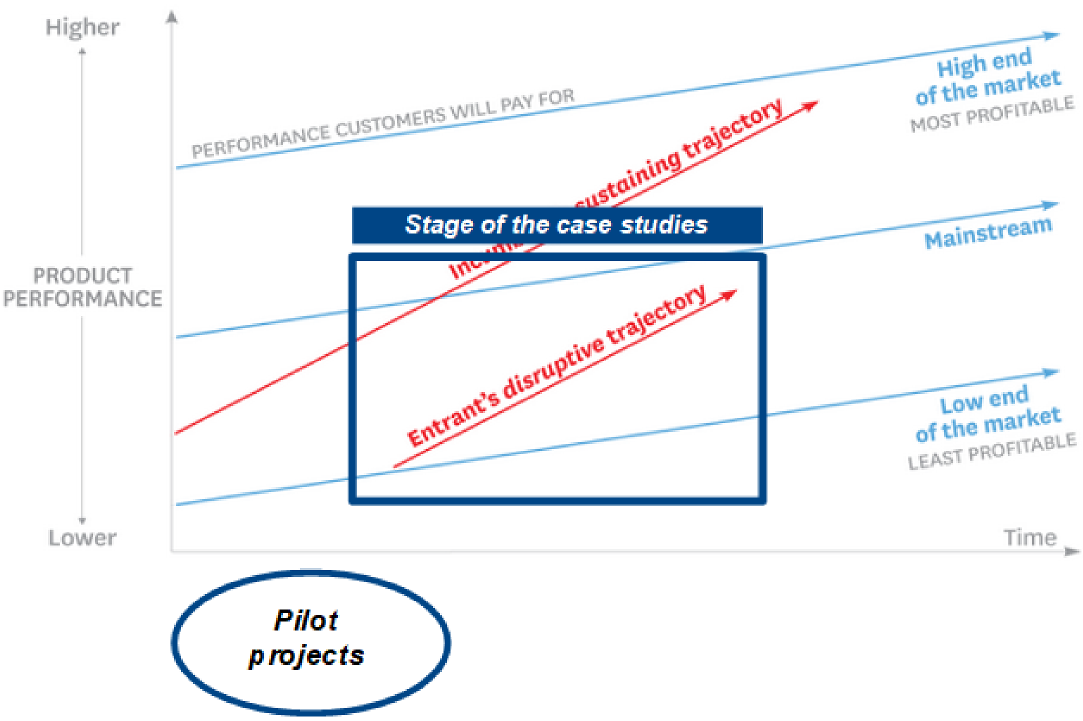

Figure 7.2. The different stages in which the case studies analysed fall according to the Disruptive Innovation theoretical approach. Own elaboration based on [Hutt, 2016].

The results obtained in the analysis concord with the theories of change used in the thesis. When combining with the coherence of the results in the analysis, the QCA analysis is completed and it has thus amassed valuable results.

7.1.2 Further considerations regarding the case studies selected for the QCA

Despite the coherence shown in the results of the QCA, a number of weaknesses can be observed in the analysis. These, however, do not compromise on the quality of the work and are presented merely to strengthen this study. For instance, the number of the cases studied in this thesis might seem to be very low for a QCA. However, this is due to a number of reasons that will be presented hereafter:

The first reason is that the topic of using blockchain technology for P2P power trading has not entered the mainstream landscape of the energy sector. In general, blockchain technology in the energy sector is mostly on a learning/explorative phase, ahead of where most other industries are but still far from being rolled out, as it can be seen in Figure 7.3 [World Energy Council and PwC, 2018]. Because of this, not many entrepreneurs in the energy sector have put work in exploring the practical capabilities of this technology for P2P power trading. Despite that, a fairly number of projects that use blockchain technology have been found.

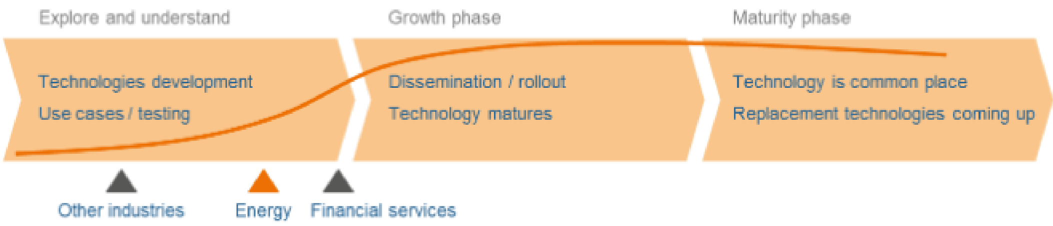

Figure 7.3. Current state of blockchain technology research in the energy sector [World Energy Council and PwC, 2018].

The second reason is that among all the projects found that use blockchain technology to find innovative applications of it in the energy sector, only a handful of them use blockchain technology for P2P power trading. The rest of them work on blockchain technology in areas such as EVs or energy certificates, among other, as it is explained in Section 5.3. By conducting a careful review on all these projects, as well as interviewing many of their founders, only ten projects were selected to conduct the analysis on. It should be noted that in Step 2 of the QCA (as explained in Section 4.1) it is important to select case studies that are consistent with each other, and that all of them revolve on the same topic. Thus, it has been considered that the ten final projects in which the QCA has been conducted upon fit this criteria.

Another important point to be noted is that because of this low number of cases and the fact that there has not been three case studies with the same outcome, the process of Boolean minimisation has been skipped, as no possible simplification has been made.

Despite all the previous, the results obtained on the QCA show that the analysis has been conducted while maintaining its integrity and that quality over quantity has been prioritized.

7.2 Challenges and requirements to deploy a blockchain-based P2P power trading platform

Once presented the assessment of the different outcomes obtained in the analysis of this thesis, it results interesting to complement this chapter with several challenges and requirements to implement and deploy blockchain-based P2P power trading platforms which have been identified during this research. Therefore, this section aims to fully answer the last sub-question which is found in Chapter 2 in order to get an idea on what is required to have a blockchain-based P2P power trading platform practically deployed.

Thus, this section will be divided in three different groups: the technical-economic, the socio-economic and the regulatory one.

7.2.1 Technical-economic challenges and requirements

As mentioned in Section 1.2, the energy sector is getting more and more digitalised. The deployment of ICT, AI and IoT platforms in the energy sector implies that automated machine-to-machine (M2M) communication and the exchange of data between smart devices and smart management energy systems will become part of the status-quo of the operations in the future [Andoni et al., 2019]. Blockchain technology is a novel and disruptive technology which has a lot of potential being discovered in the energy sector because its features fit very well with the future of the energy sector and how the energy transition is aimed to be in 2050 [D'Elia, 2021]. Blockchain technology provides trust, transparency and traceability in its operations, and that can benefit end-users to direct trade and have control over their produced electricity. However, from a technical-economic perspective, that scenario still presents some challenges which need to be tackled.

If blockchain technology is aimed to be implemented in a P2P power trading application, both a physical and a digital layer are needed in the platform. On one hand, the physical layer is referred not only to the local micro power grid and the distribution and transmission upstream grids, but also to the grid interactive infrastructure such as smart meters and other devices. Therefore, a pure technical challenge comes up with the proper connectivity and synchronisation between these devices. On the other hand, the digital layer is referred to the local market place where transactions and payments occur. To have a functional platform where peers can trade digitally between themselves, a lot of time, effort and money must be considered. Thus, scalability and connectivity of such platforms become very significant challenges to bear in mind in order to manage the increasing amount of transactions per second and the number of Internet-connected devices [IRENA, 2019]. In fact, Rivola emphasises that *"the common challenge we are always tackling in local energy communities is about the connectivity between devices (which may have limited communication capability) and the physical layer (related to the power distribution and transmission lines)"* [Rivola, 2021].

