MSc Program
Renewable Energy in Central and Eastern Europe

Blockchain: Enabling P2P electricity trading in a microgrid

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Vienna, 08.10.2018

Affidavit

I, **I.B. ELIZABETH RODRIGUEZ BRINGAS**, hereby declare

1. that I am the sole author of the present Master's Thesis, "BLOCKCHAIN: ENABLING P2P ELECTRICITY TRADING IN A MICROGRID", 73 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 08.10.2018

Signature

"Learning and innovation go hand in hand. The arrogance of success is to think that what you did yesterday will be sufficient for tomorrow"

– William Pollard

DEDICATION AND ACKNOWLEDGEMENTS

I would like to dedicate this Master's Thesis firstly, to my parents, who have given me all the opportunities that led me to where I am today, unconditional support and the education that allowed me to develop a mindset to follow whatever road I choose to take and to learn things I never imagined I would.

This Master's Thesis was written successfully thanks to the support and guidance of many different interviewed experts and advisors in the fields of Renewable energy and blockchain technology applied to the energy sector. The willingness, expertise and openness they offered during the research and writing period, allowed me to have a better understanding of a very complex topic and be able to express it in a simple way. In other words "thank you all, you were of vital importance". Additionally, thank you to the institutions that allowed me to fulfill this Master's program and to get to this point.

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Abstract

Technology grows exponentially, and it does so fast that we can barely keep up with it. However, these exponential advances are developed and applied in such a way that it becomes part of our lives. The application of some of the biggest technological breakthroughs are enrooted in our lifestyle in a way some people think it is addictive. However, technology can also liberate us in many ways, because it challenges the status quo. It questions the current systems and offers alternatives as well. Today AI, IoT, Blockchain and Smart Grids are some of the buzzwords we hear in the energy sector, but more than buzzwords, they're possibilities.

However, as technology thrives, the energy demand grows with it in order to power our "lifestyle". Today, the world energy consumption is 13,511.2 Mtoe. *(BP, 2018:8)* Unfortunately, the concern for Global Warming and other environmental and social impacts are not growing equally fast, due to current legislation, political interests or elevated prices. There is however, a growing trend for Renewable energy sources which has been adopted and implemented in the past few years in a more serious and planned manner for which some countries are putting great effort in becoming completely REN powered, thanks to different efforts by International Agencies, regulators and commissions. Furthermore, technology leaps into the future every second with new breakthroughs, and promising systems in order to make processes and technologies accessible to everyone. As Prosumers make their way into the electricity-trading sector, the current energy systems need to adapt to them, in order to successfully be able to balance electricity and allow trade. One of such promising technologies, unfortunately quite often used as a buzzword, is Blockchain, which under the right legislation could make the electricity distribution process to allow Prosumers in a Microgrid sell and purchase electricity in an easier and accessible way, without the need of a Utility company, thus making the process more transparent and less costly.

The purpose of this Master's thesis is to clearly identify an overview of what are some of the most promising applications of blockchain today for the electricity distribution sector, and then focus on the one application that is already a reality in development in order to allow decentralization and enable its free trade: A Blockchain Peer-to-Peer electricity distribution system in a Microgrid.

My **motivation** to write about this topic comes from the personal need to understand the potential of this innovative application, and how it can improve electricity distribution. Nowadays, the electricity distribution is expensive but it's also complicated. It involves too many actors, some of which are truly necessary. My eagerness for a deeper understanding of this topic and the limited information currently available today, drives me to do this research.

The core question to focus on during this project is ***"How can Blockchain be efficiently applied in a Peer-to-peer electricity distribution system within a Microgrid?"*** In order to answer this question, I will guide you through an overview of the Blockchain Technology, the current electricity distribution system and how the roles of each player in such system might develop towards the Blockchain P2P electricity distribution system. This work also includes a research on how the Blockchain P2P system can be chosen (which type) and how it can be applied in order to reduce the current electricity consumption required by the Blockchain system in PoW consensus model for Public Blockchains.

The intended method of approach includes interviews with experts and Blockchain developers in the electricity sector (Utilities and Startups), whitepapers, articles, journals, reports and books from big players in the Blockchain development sector. However, true experts and developers in the Blockchain systems do not write Articles or books, but write in Blogs, therefore in order for the information to be accurate and reliable and based on experts' insights, these will also be included.

The presentation of results and conclusions have been developed based on the research undertaken, by summarizing what has been considered to be more efficient and some final thoughts and conclusions on the overall blockchain technology applied to P2P electricity trading systems.

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1 INTRODUCTION

Since 2008, with the release of the paper "Bitcoin: A peer to peer electronic cash system" by Satoshi Nakamoto, whose identity still remains a mystery, blockchain was identified as a game-changer in the financial sector. Since then, statements about the technology behind Bitcoin and its possible applications in countless other sectors have emerged, starting with the financial sector and going all the way into the medical sector.

The applications of blockchain in the energy sector have only recently started with some testing and a few successful pilots, some of which have already tested their product and market and are starting to work on bringing their product to the commercialization phase. Additionally, big and small utility companies have started consortium projects and joined efforts to research the possible applications between utilities for wholesale trading, and enabling peer-to-peer electricity systems in order to take advantage of this area, redesigning business models and making sense of the system in order to grow work it, rather than be disrupted by it.

1.1 Motivation

The energy system today is very complex and almost entirely centralized. There are too many participants, mostly in wholesale or utility scale trading, which in the past, made it nearly impossible for small scale producers to compete, and in order to do so, you had to formally found a company and go through all of the requirements to be able to trade, and of course you had to install bigger systems in order to feasibly do this. ***The reasons*** that motivate me to write my Master's Thesis on this topic are 2: The first one is my own curiosity to understand how blockchain could be applied in the energy sector and the impact it can have in the overall system. When one of my lecturers (and advisors) from the MSc in Renewable Energy Program, Mag. Dr. Gerhard Burian, first suggested the topic, my immediate first response was: "What is blockchain? Isn't that like, Bitcoin?" My limited knowledge on the topic pushed me to want to understand what this technology was and what it could offer for the energy sector; the second reason that motivated me to research on this topic was to know if this technology applied in the small scale P2P electricity distribution (e.g. microgrids) could bring benefits for prosumers and enable an easier trading scheme for them and what impacts would it have in the overall system (the grid) and how would it be able to cope and balance the surplus electricity fed into the grid with the rise of the prosumers.

1.2 Research Problem

Today, there are 3 main problems that this research aims to solve, which support the development of this thesis.

The first of them is how blockchain can handle the ***increasing role of the Prosumer*** and allowing through the different Blockchain-based startup innovations, enable their participation in the energy markets. This is unprecedented in this area, since as of today, all consumer depend on the electricity market that Big Utilities participate in, making it extremely difficult to impossible for a consumer to trade electricity with its peers or be able to afford participating in such massive market. Allowing a Prosumer to set a price for selling or buying electricity is a new concept that Blockchain- P2P-ETS has also enabled.

The second problem this paper aims to address is how blockchain aims to integrate ***the Prosumer into the grid*** and allow the balancing of the surplus electricity it creates. The excess electricity sent into the grid without a specific plan leads to an "unbalance" on the grid. The role of renewables in general has made it hard for Balancing companies to control the electricity coming specially from PV and Wind, which depend on weather conditions and which forecast may change. Nevertheless, PV Power plants are easier to forecast in the grid than rooftop installations, since the Power Plant will normally be producing electricity during a specific time of the day and send a detailed forecast to the DSO.

In 2016, the European Commission estimates that 17GW of PV rooftop modules were installed in households in the EU28. Prosumers however, usually have rooftop PV Systems, that may or may not have the appropriate conditions (E.g.

the cleaning and maintenance it receives may or may not be as strict as in a power plant, shading of a single cell by trees or inappropriate planning, may also cause the entire line of that cell to fail, thus reducing the efficiency and generation of the module).

Another problem to be discussed is how blockchain solves the ***dependency on Utility companies*** for supply. Locally sourced clean energy trading from neighbors, as well as the certificate of electricity provenance that blockchain allows, is an important topic to be addressed as well. Today most Utility companies are still relying on fossil fuel electricity to some extent. Therefore, as a consumer it is not possible to transparently know where the electricity comes from. Blockchain also tackles this problem.

Furthermore, this paper discusses the benefits and impacts that Blockchain-based P2P electricity trading systems have in local trade and clean energy production, as well as energy-loss reduction.

The final problem this paper aims is to provide an ***efficient blockchain P2P electricity trading system***, by the retrieval of information acquired, a proposed Blockchain P2P-ETS will be provided, including the software and IoT applications that could be considered, to make the system more efficient.

1.3 Major References

Some of the major references used to develop the qualitative research for this Master's Thesis come from literature major references on the topic such as Satoshi Nakamoto and Haber/Stornetta's original whitepapers, but even more recent ones as research papers published by the European Commission in partnership with other institutions; whitepapers from the pioneers in blockchain applied to the energy sector, such as the Energy Web Foundation and LO3 technical and business whitepapers; conversations with experts in the energy and blockchain sector, such as the interview held with Erwin Smole and research papers and articles published by experts in blockchain online (e.g. Vitalik Buterin). Additionally, different websites specializing in blockchain technology were also used to better understand some concepts and to describe processes through some of their figures. However, a further description of how each section was achieved is detailed in the Methodical Approach (Chapter 2).