Another challenge for local power networks is addressed to their role within the upstream grid. In other terms, how can these local power networks help in balancing the grid from both the supply and demand sides. It is expected that the global boost of prosumers in the future will lead to a higher fluctuation of electricity through the grid. Moreover, the power demand is also expected to increase due to the electrification of the heat and transport (sub)sectors. Thus, it is assumed that grid operators will have to be more prepared for an increase in the number of, for instance, voltage faults and other power quality issues. Hence, their main challenge would be focused on keeping stability to the grid. Therefore, instead of increasing the transmission capacity of the upstream power grid, local power networks could help in balancing the grid by consuming or producing electricity and, thus, keep the grid balanced [Dorresteijn, 2021].

From both an economic and technical perspective, there are many advantages associated with a micro power grid that can switch from an on- to an off-grid state and vice versa. Rivola states that *"by providing flexibility to the grid operator (demand-side management),* *it could become profitable to integrate storage systems in local power grids"* [Rivola, 2021]. Not only the members of the local network would gain profits, but also the grid operator would save money by getting rid of this surplus of electricity that can endanger the power grid. *"It is important not to create autarchic local energy systems because the cooperation between DSOs and micro grids will be essential to maintain the balance of the grids"* states Dorresteijn [Dorresteijn, 2021]. Nonetheless, it is of high importance to highlight how it could be technically possible to balance local supply and demand when prosumers from local power networks and grid operators cooperate together, especially when using blockchain technology.

Hence, from a technical-economic perspective, some requirements have been identified in order to deploy blockchain-based P2P power trading platforms, which are:

- to adopt smart meters in order to unlock connectivity capabilities and better monitor power flow across the grid;
- to install infrastructure aimed at facilitating a decentralized operation of the power grid rather than investing in infrastructure prone to a centralized system;
- to foster autonomous micro power grids and have them become capable of on-grid and off-grid connection to make the power grid more resilient.

7.2.2 Socio-economic challenges and requirements

Besides the technical-economic challenges, socio-economic challenges also have a direct impact on the deployment of blockchain-based P2P power trading platforms. It is interesting to highlight that for the first time, social welfare within the energy sector is not strictly linked to the economic circumstances of people but also linked to other priorities such as the care for the environment [Dorresteijn, 2021]. In fact, it was found out during the research process how there exists an added value in each kWh produced locally: it is not only much cheaper for the end-user in terms of economic costs, but it is also environmentally friendly as it comes from a RES and, indirectly, it fosters the productivity on the local community [Dorresteijn, 2021]. However, there still exists a lack of social acceptance towards the fact of belonging to a local power network, which sometimes may be even increased by the lack of support from energy suppliers.

It was emphasised several times throughout this thesis that one feature that P2P power trading presents in micro power grids is related to the decentralisation of the power system. In this context, citizens possess a higher degree of freedom in the decision-making regarding their electricity produced than in centralised systems. But social commitment is required to reach this stage. Regarding the good application principles of blockchain technology in a local-level, Dorresteijn argues that *"there must be a distributed interest of each participant of sharing the system and promote locally-produced and consumed electricity. From the user's standpoint, it really does not matter what technology is used behind the system as long as the power transactions are trustful and secure"* [Dorresteijn, 2021]. Therefore, blockchain technology would probably succeed in a P2P application if there exists a social will to share and become a community and cooperate. Saxena also agreed with this previous statement: *"if people are saving money, then indirectly yes, blockchain technology increases social welfare"* [Saxena, 2021].

Hence, both the lack of social acceptance from people who has not joined yet to a P2P power network plus the fact of achieving a close social commitment from community members in the performance of their platform are two challenges which should be addressed. Nonetheless, these two identified challenges are strictly linked to the type of consensus model implemented in the blockchain-based platform. It is interesting to tackle this fact from what Saxena states regarding an advantage of blockchain technology compared to centralised management tools: *"from a technical standpoint, the centralised option will win every time if you compare the savings between implementing blockchain technology (decentralised option) with a centralised system. But, in a P2P context, if prosumers become part of the revenue sharing, then blockchain technology may emerge as a very good alternative because everybody may gain profits"* [Saxena, 2021]. In order to increase the social welfare among the members of the local network, it is of high importance to commonly reach a valid and shared consensus model from all the members. In fact, how the platform is structured internally really depends on the will of the platform members to interact with each other, and that results crucial for energy communities. The PoW is not proper for a local application as it is more complex to implement and requires a lot of computational power. Otherwise, as mentioned in Section 5.2, other consensus models that require less computational power and are easier to regulate are suggested like PoS, PoAu, PBFT or ZKP [D'Elia, 2021]. In general, what they share in common is the fact that are ruled by specific network peers, although the privacy level of peers' data may vary a bit. Anyhow, the fact of reaching a proper consensus model for P2P power trading platforms when blockchain technology is implemented is fundamental to successfully operate a platform through the commitment of its members.

Last but not least, another socio-economic challenge that needs to be emphasised is the fact of integrating a token to trade electricity within the energy community. A token can be only used internally in the platform to allow an easier trade between the peers. Otherwise, tokens can have a more profit-oriented purpose, where they are aimed to be exchanged by fiat currencies. Even if the platform is not commercial, the members could also prioritise to gain profits and pay back their own investment sooner rather than aiming to increase a general social welfare within the community. The fact of how to utilise tokens in a blockchain-based P2P power trading platform is very debatable. For instance, we can see how some startups may offer an Initial Coin Offering (ICO) in order to raise funds and create their platform from interested investors in their project (interested in acquiring their tokens to afterwards speculate with them and gain profits). However, in a long-term perspective, it is pretty questionable that members of this type of platforms will keep profiting from these tokens. The reason is simple: the marginal cost of electricity from RES has dropped during the last years, and it is expected to keep dropping as RES will be eventually more deployed worldwide. Therefore, the retail price of electricity from RES will also be lower in the coming years than today, so platforms that encourage members to participate and trade with their token may face troubles as, apparently, there will be no chances that the value of each token eventually rises up in favour of investors [D'Elia, 2021]. As it can be seen, it may become a challenge for token investors to invest in these platforms which use a token that is linked to the value of energy production of RES, since these are expected to have lower value as RES marginal costs become lower. This rather unattractive feature of the blockchain-based P2P power trading platforms powered with tokens could make investors refrain from putting their money in these type of projects. As such, new forms of incentives that do not have tokens as the main benefit ought to be explored.

As such, from a socio-economic perspective, some requirements can be identified in order to deploy blockchain-based P2P power trading platforms, which are:

- to inform the public about the benefits that can be reaped on an individual and community level from P2P power trading;
- to effectively design and implement a blockchain consensus model that is both user-friendly and that makes participants feel actively involved;
- to ensure that tokens (if they are to be used) do not endanger the involvement of participants but are used as an asset to enrich local communities.

7.2.3 Regulatory challenges and requirements

In general, the regulatory environment for blockchain technology still remains uncertain, and that is without a doubt the most difficult challenge to overcome in any sector where it is aimed to be applied. As a novel technology, many national governments worldwide are still figuring out how to adapt the regulation regarding blockchain technology. In the power sector, most current blockchain platforms are currently just being tested in behind-the-meter applications as that requires minimum changes to the power regulatory framework [IRENA, 2019].

The same legal uncertainty occurs when aiming to do P2P power trading. In the European Union (EU), the European Commission defined for the first time P2P power trading from RES in the Clean Energy Package Directive 2018/2001 [Dorresteijn, 2021]. Such an EU Directive mandates Member States to foster a more open regulation for energy communities and to grant a stronger role to prosumers and consumers in the coming years [IRENA, 2020]. So, the first step is done, but there is still a lot of work to do to legally regulate self-efficient energy communities in each EU country. For instance, in Germany, the market is very liberalised and it will not be surprising to see how in a short time, power consumers are going to establish themselves as equal energy partners with power producers and energy suppliers [Lition, 2020]. Outside of the EU but still in central Europe, as Rivola states, in Switzerland it is possible to create self-consumption communities that work like private networks. The main point, even they are connected to the main upstream grid with a normal meter, is that inside the community there must be some basic rules that are not regulated yet [Rivola, 2021]. Otherwise, far from Europe, Saxena confirms that in Canada, the regulatory framework is not friendly as the net-metering seems a concept from the future and there are not great bases for standard RES. However, Saxena states that, for instance, in the province of Ontario there are a lot of cities which are committed to be net-zero by 2050, but the idea is more about integrating EVs and have it done in a more standard way than going radical and implementing P2P power trading strategies for residential markets [Saxena, 2021]. Finally, in the USA it is only possible to do P2P power trading in micro power grids without using the main upstream grid. Although this regulation could incentivise more local communities like the *BMG*, the truth is that few P2P projects have been implemented due to limitations in the regulatory framework[IRENA, 2020].

Therefore, it can be seen how the implementation of blockchain-based P2P power trading platforms is still far from being fully regulated. These types of platforms are still in an early-stage primarily from a legal perspective, rather than from a technical or economic perspective. Dorresteijn is very clear: *"if P2P power trading platforms are not implemented yet is not due to technical issues, but purely regulatory issues. There are a lot of invested stakes in the energy sector. It is not easy to change regulations just like that"* [Dorresteijn, 2021]. The point is that in decentralised networks, further aspects need to be considered beyond the way demand and supply are balanced. For instance, just focusing on the utilisation of users' energy data, the current General Data Protection Regulation (GDPR) does not legally cover who is in charge of it, how to avoid a bad use of it, or how should DSOs and energy communities interact and cooperate in order to have a robust grid which is always balanced (as previously discussed in Subsection 7.2.1) [Rivola, 2021]. Since this is a relatively new issue, it is necessary to pass a new regulatory framework in the current energy market that would legally cover these specific situations. However, the complexity for these still non-existent but necessary policies and regulations to govern the future power sector is huge.

Hence, from a legal perspective, few requirements are identified in order to deploy blockchain-based P2P power trading platforms, which are:

- to update the current regulatory framework on a general level to bring forth the potential of new technologies such as EVs, RES, and others;
- to design a regulation that can allow and facilitate P2P trading operations;
- to have both a regulatory framework aimed for the cooperation between the grid operators and local power networks;

Conclusion 8

In this thesis, a Qualitative Comparative Analysis (QCA) has been done on the topic of blockchain-based P2P power trading projects that are being operated at the time of writing this thesis. The aim of the QCA was to identify the main aspects that characterise blockchain-based P2P power trading platforms that led to their successful implementation and deployment. The main motivation behind the writing of this thesis was the lack of studies that compares current blockchain-based P2P power trading platforms. It was considered that it is important to have this type of comparative study on a technology that has yet to become a mainstream phenomena so that future project developers can have a better understanding on how to implement a blockchain-based P2P power trading platform. Thus, the following research question was formulated:

What conditions can affect how blockchain-based P2P power trading platforms can be implemented and what are their final outcomes when these conditions take place or not?

The research question was complemented with other four sub-questions presented in Chapter 2. In order to answer the research question, two theoretical approaches were used that would help in understanding better the stage at which blockchain-based P2P power trading platforms are at the time of writing this thesis: the Multi-Level Perspective (MLP) theoretical approach and the Disruptive Innovation theoretical approach.

Three different tools were used to carry out the analysis. The first one was the QCA, in which it can be possible to withdraw results from comparing various case studies. The other two were the literature review and the semi-structured interviews, which were both used to collect as much information as possible from various blockchain-based P2P power trading platforms.

Before commencing analysing the blockchain-based P2P power trading platforms, a brief explanation on how blockchain technology works and its application on the energy sector was presented (see Chapter 5). It was found out there is a wide variety of applications of this technology in the energy sector, being the P2P one of the most important ones.

Later, the case studies to which the QCA would be applied to were presented. A total of ten case studies around the world were carefully selected so that they all revolve around the same topic (P2P power trading via blockchain technology). Additionally, five different conditions were identified which depended on the common information that was being able to collect for each case study. Additionally, it was identified which conditions each case study fulfilled.

The next step was to determine the outcomes of the different case studies according to the conditions they met and/or unmet. A total of six different outcomes were identified, ranging from those that were considered pilot projects to nation-wide implemented blockchain-based P2P power trading platforms. It was found out that various combinations of met and unmet conditions gave place to these outcomes. A tendency was detected where case studies located in the same country had a similar outcome. This phenomena was associated to the fact that the regulatory framework of the country on decentralized systems has a huge impact on the final outcome of a blockchain-based P2P power trading platform.

Afterwards, a review on the results obtained in the analysis was done and each case study was individually reviewed to determine whether the result obtained made sense. Additionally, a glance to the theories selected was done to see if these were upheld. With this step, the result of the analysis was validated.

Finally, a series of challenges for implementing blockchain-based P2P power trading platforms was presented in Chapter 7. These challenges were identified while conducting the research on the case studies of the QCA, and these were divided in three categories: technical-economic challenges, socio-economic challenges and regulatory challenges. It was found out that certain requirements ought to be made in order for these blockchain-based P2P power trading platforms to be successfully implemented, emphasizing that without a regulation that supports and facilitates these platforms, it would be hard to implement a blockchain-based P2P power trading platform.

9 Reflections

This chapter aims to conclude the thesis by presenting some of our thoughts regarding the performance of this study as well as to suggest further research that could be done regarding blockchain technology on a P2P power trading application.

Firstly, as it was reported in this thesis, there are currently not many platforms in the industry which operate under blockchain technology for a P2P application. We knew from the beginning that this topic would be challenging in terms of limited information sources on Internet plus the available time to perform the thesis. Indeed, we found out around fifty candidates on the Internet to include in our thesis as case studies, but some of them were not operative anymore, or the available information was just incomplete for the analysis. In the end, ten final case studies to carry out the QCA were deemed acceptable given the previous circumstances. However, we realised that if we would have had more time to do this thesis, we could have included some more case studies and probably could have interviewed more people, leading to a more robust final outcome. It became very interesting to meet people who work in this specific field in the energy sector, and they helped us to reach further people that could give us a hand as well. Unintentionally, we created our own network of experts in this area, so it would have become much easier to find out more potential candidates for our research.

Secondly, we would like to encourage further research on this research field. On one hand, regarding blockchain technology, which has come to stay and sooner or later it will be widely deployed and we will regularly use it in our daily lives. On the other hand, regarding P2P power trading, which offers a model for the future energy sector that may provide a lot of benefits to the society.

The main reason this thesis has been performed was to provide a new door to the research world in order to combat climate change. The synergy between blockchain technology and P2P power trading is powerful. Therefore, more research needs to be done to convince politicians and policy makers to bet on this alternative to combat climate change. As such, we hope that this thesis contributes to the cause.

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Predetermined questions guide A

As mentioned in Section 4.3, all conducted interviews consisted of a common backbone. Depending on each interview, this general guideline was slightly amended and tailored in order to obtain as much specific information as possible. As it can be seen below, the predetermined questions guideline is divided into two different sections: on one hand, questions are focused on the internal circumstances of the platform which is aimed to be analysed. On the other hand, external questions are also asked in order to obtain a a wider and more general knowledge of the blockchain technology in the energy sector from the expertise and knowledge of the interviewee.

Internal circumstances:

- What is the mission and vision of your company or your research? What do you do? What have you achieved so far?
- Why is your platform utilising blockchain technology? What is the added value?
- What is the consensus model utilised, and why?
- What type of architecture you utilise, and why?
- How are smart contracts integrated? How are internal decisions decided?
- Is your platform tokenised? Why or why not?
- Who manages the operation/functioning of your platform? Is it an internal or an external regulator, and why?
- How are local electricity prices determined in your platform?
- Who owns the energy assets (PV modules, battery device, micro grid)?
- Is it possible to expand/scale your platform to accommodate/interconnect more micro power grids of similar features that are connected between each other?
- How users should become interested? What is their role in your platform? What makes them to be proactive and involved in the project? Is there social support/acceptance?
- Are there any regulatory obstacles/barriers/hindrances to implement your platform?