1.4 Structure of the work

This Masters Thesis serves as an overview of how the blockchain technology works and how it can be applied in the electricity sector, specifically focusing in the Peer-to-peer electricity trading application for microgrids and recommendations to further optimize the efficiency of each specific node to improve the overall efficiency of the system. It also analyses some of the benefits for all players involved in the electricity trading system and what will be their potential roles in the future, but more importantly, how can they all work together in order to improve the current system and walk together towards the energy systems of the future.

The structure of the work is divided in Chapters. Chapter 1 includes the Introduction, motivation that led me to choose this topic, the research problem that serves as a guide of the challenges this paper aims to describe, the major reference from which helped understanding this complex topic and the structure of the work.

Chapter 2 describes the methodical approach used to research the topic in this Master's Thesis. Using a qualitative type of research based on research papers and experts from very different types of sources that ranged from interviews with experts, journals, research papers and even blogs, as most blockchain experts use this media to publish their articles, rather than writing a book or academic paper.

Chapter 3 describes the History of blockchain, how it works and specific information on the data structure of the blocks, how they come together and the security they provide. It also describes some of the most interesting applications in the energy sector and some use cases and stakeholders currently testing or implementing the technology.

Chapter 4 discusses the current energy system and how each player will participate in the new energy system that blockchain systems will enable. It describes the existing models that prosumers currently use, in which they may or may not be rewarded for their electricity. Furthermore, a suggestion for an efficient

P2P electricity system based on the findings from the research, is described including some ways in which each node can independently become more efficient, thus optimizing the entire system.

The benefits and limitations of this system are also described in this chapter, along with an economical, ecological and social appraisal.

Chapter 5 presents the results found throughout the research in a summarized way, including the best or suggested options to make the entire system more reliable and efficient.

Chapter 6 contains a personal conclusion on why I think blockchain systems applied to the energy sector should be further researched and developed, in order to efficiently apply it when and where it makes sense.

Chpater 8 provides the references and bibliography, which has been separated into the types of sources and interviews with experts. Finally, chapter 9 contains the appendices considered in this research.

2 METHODICAL APPROACH

The methodical approach for the development of this Masters Thesis, is through literature study and information retrieval from different sources that range from books, research papers, white papers, market studies, reports, journals, websites and conversations with experts.

For the Blockchain technology specifics section of the Master's Thesis, a Qualitative Research Methodical approach was used. Through literature studies, research studies and information retrieval from experts on the subject, both from articles, reports, but in this specific section also from Blogs and websites written by experts (e.g. coding and IT experts). The justification of the use of these methods lies in the nature of IT and Blockchain experts, since they usually do not write books or create Research study or academic papers. The second justification of the use of Blogs and websites in this specific research section is that books and publications in the nature of this topic are usually outdated, as it is a topic that is thriving rapidly.

The Blockchain P2P Electricity trading system and IoT sections have been undertaken using a qualitative approach. The use of EU Reports and Journals, but also Business and Technical whitepapers from different companies already applying such technology have been used. An extensive research was done in order to determine what are the types of blockchain and additional software and devices that a system should have in order to create an efficient Blockchain P2P-ETS. Information and statistics have also been retrieved from current blockchain technology trackers, which information is displayed in papers or websites.

The Legal Framework section was built upon a qualitative approach based on literature and considering discussions held in the SESWA workshops in May 2018, as well as conversations with Erwin Smole, co-founder of Grid Singularity and Strategic Advisor for the Energy Web Foundation. Additionally, an extensive research on the most common legal challenges in most of the projects that are being developed helped me consider these aspects.

The Economical, Social and Ecological section was achieved by retrieving information from existing quantitative studies and integrating them with the qualitative research. Different studies were found on the electricity consumption use and social benefits of blockchain applications.

3 THE HISTORY OF BLOCKCHAIN

3.1 Historical and Conceptual description of blockchain: What is it?

The very first mention of information blocks using cryptography as a security method, was in 1991 by Stuart Haber and W. Scott Stornetta in their paper "How to time-stamp a digital document". This paper proposed a way to time-stamp or certify the date of issue of digital documents, in order to prevent being tampered with. *(Haber, Stornetta. 1991)*

In 2008, a person or group of people still unidentified under the name "Satoshi Nakamoto", released a whitepaper with the title "Bitcoin: A peer-to-peer electronic cash system". The purpose of this white paper was to propose a solution to high costs involving centralized institutions in the financial sector, by introducing Bitcoin a crypto currency. *(Nakamoto, 2008)*

A year later, in 2009, Bitcoin was launched, proving that the system works. The system behind Bitcoin is Blockchain, and thus, the revolution begun. From that moment on, people have been studying the use cases for Blockchain, which ranges from the Financial sector, e.g. cryptocurrencies such as Bitcoin and Ethereum; the medical sector, e.g. the idea to create historical and accurate files on each patient and that are available in all hospitals around the world; to the energy sector, e.g. using an energy currency for energy trade, peer-to-peer distribution, mobility applications and smart contracts among others.

3.2 Technical description of Blockchain: How does it work?

What is Blockchain?

Blockchain is a system of interconnected nodes that share a digital ledger, in which every single entry of data (Blocks) is stored and shared simultaneously in the network in order to prevent alteration of any kind, thus improving the trust in the system and the reliability of the data. In order to achieve such trust, each transaction is stored permanently in the network, which means only authorized transactions are added. The main objective behind this technology is to create a distributed network, where there is no central, thus reducing costs, time and enabling peer-to-peer transactions. *Figure 0* explains the process that every new block of information has to go through to be added in the blockchain.

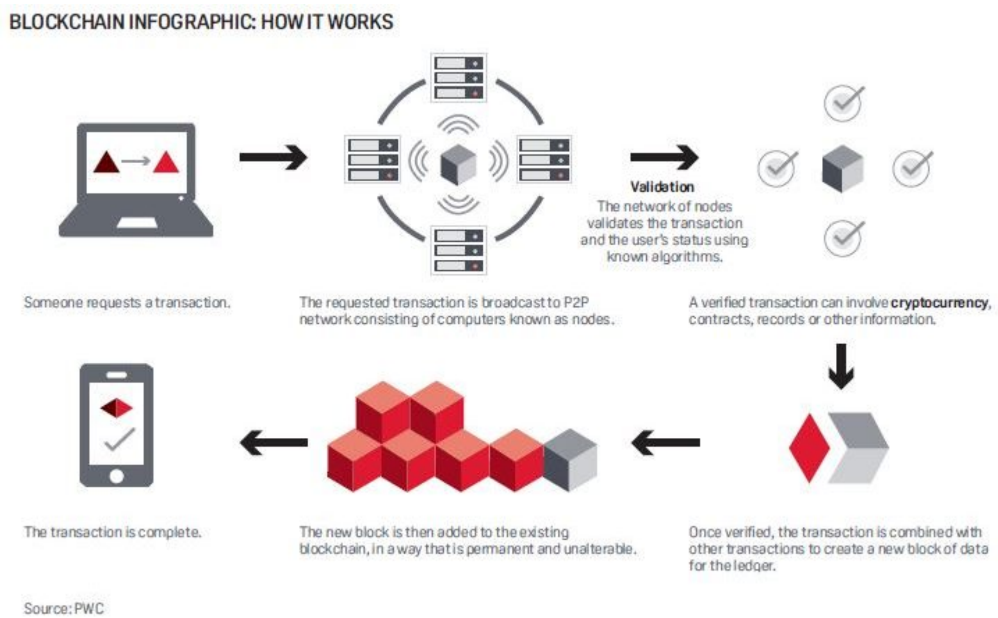
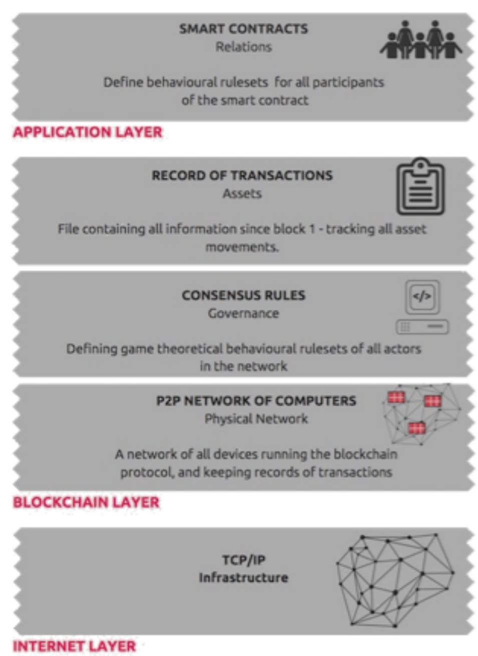


Figure 1. How Blockchain works *(Source: PwC)*

Architecture of the Blockchain

Figure 2 (right). Layers of the Blockchain Technology. (Source: www.blockchainhub.com Blockchain Technology Stack Of Ethereum and similar Blockchains, Inspired by Florian Glatz)



The architecture of the blockchain technology (shown in *Figure 2* and read from the bottom-up) involves several layers of operation.