External circumstances:

- Why blockchain technology fit so well in the energy transition in general?
- Why blockchain technology has a huge potential in the power sector?
- Why blockchain technology is a very suitable tool to manage P2P local power trading platforms?
- What do you think is going to be the role of P2P power trading platforms from today on, according to how the future power sector is about to become in the coming years?
- How is achieved a greater stability to the grid with embedded energy communities in the power grid?
- What is going to be the role of TSOs/DSOs in the future power sector?

Interviews B

As explained in Section 4.3, semi-structured interviews have been utilised to obtain further information of some implemented blockchain-based P2P power trading platforms. Therefore, the following transcribed interviews have been conducted to Mr. Michiel Dorresteijn from *Energy 21*, Mr. Shivam Saxena from *Hero Energy & Engineering*, Mr. Davide Rivola from *Hive Power*, and Mr. Alex D'Elia from *Prosume Energy.*

B.1 Interview with *Energy 21*

Interviewee: Mr. Michiel Dorresteijn, senior energy consultant at *Energy 21.*

What is the mission and vision of *Energy 21*? What do you do and what have you achieved so far?

Well, the mission and vision can be found on the website. *Energy 21* is a company that provides data-driven solutions to parties in the energy sector. For the last five years, we are expanding our services also to the other side, like energy industries which are going to manage their own energy households themselves, especially the complex sides (petrochemical sides), as energy management is complex. Also optimising their systems. We are fond of complex systems. For the last years, several industrial sides are becoming our clients. We also provide solutions to intermediates, data-management on one side and providing information on the other (forecasting for instance).

To provide this type of solutions, you have to know very well the energy market, how the market process model works in order to comply with it. So, for all our clients (large stakeholders, TSOs, DSOs, ESCOs, etc), all are confronted with a lot of challenges regarding the democratisation of the information in the energy sector, as well as available technologies to produce their own energy (PV panels). A lot of electrification is going on, many changes (challenges). And to manage that, it is all data-driven. A lot of part of our company looks forward in how can we use technologies and bring solutions to our clients to innovate and go with the changes they confront.

My role in the company is to be a business consultant, energy market consultant. Mostly working with our clients, long-term strategies and development, translating the business demands to requirements of software (fore front).

What is the status of the *LES* platform?

How we came upon this idea, that is described in the white paper (a bit outdated, it is two years old). *LES* is initiated for grid operators, but then we thought "What are the principles of good application of blockchain technology?". First, you must have a distributed interest of sharing the system, an incentive for every participant to share the blockchain. As a consumer, it does not matter the technology behind. Another one, there is lack of trust between members. They do not know each other, so how are they going to trust each other? And there is no one keeper of the proof, if centralised, no value to use blockchain technology.

So, having these principles in mind, along with local energy corporations or local energy initiatives that want to meet and provide their own local energy, then we can say: if everyone on a local-scale has an incentive to interact with local-markets, exchanging energy, then we can probably fulfil these requirements. So, we started designing and we came up with local energy systems. It is important we are not failing for autarchic local energy systems. Especially for grid operators, it is very important to keep having access to local flexibility. That is not a closed distribution system which is optimising itself. It is important for DSO to maintain the balance of the grid as well. It is possible to provide incentives that when the grid is overload, please consume! On the other hand, you also want to have an incentive to locally solve problems or produce energy. So, we created local market process models exchanging the same way as wholesale market. As a consumer, you must provide a plan for the next day, you can trade with your neighbour to buy from local market, otherwise from the national spot market. You have to maintain your own balance (responsible 100%). That is how we initiated the *LES*. Blockchain technology is still used, because we concluded that blockchain technology is nice, the *LES* has been involved in pilot projects where applications have been implemented. And blockchain fabric used is developed by Energy Web Foundation. Ethereum-based. That is a problem, as soon as Ethereum is used, for grid operators, having cryptocurrencies cause problems to maintain the grid balance. It is all about pilots right now. For instance, we use tokens where rate with Euro is 1:1, but then you have to incorporate regular banks or authorities to exchange these tokens into Euro currency. Now we are focused on Energy Web Foundation pilots: one is in a small town in the Netherlands, where we are focusing on a residential area (40 houses), running on this system for over a year. Everybody has to provide their own planning, but now is everything done automatically.

With smart contracts?

Smart contracts are used as an intermediate between the blockchain and smart meters, regarding the whole optimisation planning of household-level, separately (home energy management systems and an extra module where the algorithm is running). The other pilot is in an industrial area with larger consumers (not very energy intensive), more about distribution companies with a lot of solar panels on their roof. If you are using the flexibility with batteries, for instance, the charging of these batteries you can use for your own consumption. The main difference is that the former is focused on optimisation of local energy, while the latter is focused on the grid use (savings). In the end, both pilots should merge and have both integrated. That is the idea.

First, we test them separately. The principles of these projects are explained in the white paper. The industrial pilot is also focused on local market, but in an industrial area. In residential are, it is active inhabitants that want to solve things together (communities). In the industrial area, the social fabric is also very strong, they have a local association of the company owners and co-work with local councils. Especially when you can combine residential and industrial area, there is synergy. Significant local added value.

So, your blockchain platform is Ethereum-based. Therefore, what is its architecture and consensus model

We call it a consortium model (hybrid), just a blockchain with few nodes. Intentionally, because when looking at social fabric on both pilots, the stakeholders must be involved. Who are these, involved locally? Individuals and local companies, local governments, DSOs, and local stores/shops. The end-consumers want to have some kind of relationship with the neighbourhood, but that is limited, you do not want the energy suppliers controlling all nodes. So, the consortium blockchain, the local community can choose from their stakeholders.

Interesting that the *LES* try to increase the efficiency or flexibility of your platform by letting all stakeholders from different layers interact with each other. What are the benefits from doing that?

Several reasons. First of all, one of the most important of this interaction between layers: from the bottom, you cannot expect a local community to completely balance itself, nor to provide energy to itself. In Europe, we have been interconnecting all small local energy systems to build larger power systems. Right now, the European connection is very robust, so it is not a good idea from a technical sense to become a small autarchic residential system. It is cheaper even to be connected for users. On the other hand, if you are looking at factors for the energy transition, there is intermittent production from PV and wind, so the national goals on a regional level, maintain the balance is becoming hard, so flexibility is needed. That can be done in two ways: one, to let the grid owner (TSO or DSO) buy flexibility on a large-scale, then you can expect that third parties will ask very high prices for this flexibility; or you can also try to provide incentives for flexibility in a local level. Electrification is going on, households have charging pools and batteries, they offer a lot of flexibility. So, if you have a way to access this flexibility, to maintain the balance in the system is much cheaper. So, from an economical sense, it makes sense an interconnection with communities and grid operators.

How are participants incentivised to participate?

Local people are the participants, you can express all the incentives financially, their bids it is cheaper than from the grid (outside the local system). But a social aspect is very important as well. In these pilots, citizens are willing to participate. Maybe that is not the general opinion of all citizens, though. But being part of a local community is very important because they are part of a good idea, producing your won energy by yourself, and for them is even more important than gaining profits (financial benefits). Those are incentives for consumers, for grid operator, the incentive is the flexibility and the ability to manage their grids at a lower price. For local governments and local shops, there is an incentive to have their own social responsibility to support neighbourhoods, more about providing services to their inhabitants (social reputation).

How do users in this pilot set the price of electricity?

We have the possibility for users to buy the energy from an external party (supplier), so the general retail price will be the cap, because if local electricity is more expensive than from the grid, it makes no sense and users will buy it from outside. Local prosumers sell it cheaper, marginal price based on bids and asks, every fifteen minutes a bid is done and the price is settled.

Are there any regulatory barriers that can hinder your type of platform?

Right now, the regulatory system prohibits P2P power trading, only if pilot. If it is not implemented yet is not only because a technical issue, but purely regulatory. There is responsibility of someone if households supply energy to the neighbour, that must be tackled. Also, bout maintaining the grids, that costs money and who is going to pay this? Regulation is not allowed yet, there are two reasons for that: First, using flexible tariffs for grid usage is not allowed yet (for both individuals and industry) in the Netherlands, there is another system and other incentives to optimise the grid usage for companies. For residential areas, there are energy taxes which are not avoided by becoming a prosumer. These things have to change in case of aiming to cooperating in the energy system. Alliander (DSO) is forcing the government from Netherlands to change the regulatory framework. There are a lot of invested stake sin the energy sector. It is not easy to change regulations just like that. If you are looking on the discount of levies and taxes to locally produce energy, it has no several impact on tax incomes, it can be managed.

What do you think is the role of blockchain technology in the energy sector?

Well, blockchain technology is linked to Bitcoin, and that is difficult to regulate. But other applications can be regulated very easily. It is hard to understand for policy makers. Blockchain technology use in the energy system is only used as a ledger, track of data and track of proof. What we only do is this.

There may be some legal conflict with other regulations?

Yes, There are legal conflict with, for instance General Data Protection Regulation (GDPR): how to manage individuals' data, who is in charge of that, how it can be ensured that to possess this data is not going to be used with a bad purpose, that opens a new horizon for policy makers. New energy policies are needed, and P2P must be regulated.

It is essential, that energy communities have to play a vital role in a consumer-centred energy system. Of course, you can choose for something else, but the principles will remain. In the Clean Energy Package, communities are mentioned.

LES project attracts a lot of interest from other communities. Those communities in industrial areas, blockchain technology is very difficult to understand for them, so they refuse it (social resistance due to lack of knowledge).

B.2 Interview with *Hero Energy & Engineering*

Interviewee: Mr. Shivam Saxena, President of *Hero Energy & Engineering.*

What was your motivation behind doing this research project? What made you decide to implement blockchain technology for P2P trading?

We are getting into more functional uses of blockchain technology, where it can be used in the industry in a permissions environment rather than free-for-all completely decentralized network which does not flow well for power systems.

In our case, we are not blockchain experts, we are power system experts. A lot of people think that if we do P2P energy trading, we are cutting out utility middleman, and that is not exactly the case. In fact, we do it through the utility, there is a lot of saving to be had. If you both produce and consume energy locally, the overall energy efficiency is so much that you really gain a lot, and that adds a lot of resilience to P2P energy communities. Starting with that premise, not necessarily with blockchain technology at all, but the reason why we try to use blockchain technology was because utterly when energy markets are connected, they are connected by a trusted authority, usually at the transmission level. There are no trust issues there. When you work in a P2P type of system, it is not clear who is administering that market (such as the complexities of the trade), which represents trust issues. So, in order to get away from these trust issues, either you go to centralized environment where one person is regulating/administrating the market, that will be possible, scalable, so blockchain technology is a good candidate. We found two motivations: i) if we do some P2P energy trading, what is the net factor of the power system; ii) how can we use blockchain technology to better adopt this and make it more commercially available. So, the real reasons why we used blockchain technology was mainly to address these trust issues in the administration of the market.

So, it was more about the trust rather than the process about implementing more RES, right?

Yes, specifically to blockchain technology, yes.

We are going to divide our questions into two categories: internal circumstances regarding your platform; and external circumstances regarding other circumstances could affect the platform. So, in your platform you are not using any tokens as it would require more energy to mine and manage it. How is that?

I would not say we are not using tokens. In the consensus protocol in blockchain, we do not do any mining for that. We are basically using Hyper Ledger Fabric, which has something called Practical Byzantine Fault Tolerance (PBFT). Instead of everybody has right in the consensus process, there is only a trusted set of nodes that know that. Then there is no real need to involve everyone in the network. However, it is possible to have tokens in this kind of systems, but the reason we are not doing token is because we are just interested in money transfer and lower the peak demand of the system. We are not looking at other behaviors at the moment. But it is a good way to do that, because with a digital token you can encapsulate a budget of things in one object (asset), such as your participation or your renewable shares. That is a good way of doing it, but for that it was irrelevant to our project and we thought it was not necessary to invest in tokens at all.

Fine. We thought that was an interesting feature because we investigated other projects and some of them use tokens. So, the fact that in your project there were no tokens, that became interesting for us.

Yes, but those motivations are a little bit different, I think, for commercial projects. This is a research project, so we are just focused on what aspects are going to create net zero energy contributions and how we can do more things on a part-system side. If you analyze other projects like *EnergyCoin* or *PowerLedger*, these are more commercial and more user-oriented. So maybe people can actually look into the management of the tokens and see what they want to contribute. And maybe from the RE you produce, you can go to a merchant and even cash these tokens. There is a motivation where this token can be used for. For us it could be included if we were doing it on that path, but at the moment we did not think it was necessary to do it so.

So as far as we understand, this research project aims to develop a platform which is not profit-oriented.

Yes, in our platform, the blockchain technology is just the intermediate for the utility. Is the way for the electric utility to have decentralized control over something that they would not have in the first place. For us as a provider, we would generate fees for maintaining the blockchain, its transactions and its algorithms, but the real savings are going to be for the utility, not necessarily to the peers that actually participate in these markets.

So, we can assume that it is correct to say that it is not a 100% decentralized system, as in case of control, manage or anything fails, someone has to become responsible and solve the issue.

Yes, it depends who is the node in the network. In a commercial environment, the utility would run one node, just to make sure that nothing is going on, nobody is gaining the system, the auctions are running properly, and then us as a provider we run one node. So, I would not agree there is a sense of centralisation, I would definitely say it is not as decentralised as other platforms, where even peers have a way to fill it up what is going on, but I would not say it is centralized either. That is the definition of permissioned blockchains, a hybrid platform where it is centralized and decentralized at the same time. There is a degree of decentralization. But regarding the second part of your question, if there is a problem (software wise), we have to fix it. But since all the work we are doing (such as the smart contracts we are developing) are available to all nodes, that is what makes this platform decentralized.

In your platform you say you use a Hyper Ledger Fabric blockchain and you have developed different channels in order to handle the blockchain function. And you stated it helps in better scalability and abstraction. You divide the peers into channels, so there is less time to validate and to do for the communications with each different node.

Fine, so here there is couple of things. On one hand, the motivation of channels is more about abstraction, because these channels have their own private ledger. The main thing is that you can have one community ledger for each channel. That is much better for a privacy point of view, because everything is relevant to that channel. That is what we call abstraction: you only know what you need to know. On the scalability perspective, if we can segment the nodes/communities, better. But there is a trade-off, as in Hyper Ledger Fabric, if you look at the number of channels, there is a maximum number of channels. To sum up, more channels are not necessarily for more flexibility, there is a trade-off at some point, so you can manage that these channels are appropriate.

Because we were wondering if the channels were isolated from themselves. Or if there is communication between them.

At the moment here is no communications between the channels, but that may change as we get into more complex use cases. So, we just considered one community trading within itself. Maybe with hundred communities, that design may change, but that is something we do not explore in our project.

In your paper you did not mentioned how blockchain technology can help the stability and control of the power grid.