The Internet layer, which is the core system and infrastructure, is the layer responsible of transporting the bits of information together.

The ***blockchain layer***, which includes other layers like the ***Network layer*** (e.g. nodes that participate in the P2P system); ***the consensus layer***, in which the consensus protocol is defined whether is PoW, PoS, or any other and the ***record of transactions***, which contain the entire data from Block 1. The top layer is the ***application layer***, which is separated from the blockchain layer in order to facilitate dApps, Smart contracts and other applications to be implemented into the system. *(Xiao, 2016)*

Data structure of the blocks

As shown in *figure 3*, the blockchain is a group of blocks that have been previously validated one after the other by the participants and added into the system creating a chain. Once a block is created it is immutable and permanent. But, what is the data contained in the block? Each block contains a block header, a block body, transaction information which includes the block ID, transaction amount, time, sender and recipient information, a merkle root and a timestamp. Each block header contains the hash value of the previous block to ensure the integrity of the blockchain. *(Wu et. al., 2018:3)*

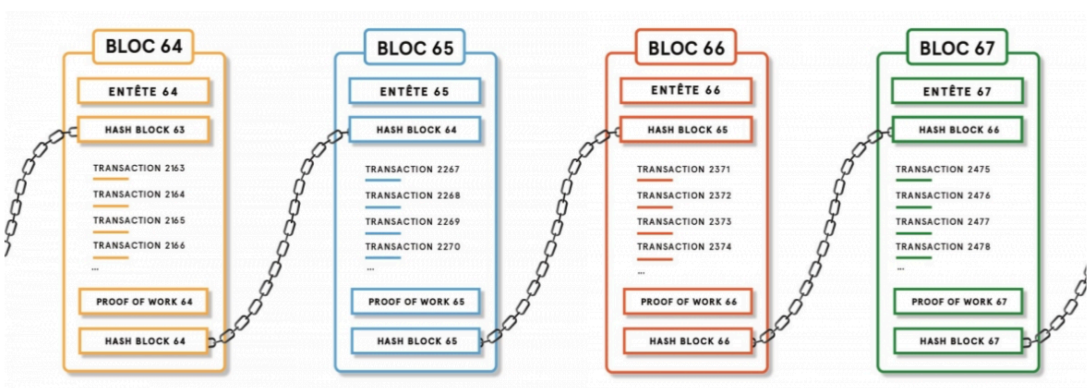


Figure 3. Inner structure of the Blockchain. *(Source: blog.theodo.fr)*

Cryptographic Hash

A hash is a type of algorithm that has the ability to turn any input, regardless of the length, into a fixed length output, also called "Hash sum". It works in the following way. *Figure 4,* shows an example using one of the most common and secure algorithms today SHA-256 (Secure Hash Algorithm with 256 bits length). In this example, we can see that regardless of the length of the input (Short with Hi, or long with Welcome) the result is a fixed string of characters. Therefore, there is a fixed outcome for Hi and for Welcome. *(Blockgeeks.com, 2018)*

INPUT	HASH
Hi	639EFCD08ABB273B1619E82E78C29A7DF02C1051B1820E99FC395DCAA3326B8
Welcome	53A53FC9E2A03F9B6E66D84BA701574CD9CF5F01FB498C41731881BCDC68A7C8

Figure 4. Example of Hashing *(Source: blockgeeks.com)*

However, even the slightest change in the input, will completely modify the outcome in the string. The following example in *Figure 5* shows how the output changes when the first letter changes to a lower case, despite the message being the same.

INPUT	HASH
This is a test	C7BE1ED902FB8DD4D48997C6452F5D7E509FBCDBE2808B16BCF4EDCE4C07D14E
this is a test	2E99758548972A8E8822AD47FA1017FF72F06F3FF6A016851F45C398732BC50C

Figure 5. Example of Hashing when the input is modified. *(Source: blockgeeks.com)*

For this reason, hashing is used in blockchain technologies. Whenever a transaction has been hashed it becomes immutable, therefore if anyone tries to modify or tamper with it (regardless of how minimal the change is), the hash will identify the change.

Merkle Trees

A Merkle tree is a cryptographic verification tool that serves as a summary of all previous transactions in a ledger to ensure its integrity. It works as a data structure (a tree) where each leaf-node is a hash of its child nodes (see *Figure 6* below). It was first patented by Ralph Merkle in 1979 and it's currently used as a vital part of the verification process in a blockchain. Since every transaction is hashed, it is possible to verify that the reliability of the data remains. Merkle trees are also useful regarding memory and computer power required to verify transactions, since they are a verified summary, only small bits of information need to be sent across the network instead of the entire ledger or database to then check transaction by transaction, thus saving time and computing power.

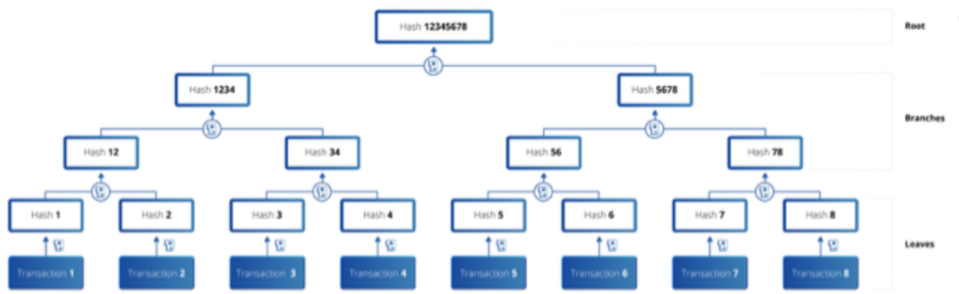


Figure 6. Example of a Merkle Tree and how it works. *(Source: lisk.io/academy)*

4.2.2. Types of Systems or Networks

Oxford dictionaries define a system as a group of related hardware units, programs or both, especially dedicated to a single application.

There are 2 main types of systems or networks; Centralized and distributed systems, as shown in *Figure 7*.

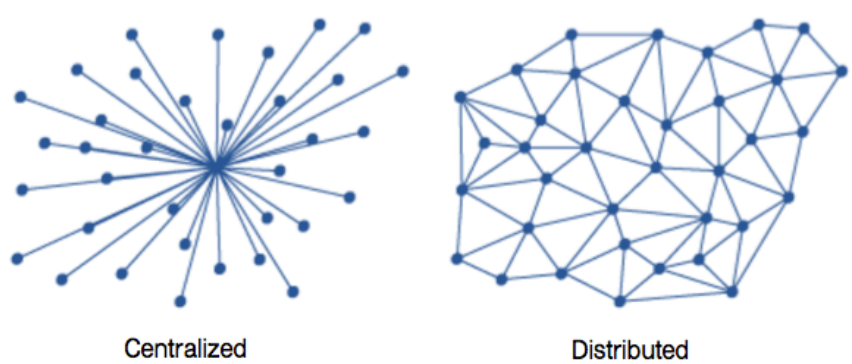


Figure 7. Types of Systems or Networks. *(Source: Medium.com)*

Centralized networks require a central computer or database system where all the transactions are stored. Whenever there is a new transaction from any of the participants, it has to go through the central and be validated by it. The intermediary or central is used to create trust in a network where the participants do not know each other. An example of a centralized system would be a Bank, and an example of how it works is when "Mark" wants to send money to "Alice", in this case, Mark sends the money to Alice through the Online Platform of his Bank, but it does not go directly to Alice, first the money goes though the Bank Central, who validates the transaction and then sends it to Alice, that is if Alice is not in another Bank, otherwise there would be 2 banks involved. This is why centralized systems tend to be more costly, since each middleman charges a fee for their services. Having a central has some benefits but also some disadvantages. An easy analogy to explain a Centralized Network would be if Alice wants to send a letter to Mark through Clara (the middleman). In this Case, Alice depends on Clara not losing the letter, not being hit by a bus in the way to Mark and trusting that she won't open the letter and read it, or someone will take it from her hands (and that is if Clara doesn't charge her money to do so). In a more realistic example, if Mark wants to send money to Alice, but the online platform is under maintenance, or it's a weekend and the banks are closed, he cannot do it, because both Mark and Alice depend on the middleman, in this case the bank. An extreme case of this would be if the Central is compromised, hacked or threatened in some way.

Distributed Networks: A distributed network or system (e.g. Blockchain) shares the information or transactions (Blocks) with all of its nodes, thus no longer requiring a central to validate it. The Blockchain technology is a distributed network structure formed by a group a of blocks or nodes, where each node receives the same information as all the others simultaneously and is secured by cryptographic puzzles, making the transactions stored in it permanent, immutable and increasing the security and trust in the system. Trust in distributed networks are achieved by consensus, since every single node has the same information, it is extremely difficult to corrupt the entire network. Using the same analogy we used before, in this system, Alice would give the letter to Mark personally, while having 10 other people in the room seeing the exact same thing, and thus being able to validate that Alice indeed gave a letter to Mark. If anyone else tried to say she didn't, it would not be possible, as there is 9 other "nodes" that can corroborate this information.