Blockchain by itself it is just an enabler technology. It is not going to add more stability or control to the system. What it can do is to run smoother and remove trust issues in the platform, so that people are not concerned, and that is more like a psychological fact. Our overall project includes stability and control because the algorithms that are running on the blockchain reduce peak demand by 52%. When we do that, we increase the level of stability in the system automatically. What is important to be noted is that we could have run this project without the blockchain and we could have achieved the same results. In fact, for our performance perspective, that would be even better, because a centralized entity that runs a platform where people trade with bids and offers, that is how markets work today. We could argue that blockchain enthusiast that the uptake or people's willing to participate in this type of market may be more if there is trustless infrastructure in place, as they own a piece of that network. If there are savings from that network, these are directly flying back to them. That is the only way I would justify that blockchain adds a bit more of stability and control, but it is important to highlight that blockchain technology itself, in this case at all, does not provide any increased control and stability of the power system. In the governance, yes, not in the mechanical operation.

So blockchain technology is not providing a better technical solution, but increase more the social welfare, as the citizens here have a different role compared with what they could have in another more centralized context.

Yes, exactly, blockchain technology increases social welfare. In other cases, blockchains do provide a better technical solution, if you look at shipping merchants for instance. But if you look at it in a larger context, if you are reducing business friction, if you have people that have private databases and are not really wanting to share but having all in a ledger, then you are actually saving people money and that is a better technical solution. And this is specific to our model at a residential level, you can argue that you could do this with a fairer degree of centralization and be fine. But if you look larger on the players, we are talking more about the technical solutions.

No more questions regarding the internal circumstances of the project. Actually, let's link this concept of stability of the grid with the role that DSOs could have (if it had a role) in this specific context that you developed. And somehow, we would we jumping to the second half of the interview, the external circumstances of the project. So, could we ask what would be the role that the DSO would have if it had a role in the management of your micro power grid? And at the same time as well, do you think that maybe the regulation you have in Canada is friendly, if your prototype had to be implemented in

any other area, or you present some legal barriers?

Let's take these questions in a reverse order. The regulatory framework in Canada is not friendly, in fact the regulatory framework here in Ontario (that is our province in Canada) is behind 15-20 years. So net metering is a concept from the future. They do not even have great basis for standard distributed energy resources, there is no way that this regulatory framework can adopt this technology for the next 3-4-5 years actually, so this is not going to happen. Unless there is a push to update the regulatory framework, but it is not quite there yet. It had to be a research, and if it was a little bit bigger pilot, if we had spread across a geographical area, we would have probably got permission from the regulatory framework. Just to make sure that we could do it.

Regarding the DSO, its role is very important. First of all, the DSO runs a role in the network. Secondly, the DSO should probably be giving some advanced levels of permissions (that is why we have permissioned blockchains). Just to make sure that the market is being administered fairly, in a way that is cohesive with the rest of the network. So, the DSO is sending specific market signals like the demand response. In the conference paper, there is a followed journal paper that discusses the demand camps. So, the DSO can actually set demand camps on each market interval for demand response scenarios. So, if you set the demand camp and the market price goes up, and the non-critical loads that you do not need, they get shut off because the MCP is very high. So, in this case, the DSO has a large role and they can layer any other services within this platform. So, this is a platform for utilities: emitting some pressure to the utilities in terms of administrating in a decentralized way. Now they do not need to administrate these markets because it is done by smart contracts, but there is a way that they could be involved. So, for sure, the role of the DSO will move forward and will have some advanced permissions.

And do you think that there are going to be some promises for the future that are going to change this? Like, is it politically motivated to move forward on this transition, or there are other reasons?

All the countries that are committed to the Paris Agreement, trying to be net zero by 2050, if you have a strong political framework, strong political backing that filters down the provinces, and it is up to the provinces to actually get the technical plans in terms of getting more distributed energy resources in an auction. I do not think the start will come with the P2P but finding how to operate front the meter and behind the meter, distributed energy resources providing services to the grid, and later, you may find more isolated microgrid scenarios where P2P energy trading will be a fact. But like in your research area, either there is a lot of and extreme amounts of pressure to change like in Germany; or we are in this bounding of solar and they are causing issues in the power systems stability. Nevada is one case, Mexico another one. Instead of separating people from the grid and having more island-based micro power grids, and that is where this type of administration becomes necessary because now there is not a central authority that manages systems that are all private. If it is more like in Ontario or Canada, we are more in the middle: a lot of cities and provinces are committed to be net zero by a certain time, usually 2050. But the idea is more about getting EVs involved and have it done in a more standard way rather than going radical and implementing P2P energy trading strategies for residential markets.

So, your project is more about to contribute to this change, instead of showing that is possible to implement a blockchain platform for P2P between prosumers.

Yes, exactly. It is meant to assure that as a utility, you can get some specific savings. In the journal paper, we did some basic analysis regarding the capital expenditure. Just by reducing the peak demand by 52%, they can save 100M USD in capital expenditures because now they do not need to upgrade their transformers and stuff. That will hopefully motivate the whole premise of why we are doing this. Because eventually we have to electrify (as well as heating and transport). Current power systems are not ready for it.

Do people want to be prosumers? Is there a push from them to trade electricity instead of letting utilities do this task?

In Ontario there is not so many people motivated to become prosumers. If they invest in distributed energy resources, they are interested in the payback. If you get a battery and EV, that is around 40-45K USD, so the payback extends over 10-15 years, so if you are sure you are going to be in your home for the next 10-15 years, fine. Otherwise, who knows that. Fundamental things must change, and unfortunately, people are only motivated by money, and the business case is not there as they payback time is too much. That may change as carbon tax becomes higher (we rely on natural gas; it costs one third of the price of electricity). So, as residential consumers, we are not motivated nor have any incentive.

Is the project financed by prosumers, or by any other entity (private or public)?

As a research project, it was funded provincially and federal.

How is the power grid in Canada? Is it well interconnected?

We do have some ties. For example, in Ontario (eastern side) we have two ties: on the left, to New York; on the right, to Minnesota. So, we do not call it "trading" as it is not as organized as in Europe, but there exists imports and exports between Canada and America. And some of the American power grids are tied to each other but they are not dealing with a big number of renewables. In one sense, it is good because there is not a lot of trading across those ties, you can really optimize on real time if you have a fix renewable energy. But we do not have this, only in California. There they are having problems when they have these peaks and falls. But on the other side, the more disconnected grids are, the higher the chance to experiment. You can contain your problems in a smaller area, locally. If you are also dealing with interconnected networks and swings across voltages, some other country's problems can be your problems as well. In Canada we will have the European scenario (Germany) in the next five-ten years.

In Hawaii there is also a high penetration of rooftop solar PV. Do you think that blockchain technology has potential to be implemented there in the whole island since there are a lot of prosumers?

I think before blockchain technology is implemented; they will do a lot more behind the meter straight to utilities. If portion of Hawaii, their communities, are so influenced by solar PV that they want to go away from the grid and have their own infrastructure, that is where blockchain will become a lot more important. Or if there is a way, for example, if the DSO invest themselves in the infrastructure as decentralized and they do not want to depend on a single term of software, then blockchain technology would have a chance to succeed. It really depends on the maturity of the technology, and it depends on the players (regulators, TSO, etc). Otherwise, with few players, there is no need.

An important driver for that are the high prices of gas to be exported to Hawaii, as it is the most expensive state when consuming oil and gas.

If you compare the savings between implementing blockchain technology in a decentralized context with the centralized system, the centralized option will win every time, just from a technical standpoint. If everything decentralizes and prosumers become part of the revenue sharing, then blockchain technology may emerge as a very good alternative because everybody is using the auction. But I am not sure that the regulatory is going to support that. The other thing is this spiral: people are going to depend more and more on RE, so maybe the utilities will diminish this. So, utilities may implement blockchain technology as a service just to keep a piece of all these energy transactions between people, so blockchain technology may have a business case over there because things will continue decentralized.

B.3 Interview with *Hive Power*

Interviewee: Mr. Davide Rivola, COO and co-founder of *Hive Power*.

What is the mission and vision of *Hive Power*? What have you done?