Types of Blockchains

There are 3 main types of blockchains or Distributed Ledger technologies, each of them has advantages and disadvantages in validating transactions speed depending on the consensus protocol chosen for each. The original idea behind blockchain is aimed to public blockchains, however this requires PoW, which limits the transactions per second and makes the entire process non energy-efficient. A brief description of these 3 main types of blockchains is provided below.

Public Blockchains

These type of Blockchains Networks are open and non permissioned. This means anyone can create a transaction and participate in the consensus process as well. These blockchains use cryptoeconomics such as "Proof of Work" or "Proof of Stake" in order to increase security in a network where nodes are anonymous. An example of such systems is Bitcoin and Ethereum. *(Buterin, 2015)*

Federated Blockchains

These types of Blockchains, also referred to as Consortium Blockchains, differs from the Public ones, since not anyone in the internet can access it or participate in it, but only a selected group of nodes have access to validation. The reading of the information in these systems can be either public or permissioned within the system. In other words, this is a hybrid solution between Public and Private systems. *(Buterin, 2015)* An example for this system would be a group of 15 Electricity Utility companies, each of which is operating a node. In order to reach consensus in a system like this, a preselected group of 10, would have to validate each transaction. *(Adapted example by the author, from Buterin, 2015).*

Private Blockchain

Very similar to a Consortium Blockchain, a Private Blockchain is where writing or validating permissions are kept within one organization. Reading the information in these systems can be public or restricted, but in a smaller scale (e.g. only to some people within the organization). *(Buterin, 2015)* An example of such systems would resemble the intranet of a company)

Table 1. Differences between types of Blockchains. (Source: Blockchainhub.net)

	Public No centralized management	**Consortium** Multiple Organisations	**Private** Single Organisation
Participants	**Permissionless** - Anonymous - Could be malicious	**Permissioned** - Identified - Trusted	**Permissioned** - Identified - Trusted
Consensus Mechanisms	**Proof of Work, Proof of Stake, etc..** - Large energy consumption - No finality - 51% attack	**Voting or multi-party consensus algorithm** - Lighter - Faster - Low energy consumption - Enable finality	**Voting or multi-party consensus algorithm** - Lighter - Faster - Low energy consumption - Enable finality
Transaction Approval Freq.	**Long** Bitcoin: 10 min or more	**Short** 100x msec	**Short** 100x msec
USP	**Disruptive** Disruptive in the sense of disintermediation. No middle men needed. Unclear what the business models will be	**Cost Cutting** Can radically reduce transactions costs. Similar to SAP in the 1990s. Extreme cost cutting opportunities. Less data redundancy, higher transactions times, more transparency	**Cost Cutting** Can radically reduce transactions costs. Similar to SAP in the 1990s. Extreme cost cutting opportunities. Less data redundancy, higher transactions times, more transparency

3.3 How and why should Blockchain be applied in the electricity sector?

The first question to be answered is why. Why is Blockchain being considered as a technology to be implemented in the energy sector? It is important to understand what are the drivers that have motivated energy startups to bet on it and utility companies to research it. *Figure 8* shows the main drivers for the Blockchain technology applied to the energy sector.

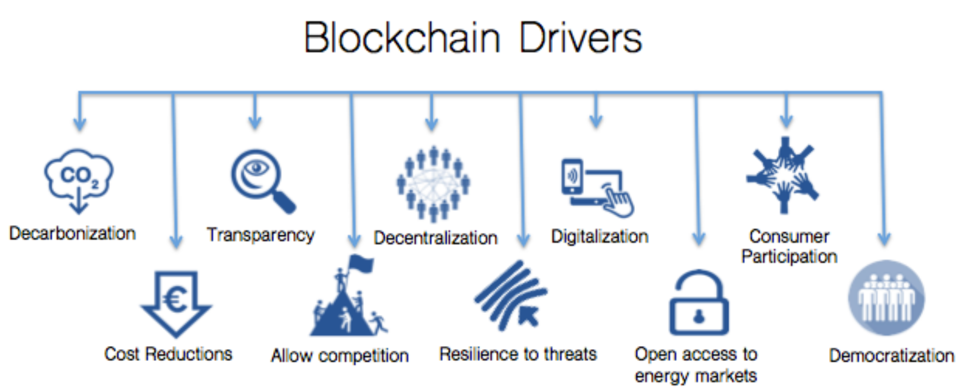


Figure 8. Drivers of the Blockchain applications in the electricity sector. (Own Figure).

Although Blockchain is a new technology still under development, a massive amount of studies are being undertaken by current players of all sizes in the electricity market, from Energy Consulting companies, to Energy Utilities, Startups and other smaller scale companies, to be able to understand the possibilities and apply the benefits of this system in different areas within their corporations or their clients and in some cases to understand how they can adapt and evolve. The applications of the Blockchain technology in the energy sector are relatively new and due to the complexity of the energy transmission and balancing processes it still requires further development for physical energy transmission to be possible.

Nevertheless, the Market and transaction applications for the electricity sector have already started being tested and have successfully launched several pilots, in order to further improve the technology and work out the challenges.

Identified Use Cases of Blockchain in the electricity sector

GTM Research has identified 18 Potential use cases for the application of Blockchain in the energy sector, of which most of the electricity applications currently being tested are focused in Transactive energy solutions (*Figure 9*). *(GTM Research, 2018)*

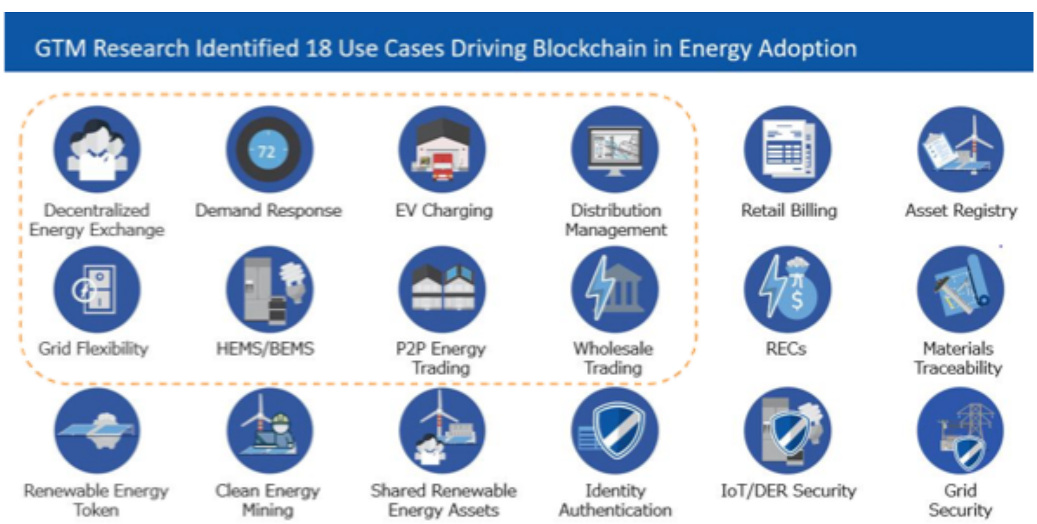


Figure 9. Identified Use cases for Blockchain in the electricity sector. *(Based on GTM Research Figure)*

Transactive energy is defined by the GridWise® Architecture Council as "*A system of economic and control mechanisms that allows the dynamic balance of supply and demand across the entire electrical infrastructure using value as a key optional parameter*" *(GridWise®, 2015:11)*. Paired with Blockchain can give endless possibilities and provide new innovative solutions to the current trends in the energy sector.

A description of some of the most common applications being developed in the electricity sector, include the following:

Wholesale energy trading between Utilities: The Enerchain software for Utility trading project, developed by Pronton, a german IT company, along with 39 other Utility companies including E.ON, Verbund and Enel is probably one of the most interesting Blockchain projects that has been tested with a Blockchain application for energy trading in a utility scale. The further development of this system and the adoption of the energy utility companies, would eventually allow wholesale trading, among them. *(Reuters, 2018)*

Smart Metering: The application of Blockchain-based Smart Metering (or smart computers that act as meters, which are further discussed in this paper) will allow DSO/TSOs have real-time accurate information of supply and demand of electricity from Prosumers for balancing the grid; this will also give more security that the Meter has not been tampered with.

Peer-to-peer (decentralized) electricity distribution: The idea that consumers can now also be producers is liberating. Therefore the ability of Blockchain to allow trading between Prosumers and consumers will reduce costs, electricity losses, demand response and interaction with the grid but above all will enable a marketplace for Prosumers through different Startups and software developments that go alongside with it.

Bill Payment: The use of Blockchain and Smart contract based systems will allow Bill Payments to be more transparent and easy to manage, with blockchain giving the transparency and smart contracts providing the automatic payment when the correct criteria is met on both sides.

Green Energy Provenance Certificates: Another interesting application of Blockchain in the energy sector is providing security of provenance for clean energy. Since Blockchain allows time-stamping, a reliable chain of data and transparency, It would be possible to track where the electricity that a consumer is buying comes from.