In the last two years we were more oriented to smart grid and energy analytics, closer to the market. If you want to make business with community power trading, it is still too early, blockchain technology in this micro-level is more about proof-of-concept, research, pilot projects, not a real business yet. We manage the flexibility by plugging to different data hubs from energy utility or providers to manage local and global needs for national markets.

The problem of blockchain technology, is you want to apply to energy communities, you must have a very strong physical layer. Especially in the energy, there are many partners you have to trust. A lot of regulation as well that needs to be approved by the national regulator. It is really tough to create a blockchain in communities right now. blockchain technology works best when it is virtual, with ideas and concepts with no barriers. In the energy sector there is a very huge barrier which is, on one hand technical because a lot of devices that are on place have a very limited communication capability rather than computational capability. So, even the latest generation smart meters, they are unable to connect to blockchain technology. Because they communicate to power lines, but their computational capability is not powerful enough. On the other hand, what these devices do, it is already normalised or standardised, there is a huge inertia on that.

That is why we are now working on a pilot project in Lugano (Italian area of Switzerland), where we have a small village where we have created an energy community. There are 18 households, some of them with PV modules. Basically, we have a device which is installed in each household that communicates with the meter. Because the meter is not ready to be connected to the “project”. We communicate to a standard optical port which is available to the meter to get the data, and then we can also use the meter as an actuator, so the blockchain adaptor can feedback some commands to supply the loads (typically heat pumps or boilers). This is a proof-of-concept, so we can do that right now with blockchain technology, but in order to be economically available, all of this should be inside the meter itself. But eventually, blockchain technology will go in many places, especially in IoT domain. This project is called *LIC*, a national pilot project by the federal office of energy. We try through blockchain technology to self-organise the system. We use Cosmos blockchain, alternative to Ethereum. It does not use Proof-of-Work (PoW), you have a main blockchain which is Proof-of-Stake (PoS) (energy efficient) and you can create side-chains. You test this chain and if it is tested well, you can add to the main chain. The advantage is not to use too much energy. For micro transactions, PoW is not efficient. For this side chain, you use Proof-of-Authority (PoAu) because it is trusted. Not private either, but hybrid. And we do not need tokens, because as proof-of-concept, in Cosmos you can basically write Euro code and run it in a distributed manner, so you do not need tokens internally. Maybe for the payment we could use it, but it is still a bit early (regulatory barriers).

The blockchain technology is focused for centralised institutions in your website. What is the level of decentralisation you want to achieve?

Basically, what we want to test out in this project is mostly that the nodes of each house can self-organise and manage their energy. Some P2P project are mostly on the credit part (classical trading); we want an optimal operation of the flexibility and to optimise the consumption. So, we try to reach a consensus between them. Of course, the meters are owned by the community manager, so it is centralised because of physical work. But this is not the goal of this project. The goal is to try if they can reach a self-coordination compared to this algorithm control.

So not only profit-oriented, but also aiming to increase social welfare?

Indirectly, social welfare is expected to be higher as well because you will increase the self-consumption for local energy fromRES, so you have a better usage ofRES, beneficial for everybody. But the peers are also benefited because the local energy is cheaper, so by doing that you will be able to sell your energy for a better price to a neighbour and buy local energy for a cheaper price than the grid. Usually, when you pay to another neighbour, you just pay the energy generation portion, but when you buy from the grid, depending on the country, the energy part is only a third of the total price. The other two thirds are about transportation, taxes, fees, etc. So, when you inject, it's for 5-6 cEUR, when you buy it is for 18 cEUR, so you can find a price in between set by the seller and the buyer. Moreover, there are other aspects as it is still a pilot project, because in this project we have a neighbourhood battery to optimise the whole neighbourhood but will never be profitable as the battery is too expensive. No way you can payback the price of a battery. And other blockchain adapters also cost a lot.

So, by assuming that any type of project like that includes a shared battery device, there will not be a business case due to the high investment, right?

Exactly, to be profitable for batteries, you should provide more industrial services or have agreements with the DSOs to provide flexibility when the grid is congested (demand-side management, indeed). There is the *Parity Vision* project: we are going much deeper into the regulatory questions regarding how you should structure a P2P local energy market that is viable and fits with the actual existing stakeholders (DSOs, suppliers, etc). In this project, it is still too early, but it has been developed a local energy market. There exists a regular market, and then the DSO, by changing the price of the grid, indirectly steer the local energy market. This is only possible if you run the physical grid, but DSO cannot participate and set the price of the grid, they cannot affect the local operation of the market. The barriers are not technological but related to regulatory framework.

And within the local energy market, how is the local energy price set?

As a consensus community project, in Switzerland you can already create self-consumption communities that work like private networks. The main point, even they connect to the grid with a normal meter, is that inside the community there are some basic rules, but still it is quite free. It is mostly a regulatory innovation approach; you can take the Euro price. Our system has a fixed grid price as external grid price, but internally, depending on the energy which is being injected or it is consuming the community, we can split it proportionally to all peers who live there, and that creates a dynamic pricing. And this dynamic pricing is known, so the simulation can optimise the system. We design the algorithm in a way that is beneficial for everybody.

And focusing on the regulatory framework, we guess smart contracts play a very important role in the grid and in the whole system?

From a hybrid approach, we have a normal classical contract with basic rules, and then we have a smart contract which is operating in a small scale. Right now, it is very difficult that we accept a smart contract as a legally enforceable contract. We want to set up now a Paypal contract, which has the basic rules, and then implement more rules in a smart contract. This way, nobody could say your smart contract is wrong, because they could refer to the legal "main" one. This will take a bit of time because in order to have a fully legal compliant contract, you should have full digitalisation. That is why it takes time, because right now sometimes when people ask why you need blockchain technology, it is hard to answer because it is still early. Everything should be digitalised to have full potential, still a long journey. Another point which is tricky is the General Data Protection Regulation (GDPR), its content is made for the situation in 90s. The problem with blockchain technology is that in GDPR you should be able to delete your personal information. There are many big discussions about how compliant a blockchain could be to fit in GDPR. In another project we stored the data in a centralised data base, and we anonymised the data that we had to send to the blockchain. So, if you want to delete a person, you delete the relationship with his/her pseudo-anonymised data and the real data, so you cannot go back to the actual "findable" information. That would be more compliant, but eventually the GDPR should legally cover any stored data from any technology. Now it is only possible with a database (centralised) and someone who runs this database. If the project is not connected to the physical world (financial sector) it is easier to implement. Difference between "money" and "kWh of electricity", so it is easier to digitalise some abstract asset, that does not really exist.

In your already implemented projects which has smart contracts, which kind

of issues did you have to overcome?

When we did our first proof of concept, it was Ethereum-based smart contract, that was very limited (limited memory and resources), we had to limit the number of lines (in other terms, what we wanted to put into the blockchain). With Cosmos we are a bit more flexible, but at the same time if you go too deep to put everything into the smart contract, then it gets difficult to run the nodes and simulate the operation of the blockchain. So, what we did is more computing consuming activities we do outside, with an adaptor it is similar than a Raspberry but for industrial application, a bit more stable, and there is a lot of space to run a forecasting system, to calculate the consumption, local optimisation algorithm and so on. That is completely off-chain. Then, the result of the decision of the local node is inside the blockchain, because if everything would be on-chain, it would be too time-consuming (to manage the claims, decisions).

Specially in the power sector, there must be a real-time operation?

Yes, the challenge we are still tackling is about the connectivity. We have to devise our way that if a node is not connected for few hours, it can reconnect and send the information. We have a lot of back-up solutions. In the energy sector, if you connect your devices with the power line, then it is very limited. Even if you have a very powerful 4G sim card, the connection is good but it takes a lot of data, and this costs money. There are some industrial cards that cost almost nothing and you get 1 GB for 1 year (in terms of bandwidth). So, if you consume a lot, even if you do not have to pay for the transaction fee in the blockchain, you have the physical world. A blockchain consumes more bandwidth than a centralised solution.