Energy Coin Incentive for green energy producers: Since Blockchain allows production origin tracking. Another use case in this area is to award the producer with excess energy (from clean sources as PV or Wind), with energy coins (a standard would have to be applied to determine the value between the energy coin and the amount of electricity production, e.g. 1EC = 1kW). This could be applied when there are shared energy storages, in order to trade electricity.

Blockchain EV Charging: Another Blockchain application that is currently being tested is to create an EV-Charging friendly platform, which allows both EVs and Charging Stations to trade electricity not being used. This application is also aimed to create a communication between the system and the participants, paired with the grid, in order to automatically allow transactions when prices are low (for charging).

3.4 Where does Blockchain in the electricity sector stand today?

Blockchain has slowly moved in the last few years from the learning phase to the adopting phase. The year 2009, with the official launch of Bitcoin started the Blockchain Revolution 1.0, which involved early adopters and Use case researchers to start learning and understanding Blockchain in order to be able to apply it in different business models. The past few years have allowed adoption to become a reality, today successful pilots and tests have been developed and the slow adoption of the blockchain technology, paired with the rise of new startups and innovation players are forging the way to a fully blockchain applied future.

One of the reasons why this technology remains under development is that there are still several challenges to address, which will be further described in this paper; some of these challenges involve the number of transactions allowed per minute (still low, depending on the consensus protocol chosen), the high consumption of electricity required for mining and the regulatory frameworks that still need to be developed.

In 2018, Deloitte undertook a survey to 1,053 senior level executives in North America, Europe & the U.K. and China, of which all of them had an understanding or expert knowledge of blockchain. This survey shows that 39% of the respondents' companies plan to invest $5 million dollars or more to this area in the coming year; 39% responded blockchain is overhyped; 43% of the respondent's companies have blockchain in their Top 5 strategic priorities and 74% of the respondent's companies are either already participating in a blockchain consortium or would like to do so. *(Deloitte, 2018: 18, 19, 23, 25)*

For some enterprises it is easier to build their business models around blockchain today due to their corporation structures, especially new companies and startups with less than 5 years of operation. However, companies that have been established more than 20 years ago, may have to do a deeper research in order to properly identify how will the implementation of blockchain make sense in their current business model, infrastructure or reviewing if those business models and infrastructure should evolve in the direction of these new technologies, which of course takes a longer time to adapt. It is important to understand, that blockchain should be seen as a solution to improve the transparency of processes, enable market places for P2P, data flow, etc. and that the use of blockchain without a business value that makes sense, is completely useless. Therefore, the soul of a blockchain application should be the value and the solution it provides to an existing business model. *Figure 10* provides a map of different projects being developed or in their pilot stages around the world. Projects like the Brooklyn Microgrid by LO3 (USA), PONTON (Germany), Sonnen & TenneT (Germany), PROSUMER (Switzerland), SunContract (Slovenia), Wien Energie (Austria), Verbund and Salzburg AG (Austria), Vandebron & TenneT (Holland), among other projects that are being developed; many of them led by electricity Utility companies. This map gives us an overview of the activity worldwide, clearly being Europe the Continent where most projects are being tested and developed. *(Indigo, 2018)*

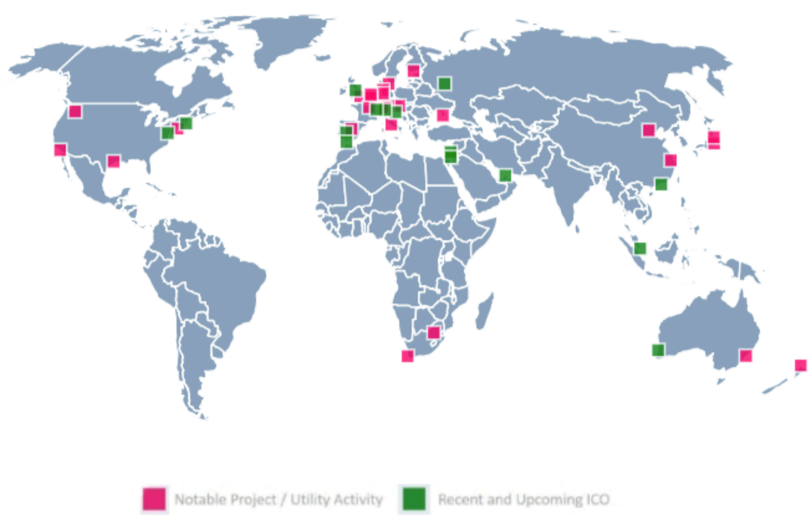


Figure 10. Global Blockchain Activities Map. *(Source: Indigo Advisory group)*

Figure 11 explains the different stages of different applications of Blockchain, that go from hype to actual deployment. This figure also shows that the

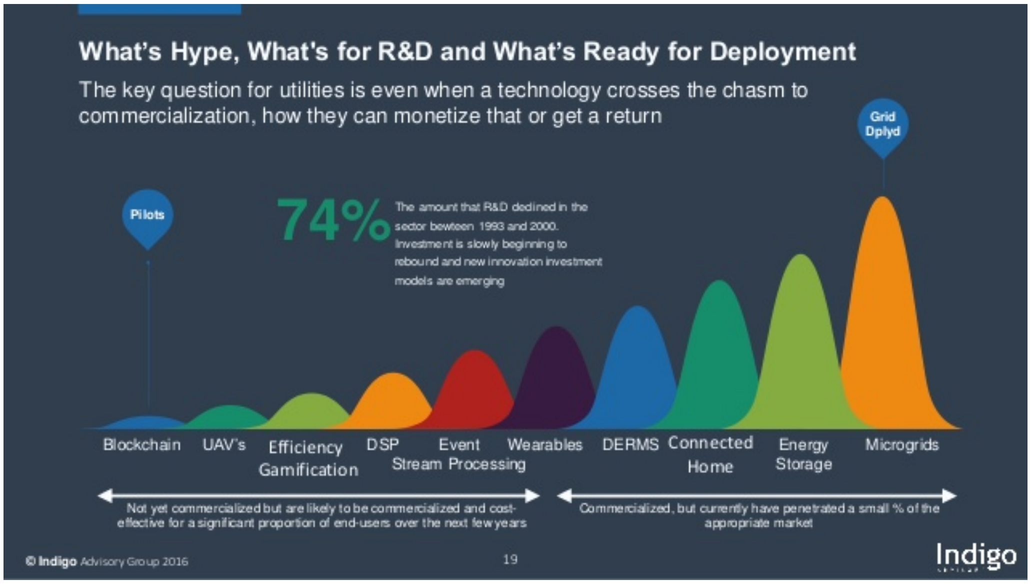


Figure 11. Where Blockchain applications stand today: Hype, R&D or Deployment-Ready. *(Based on Indigo Advisory Figure).*

3.5 What are some of the Blockchain-based projects being tested and/or developed in the energy sector?

The wide range of applications for transactive energy using blockchain, has led both Utility companies and startups to test and develop the application of this technology in their business models. While many of these Pilots and projects are aimed to allow P2P electricity trading participants access the energy market, there are other projects being developed in the area of EV charging, wholesale energy trading between utilities, ICOs and energy tokens. A brief description of some of the most interesting projects is provided below.

LO3 Energy´s Brooklyn Microgrid (USA):

The company LO3, has already developed an energy community of participants acting as prosumers and trading electricity locally. Not only are they pioneers in the P2P electricity trading system for microgrids, but their TransActive Grid smart computer, is able to communicate accurate and real time data on energy consumption and production to the DSOs, which will aid them for grid balancing.

Furthermore, TransActive Grid is also able to communicate and control smart appliances at home, which allows them to respond to the demand both for the market and the grid.

Grid Singularity (Austria):

Austrian start-up Grid Singularity is a very promising startup that aims to create an open, decentralized energy market. Led by a team of experts and advisors in both the energy market, the blockchain technology and smart contracts, they are developing the platform necessary to allow open source and dApps to participate, in order to provide innovative solutions in the energy market, thus solving the paring Prosumers' generation and consumption with regulation, yet still giving them the power of decision.

Electron (UK):
A U.K. startup that aims to provide sustainable systems in order to support the industry's transition to smart grids and new decentralized energy markets. Their products include platforms for meter registration (currently only for gas now) and flexibility trading, but also supporting community energy projects.

Energy Web Foundation (Austria):
A collaboration project started by Grid Singularity and the Rocky Mountain Institute in order to create an open-source, scalable blockchain platform. This platform is currently in Beta version and is tailored for the energy market needs. An interesting difference in their system is that they use PoA as their consensus protocol, which enables about 1,000,000 transactions per second *(Smole, 2018)* and reduces electricity consumption drastically, which means it is highly scalable and has a potential reduction of costs.

Power Ledger (Australia):
An Australian startup that has had a massive success in the blockchain and energy applications world. They aim to provide clean, reliable and low-cost electricity in order to reinvent energy systems. Some of their products include blockchain-based solutions for peer-to-peer trading, micro grid trading, carbon product trading and electric vehicle settlements.

WePower (Australia):
Another Australian start-up that has created a platform for trading energy in Australia based on smart contracts with which the producer can sell its renewable

energy upfront in the energy market. They have also implemented their own cryptocurrency for their energy trading process called WPR token, as of September 2018 worth $.0176 USD. *(CoinMarketCap, 2018)*

Conjoule (Germany):

A German startup working to enable local peer-to-peer electricity trading. They have created a platform in order for prosumers and consumers in local markets to trade their excess electricity, thus allowing them to participate in this economic activity.

Verbund & Salzburg AG (Austria):

Currently testing 3 projects, 2 projects in Salzburg and Lower Austria which will enable residents in multi-party houses to trade solar power amongst each other; the other one, to enable peer-to-peer wholesale electricity trading in a consortium with a total of 35 utility companies participating on it including Enel, Axpo and E.ON.

Sonnen & TenneT (Germany):

Since the end 2017 Sonnen & TenneT have been testing a pilot project for decentralized blockchain-networked house energy storage systems in order to stabilize the grid. Further results are expected in 2018, but the purpose behind the project will be vital for blockchain systems, due to the rise of Prosumers connecting to a traditional grid. Innovative solutions such as these projects need to be created alongside the blockchain technology in order to be able to deploy the technology without damaging the current electrical network and infrastructure.

Figure 12. Blockchain key players in the electricity sector today. *(Own figure based on Indigo Advisory Group's Figure for blockchain stakeholders)*

4 THE APPLICATION OF BLOCKCHAIN IN A P2P ELECTRICITY DISTRIBUTION SYSTEM

4.1 The Traditional Energy System, Players involved and their new roles in a Blockchain P2P System

5.1.1 Overview of current energy system and main actors

Today, many countries still use the Traditional Energy Systems. These energy systems include the Power Plants, which TSO (Transmission System Operator), DSO (Distribution System Operator) and the consumer. A brief description of each player and their role in the electricity trading is provided below. *Figure 13*, then explains the relationship between each of these players in the traditional energy system.

Power Plants

A Power Generation Plant is an industrial facility that produces electricity as an end result. There are different types of Power Plants, from fossil fuels-burning plants (Coal, oil or gas), nuclear Power Plants or Renewable Energy Plants (e.g. Biomass) or CHP Plants. These plants produce the electricity that is then transmitted to the TSO, according to the scheduled plans and agreements they have reached. Most of these plants are easy to handle and schedule, since they can be programmed, depending on the demand.

TSO

The transmission system operator is an entity in charge of transmitting electric power (HVDC) from the Power Plants to the Distribution System Operator. This operator is also responsible for maintaining and expanding the Grid, as well as balancing the Supply (from Power Plants) and Demand (required by consumers) in order to avoid fluctuations in the voltage (in Europe 50Hz) thus preventing damages to equipment, infrastructure or blackouts. In order to do so, TSOs require the use of real-time transmission systems and a very precise coordination with both DSOs and Power Plants in order to accurately plan the electricity flow.

DSO

Distribution System Operators, are entities responsible for handling low, medium and high voltage in specific areas (e.g. a city), and supplying it to end consumers. They are also responsible for ensuring the supply in such given area, maintaining and developing the network that they operate in, in order to improve the reliability of it and ensure the quality of the electricity provided. *(Emissions-euets, 2018)*

Consumer

Any household, industry or business that require electricity to fulfill their daily activities can be defined as a consumer in this context. The consumer then will have an economic participation with the market when acquiring this service in exchange for a payment to the supplier.

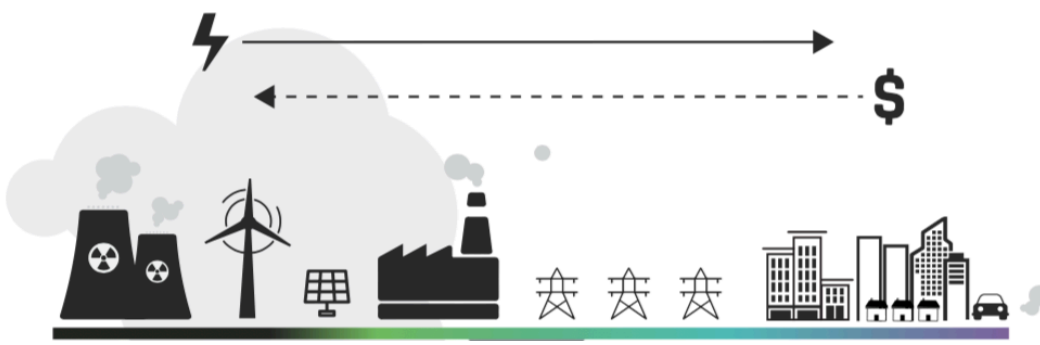


Figure 13. Traditional Energy System. *(Source: Hartnett et. al., 2017 The Decentralized Autonomous Area Agent (D3A) Market Model by the Energy Web Foundation).*

5.1.2 Energy Players and their New Roles in a Blockchain P2P Electricity Distribution System

The increasing use of Renewable Energy sources has also changed the traditional energy trading system. Today, we have other actors such as Wind Power and PV Plants that are far more dynamic than burning plants, since they depend on weather conditions. Therefore, they require a bigger effort in planning and are also less predictable, despite forecasts (E.g. a forecast for wind may give information on wind speeds and timing, but if at the estimated time, the wind turns out to be stronger than predicted, Wind Power Plants have to be turned off for safety reasons, which would require a backup Power plant to be able to kick in with fast response). *Figure 14*, explains the relationship and dynamics considering these new actors. Furthermore, the increase growth in Prosumers, using PV Rooftop systems, can also contribute to the energy production unpredictability if the DSO do not have information on how much electricity will be produced and consumer, since these players are not directly monitored. Therefore, a feasible system considering Prosumer-trading needs to be developed, and that is one of the benefits Blockchain Systems can offer to stabilize the Prosumer interaction with the grid.

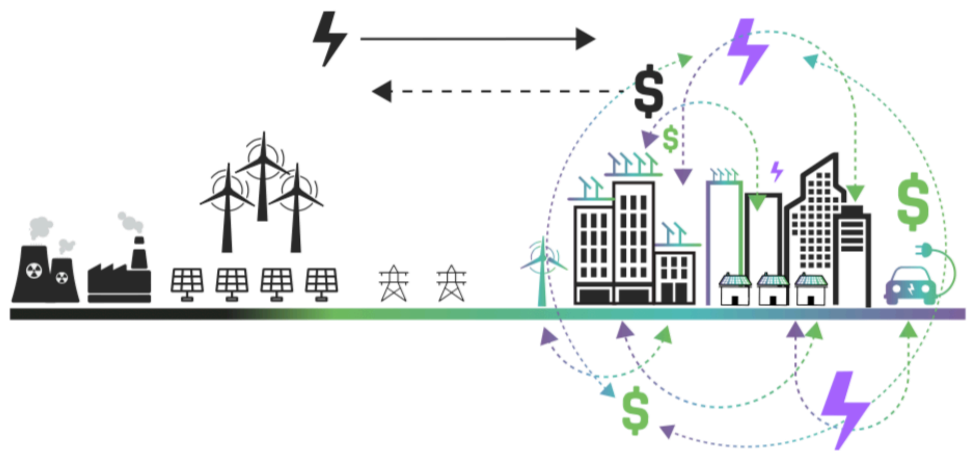


Figure 14. The New Energy System. *(Source: Hartnett et. al., 2017 The Decentralized Autonomous Area Agent (D3A) Market Model by the Energy Web Foundation).*

Several startups have already started addressing this challenge. Grid Singularity and the Energy web foundation are developing D3A, which is a marketplace for different types of participants from prosumers to the utility sector; LO3 has created an energy Market for Prosumers, both of which will be further described in this paper. However, it is important to mention that LO3 has successfully tested a Blockchain based system to enable P2P electricity transmission, in which it is possible to implement a smart computer, called "TransActive Grid", which not only measures electricity production and consumption as a Smart meter would, but it is also able to interact with and manage all the smart devices at home, in order to be able to be demand responsive. This means, that it is possible for this computer to automatically switch on/off certain devices depending on the flow in the grid, if there is an overload, this device would automatically switch off selected appliances in order to comply with the grid; On the other side of the spectrum, if there is a higher supply of electricity and prices are cheaper, this computer is able to automatically charge your car in order to take advantage of the price, thus contributing to the balancing of the grid.

TSO/DSO New Roles in the Blockchain P2P electricity-trading System

The application of Blockchain will change the role that DSOs and TSOs currently have in the Energy Trading Systems. As previously mentioned TSOs will eventually need to solve the resilience and security of the grid, while also successfully monitoring and balancing the electricity coming from Prosumers (through the information provided by the DSO).

Today, Prosumers still play a very small role in electricity generation and trade. Nevertheless the Blockchain P2P electricity-trading models are bound to thrive, slowly but steadily and securely. This is the main reason most TSOs and DSOs are looking into possible applications of Blockchain technology that can potentially be applied both in small scale trade to the utility sector.

As all new technologies thrive, disruptions in current systems occur. This is one of the aims of Blockchain, which is likely to happen if it continues to thrive. However, the odds are that TSO/DSOs will not disappear completely, we can currently see many research and pilot projects from utility sector in this are as they learn to adapt and change their Business Models and Revenue streams. Therefore, only their roles will change.