The most promising project of blockchain technology right now wants to tackle national markets (TSO level), it is the *Equigy* project. It is not P2P; they are tackling the balancing of the national system on blockchain technology. It is a bit easier to tackle with blockchain technology. Blockchain technology in the energy sector is going to be implemented first in macro-scale, and eventually will go down to micro-scale.

Why do you think that blockchain technology will fit so well in the coming energy sector or current energy transition?

In a long-term vision, when we go in a micro-scale level (with kWh), you need fully automation in order to save a lot of costs on operation. And blockchain technology, in a mid and long-term perspective, its marginal cost will be very low too. Everything will be automatic, there will be no intermediaries, and the digital devices will be more standardised (in order to be useful once they are purchased and operative), and they will become smarter (fully autonomous) but within certain rules. That is something to tackle regarding the safety/security aspects: you can standardise these big devices but in a small-scale it is difficult; you need something to orchestrate this kind of automation. Machine-learning, AI, higher connectivity to Internet, then you need something to manage a little bit all the operation. The devices are getting more intelligent because their computational capabilities are increasing faster than storage and communication.

B.4 Interview with *Prosume Energy*

Interviewee: Mr. Alex D'Elia, President of *Prosume Energy*.

What is the mission and vision of *Prosume Energy*? What have you done?

Before in *Prosume Energy*, they initially wanted to have a token (Initial Coin Offering (ICO)), but finally they did not. Why? Because people were mixing the energy market with the financial market. If I offer you a coin which has a value of energy, we know that the energy price will go down in time. The energy, if it comes fromRES, the fuel cost is zero. The more the time goes, the more the cost of this energy lowers because the implementation costs of technology are getting lower. Currently, you can install by yourself a PV installation for now more than 1,000 EUR/kW more or less. In 2008, it costed 16,000 EUR/kW. If we think about this evolution, they were offering a coin for a value of energy that they will later trade. Because if you buy the coin, you think that you will exchange this coin for energy from their platform. But people that trade coins, they want to have a higher value, like in Bitcoin, trying to speculate. But if the price of energy is going down, and I buy a coin now, the coin will go down with value. So, it has no sense if the purpose is to make profits from these coins. Exchanges are market exchanges, the prices are fluctuating constantly, but the energy is an asset which its price will go down, not like gold which is scarce resource. But definitely not with the price of energy (at least fromRES). They did not want to provide a coin to *Prosume Energy* platform users, like: get this coin, you will later be able to trade it in your platform, it will have more value after. No, that's bullshit. Platforms like this do not consider the social aspects (ethics). Instead, *Prosume Energy* focused more on aspects like interoperability of technology, where blockchain is useful. It is a decentralised technology that really couples with a decentralised infrastructure.

What about the security of data of an energy community which uses blockchain technology?

Blockchain is a decentralised technology that really couples with a decentralised infrastructure. That's where we can find a value because if you think about energy, the organisation is a pyramid (power is centralised). But with the revolution ofRES, the organisation is becoming more decentralised. So, you can couple the decentralisation fact of this technology with the infrastructure, but you do not have to fall into the loop of many of them where this is just solving everything. Because if I want to maintain privacy and control of my energy community, I do not want that people out of my community knows what we are doing between us. But when you put the data on the blockchain, everybody can read it if is based on a public-blockchain like Ethereum (as *SunContract*), then I can trace what they have in their wallets (*Etherscan*). So, there is a privacy/security issue here. So, on a social aspect, we have to pay attention on where and how to use a blockchain, and for what. In communities, there may be some data on-chain, and some data off-chain. But it is also important the consensus model. You could use a distributed ledger in a community to prove that no one is cheating but still has another consensus method which is decoupled from the distributed ledger. A blockchain where the consensus method is tight to the smart contract into the blockchain, that is not good. Because I rely on the consensus that people are deciding. For instance, in a Proof-of-Stake (PoS), you must have a stake of the community. But what if I am someone who just joined the community and does not want to stay much longer, but participate while I am there. Depending on the subjective criteria of the main stakeholder of this PoS blockchain, maybe I am rejected for external reasons. I would need a stake to decide what is going on. So, in the energy sector, these things must be separated if you want to maintain freedom for the people. That is why new consensus models like Zero-Knowledge Proof (ZKP) are interesting, because you can prove you are you, that you want to trade energy, but no need to have a stake or show further personal information. I can provide a proof of my identity without making full disclosure of my information. In many energy blockchain-based projects, once you are there, you know almost everything of each participant.

What are the best consensus models for blockchain-based P2P power trading platforms?

The PoS, the ZKP, the Practical Byzantine Fault Tolerance (PBFT), or the Proof-of-Authority (PoAu). In PoAu, you need to demand your authority. For example, *Prosume Energy* used in their first delegation, PoS. As *Prosume Energy* did not want to be a public blockchain, they did not want to follow Ethereum blockchain nor use Proof-of-Work (PoW). Then, Hyper Ledger blockchain became better as there were many tools to implement, so they used Hyper Ledger Fabric and then Hyper Ledger Sawtooth. Here they could decouple all the consensus methods because they are more flexible. Still focused on full PoS, full PoAu, because I am the provider, you are a citizen, you sign a contract, I sell to you the energy, I have the authority, so the big organisation can decide about the community. If I have to think about who maintains the privacy for the user, flexibility, maybe being dependent on a central authority goes against the idea of decentralisation. So, it is interesting how things are changing, interesting that your thesis provides different analysis, different studies, different perspectives. There is a huge discussion about the limits of this. Providing a thesis where you take a different perspective of people who are fond of Bitcoin to speculate, Ethereum to solve everything by using blockchain, engineers who are stuck in the energy sector but still think that blockchain technology will solve everything, sceptic who are against blockchain technology but they say it uses a lot of energy as if only PoW existed, and others like Alex (me) who are agnostic: users do not want to know/care so much about the tool it is used, you just want things work in a practical way to trade energy. Technology solve things, but depends on the adoption, context, how mature things are, as well as on political issues. Blockchain is a double-edged sword, it can be really useful but must be utilised properly/correctly.

Are you optimist about implemented and regulated P2P power trading in a short-term? How could blockchain technology foster that?

The market is the one deciding how you exchange energy. Also, because if you do not own all the area and only now with the laws are adapting to the RE directive, only now you can really have a community. Before, if you are the utility and you sell me the energy, and I say hey, I produce energy, I want to sell it to you, for anyone to buy my energy, it must be cheaper than the one from the utility. For me, to sell it to you, I will always try to be as near to the price to the utility as possible. If the utility is selling energy at 10 cEUR/kWh, I might sell it at 9.9 cEUR/kWh. So, in that case, when you have providers and utility, it is more *P2Market* because there is no real P2P market. The selling price for peers is defined by the price of the utility. That's why, currently, besides islands, you do not have a real P2P because the laws are not ready, you do not have storage enough.

In fact, it is easier to implement blockchain in the energy sector in a macro-scale (wholesale market, big industries, TSO), rather than in a micro-scale (communities), mainly due to these specific barriers.

Do you think it is necessary to integrate smart contracts in P2P power trading communities?

Blockchain technology, as a decentralised ledger, allows the fact of deciding the consensus method regarding the governance. But if you really want to trade, to use it for something valuable, you have to be every time in a sort of contract. In the energy sector, you usually sign the contract once in a year, or every three years. You do not sign it every day. But if you want to get into a market with different stakeholders, then yes, you need a sort of smart contract. But the approach is that the smart contract does not need to be bound to the receipt. The receipt is like a demonstration/certificate that the date has been exchanged, but the smart contract is happening in a different layer, but it is smart when it is automated, machines are deploying the contract by themselves. We are working on smart contract decoupled from the blockchain because people must be able to manage the smart contract without having problems. They need to understand what they sign, because currently you need to be a programmer to understand a smart contract or what the machine is doing.