The TSO is an indirect player in a Blockchain P2P Electricity distribution system, since electricity is created independently and distributed in a short distance from where such electricity was produced, in other words, it is locally sourced and consumed. However, the DSO's role would certainly change. They would no longer be the main supplier (middleman) within a microgrid using a blockchain-based P2P-ETS. However, although highly unlikely with the use of Battery storage, we must be aware that the microgrid, even when powered by clean local PV electricity, still depends on weather conditions as any other PV Rooftop system, therefore, there still needs to be a connection to the main grid and the possibility to obtain electricity from the DSO (Utility Company) in order to ensure electricity supply.

Additionally, the DSO could benefit from the microgrid measurements for balancing the grid. Since an efficient Blockchain-P2P-ETS requires a smart metering system or computer for accurate production and consumption measurements. This real-time information could then be shared with the DSO in, in order for it to accurately plan their energy forecasts and balance the grid's supply and demand. The DSO would then supply more accurate information to the TSO, which will lead to a healthier electric grid. As the rise of prosumers grow, it is paramount to have an appropriate way to integrate prosumers into the grid in order to secure its integrity and use.

The New Role of Consumers in the Blockchain P2P electricity-trading System

In a Blockchain P2P-ETS, the consumer can either remain a consumer, buying electricity from the Utility company; or it can become a Prosumer. A Prosumer is a consumer that also produces electricity (in this specific example). The most common type of Prosumers in the energy sector are those that own or share a Small scale electricity generating module, usually small PV rooftop systems.

The rise of Blockchain applications and pilots in the P2P-ETS scheme, have created a market for Prosumers to trade their energy. This is a change that is unprecedented in this sector, since Utilities today still hold the monopoly of the electricity distribution to end consumers. The new role of Prosumers in these systems, and the freedom of choice, both to set selling prices (Prosumer) and choose electricity buying prices (consumer / other prosumers) is only the beginning in the electricity market disruption that the blockchain revolution for P2P-ETS has enabled.

4.2 Peer to peer electricity trading in a Micro-Grid

One of the most interesting applications for blockchain in the electricity sector is the idea of being able to distribute electricity on a peer-to-peer model without requiring an electricity supplier. This application is already being used in a smaller scale, mainly microgrids, in several projects around the world. One of the most famous ones is "The Brooklyn Microgrid" developed by LO3, which started in 2016 as a test with 3 residents trading electricity in Park Slope, USA *(Exergy™, 2017)*. Austrian's Utility Company Verbund has also began testing a similar project in partnership with AG Salzburg.

In order for a Blockchain P2P electricity trading (from renewable sources) to be possible several basic requirements are needed in the system:

1. One or more electricity producers **(Prosumers)** need to exist. This means that there has to be an installation (usually PV rooftop systems), which generates more electricity than it's consumed, to be able to trade the remaining electricity.
2. A **blockchain-based platform** is required to enable the electricity trade among prosumers.
3. A **Storage Battery System**. This topic is further described. However, it is important to mention it, since a storage battery system will allow the storage of the "product" which generation will happen during the day, but it will be traded or consumed normally in the evening. Therefore, it is suggested in a system.
4. **Smart Contracts**. Further described in this paper, Smart contracts are important to enable settings that will allow the transactions to happen automatically when criteria is met.
5. To define the **payment method** of the product and how it will be accomplished in the transactions (e.g. cryptocurrency, production/consumption balance between prosumers, etc.)
6. The **physical peer-to-peer networks**, in order to be able to physically and computationally achieve transactions.

Current Model for Prosumers sending electricity into the grid

Today, the EU28 has different regulatory and market remuneration processes depending on the country for exceeding electricity fed into the grid by Prosumers. While some countries like Austria, Bulgaria and the Czech Republic have different legal frameworks for allowing the surplus electricity fed into the grid to be sold by the Prosumer and allow a remuneration for it, other countries like Belgium, Denmark and Greece use compensation schemes between the electricity consumed and the surplus.

In other countries like Slovakia, the electricity surplus in the residential area can be fed into the grid, but does not offer remuneration or compensation. In most cases this is not possible due to the metering systems or entire conditions of the grid in such countries. In other words, these schemes limit the possibility for prosumers to sell their surplus electricity, and those countries that allow it, will set a price based on the market that may not be entirely transparent. Blockchain offers the possibility to design the system from bottom-up, in order to be able to decide prices within the network as a producer and as a consumer, while also allowing information in the whole process to be transparent and available to all the participants. *(GfK Belgium Consortium, 2017)*

4.2.1 Existing and proposed Blockchain P2P electricity-trading Models

There are several P2P transmission models that are being developed and some are currently being tested and deployed in smaller scales. These models involve several main actors depending on the model. The Nodes, which for the purposes of this thesis, are the households within the system that will be participating in the Blockchain and are considered Prosumers with a generation capacity of 10kW or less. The Smart Contract which is described below and a brief description of how they will interact with each other and exchange information is provided. *Figure 15 (next page)* explains in a brief way the process that a transaction will go through in order to be achieved. This specific example, uses Ethereum as a cryptocurrency and Ethereum's smart contracts. However, most platforms nowadays have their own cryptocurrency to enable transactions in their platforms (e.g. LO3 uses the XRG coin).

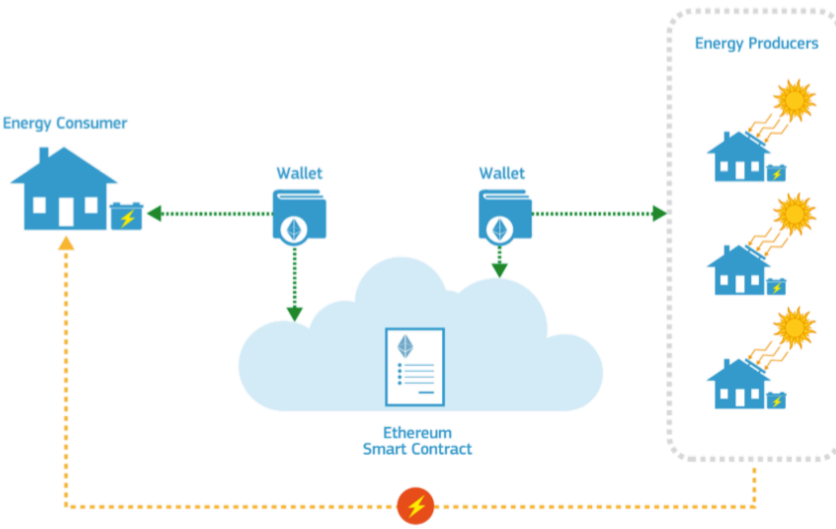


Figure 15. The Blockchain P2P Model for electricity trading. *(Source: Ioannis, et al. 2017).*

The Nodes forming the Network:

The Nodes in this scenario are a group of homes in a smaller area of a city, community or neighborhood (e.g. the Brooklyn Microgrid) that are able to produce and consume electricity, powered by rooftop PV Panel installations but also acting as nodes. The PV installations sizes and capacities will vary depending on the available space on each home. The community members also require a Battery to store the extra energy produced, the capacity of such batteries will be determined by the size of the Solar PV modules capacity.

Smart Meters (or Smart Computers):

In this scenario, smart meters are a crucial hardware required to send accurate information to the Blockchain. Smart meters serve the purpose of monitoring the production and consumption of the electricity in each household (node). In order to do so, the smart meter chosen needs to be able to measure the production and the consumption in each household participating in the blockchain P2P system. The smart contract or the controller system (in case a central storage is being used) within the blockchain will be able to automatically match transactions by determining, based on the criteria, which node or nodes require or have extra energy to distribute. Since the blockchain depends on the accurate information sent by the meters, this raises a security concern. Smart metering today can be tampered with, as it is a sole component sending information (in each node), this can make information unreliable and hard to be verified by other nodes. However, there are some interesting solutions to deal with this problem with trusting computing systems, such as Trusted Platform Module (TPM), Trusted Execution Environment (TEE) or Secure Element (SE) *(Ioannis, et al. 2017)*

Smart Contracts

The concept of Smart contracts was first introduced by Nick Szabo in 1994, where he suggested to codify them and create a software (and hardware) that could perform transactions automatically. A smart contract is in simpler words, a program that has the ability to automatically perform transactions based on specific criteria set by the participants. Thus, this program operating within the Blockchain system is able to move assets from one account to another if the conditions encoded in it are met. *(MIT TRE, 2018).* Therefore we can say that Smart Contracts depend on the criteria that have been previously encoded in it.

According to K. Christidis et. al, (2016) the following characteristics can be observed in Smart Contracts:

1. The Smart Contract Program is autonomous in the blockchain and it can control and transfer assets from one account to another.
2. The Smart Contract helps apply business logic in the form of coding, where it can meet specific criteria set by the users in order to "make decisions" (e.g. when 10kW of electricity are transferred to Alice, X amount of euros will be transferred to Mark's account.
3. Since the code in the contract is absolut once the transaction is done. The code and data structure needs to be revised and consider all possible outcomes. The criteria to be met needs to be clear and specific (e.g. only buy electricity from producers with a cost of €0.20 cents per kWh).
4. A Smart contract is part of the blockchain; therefore every node can view the code in it, however only the participants involved in a transaction can "sign it" with their own key.
5. Whenever a transaction is done, every node in the network will receive a cryptographic trade of it, thus being traceable by anyone in the network.

In a P2P electricity trading system, the Smart contract is in charge of identifying, using the information stored in the Blockchain, which nodes could "perform a transaction" depending on their electricity availability or requirements, currency availability, price settings and other criteria. When it finds matching criteria between one or more nodes, the smart contract is capable of automatically performing the transaction. This means if Alice (A) requires 10kWh of electricity, and Mark (B) and Clara (C) each have 5kW available, the smart contract is able to send both B/C's available electricity to A, and do the payment transaction from A to B/C automatically.

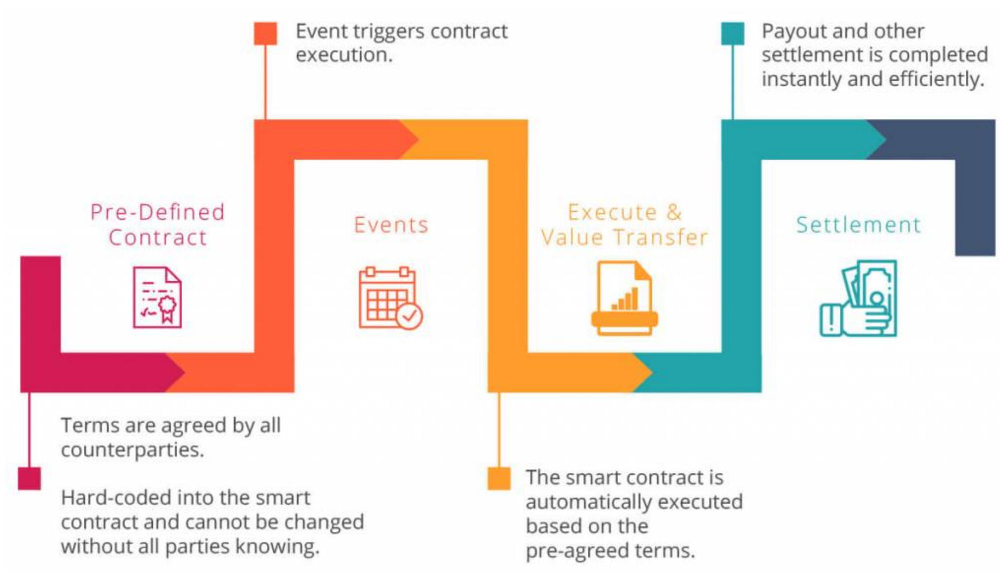


Figure 16. How Smart Contracts work. *(Source: weblineindia.com)*

The use of a Central Storage System (e.g. Helios):

This P2P Model, also known as Helios, which was tested and reported by the Joint Research Center (JRC) and published by the European Commission, uses a CSS Controller, an automated system fed by the information from the smart meters installed, this provide a clear identification of the amount of electricity each home "node" is producing, saving into the battery and consuming. This controller allows the Smart Contract to automatically perform the transaction between the nodes if the required criteria are met. Some of the Criteria include determining whether or not node A has the amount of electricity required by node B, and that node B has the amount of tokens required to pay for it. The controlling system has the entire information of the energy consumption and production of each node. This model is designed for smaller grids, and it works under the assumption that whenever a node has electricity excess, it can be either stored in the central storage system or released to the grid. In both cases, the electricity excess is "rewarded" with Helios coins, which can later on be exchanged for electricity. *Figure 2*, explains this model considering their own coin "Helios" for the transactions.

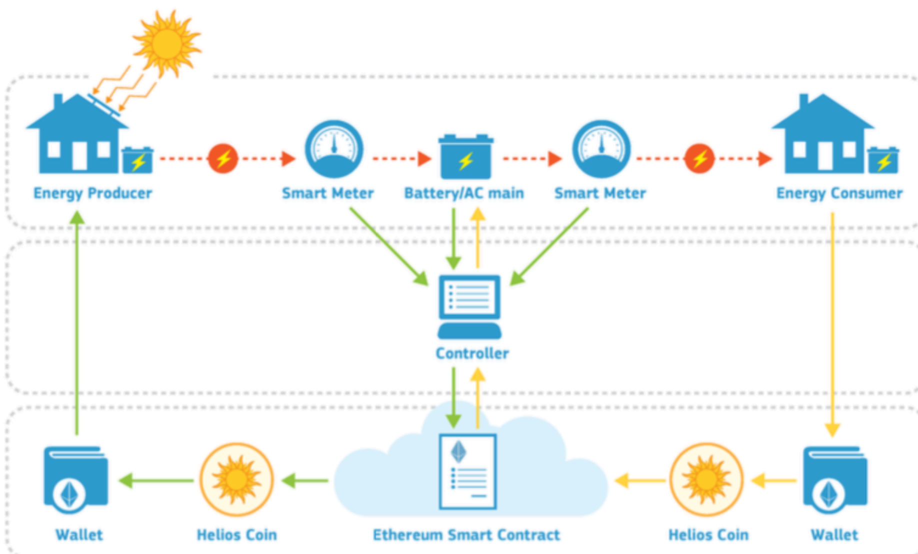


Figure 17. Blockchain P2P Model (using a CSS, Helios). *(Based on the Helios Model Overview; Ioannis, et al. 2017)*

Energy Coins, Token System and payment Method:

In order for a transaction to be processed by a Smart contract in a blockchain P2P electricity trading system, a payment for the product needs to be available in the consumer account. The most common payment methods in blockchain P2P systems is through cryptocurrency, either existing ones (e.g. Ethereum tokens) or the blockchain platform system provider's energy token (e.g. XRG Coin (Exergy/LO3), POWR Coin (Power Ledger), SLR Coin (SolarCoin), usually working under the Ethereum protocol as well). However, other options can be considered such as alternative currencies, fiat coins or coloured coins. However, other options can be considered such as alternative currencies, fiat coins or coloured coins. However, this paper will only focus on 2 payment options that are considered the most feasible ones.

Cryptocurrency linked to a currency:

A cryptocurrency by itself, has no real monetary value, you cannot go to a bank and withdraw cryptocurrency. The value from Bitcoin and Ethereum that we hear of every day is the value given through speculation. Since it is based on speculation, the value of such currency is currently changing, which makes it great for the speculation market, but not so great for commercial purposes (or at least not yet). Imagine that the value of your salary would change everyday; it would be hard to plan or manage your financial life. Therefore an option that is often suggested for trading within blockchain applications is to link a specific cryptocurrency (in this case an energy token) with a real currency (e.g. Euros, pounds, dollars). Under this scheme, cryptocurrency would be backed by real money, just as real money is backed by gold or other values.

Green Certificates:

Another option for payment systems that would benefit some companies to achieve their green energy quota, is to set a specific amount electricity provided from renewables in exchange for green certificates, which can then be sold to intermediaries, energy suppliers or companies. Today, the average price for a green certificate is €86, and for every 1,000kWh you receive 3 green certificates, which have a total value of 258€/1,000 kWh. *(www.energuide.be)* Therefore, a P2P trading system using a blockchain technology could also implement a payment using green certificates.

kWh for kWh:

Another viable option, although it mostly only applies on trading among prosumers with other producers, is the exchange of kWh produced for kWh consumed. Under this scenario, prosumers could generate electricity during peak hours save it or send it to the grid, the system would generate a count check of the amount of kWh generated and reduce it from the "account" once the electricity is consumed.

4.2.2 An efficient Blockchain P2P electricity trading system

Type of Network and System:

According to the research undertaken, the ideal blockchain system to be implemented considering transparency and safety is a Public Blockchain, this will enable the system to have more options to match criteria, rather than having a private blockchain, where a permission needs to be given to access.

Consensus Protocol:

Regarding the topic of consensus protocols for public blockchains, the one considered to be the best option is PoA (or as a second option: PoS), which are described below. The main reasons, is that it still allows anonymity for the users, but the security of knowing the participant. Additionally, PoA also allows a much greater number of transactions per second.

Proof of Stake (PoS)

There are some new options being developed in order to tackle the above-mentioned problem. The first one, which is currently being implemented in Casper from Ethereum, is called Proof of Stake, PoS offers a significant improvement in both transaction rates and energy efficiency, this is important if we want to implement blockchain in the energy market, since energy transactions happen continuously at very high rates. PoS offers a consensus protocol where the network is protected by the current stake of each node or participant (amount of tokens). This means, that in order to make the network more reliable and each node trustworthy, each of the participants have to put part of their own stake in the system. Miners in PoS are usually called forgers. Forgers do not earn tokens when solving the cryptographic puzzles, as opposed with PoW. So how do they earn? They use a fee system, through which usually refers to the "cost" of computational efforts required to process each transaction. In order to increase the security of the system, Vitalik Buterin has created the Casper Protocol, which is a set of rules, in order to determine if any of the validators is acting in a bad way. If the algorithm detects any bad behavior, the validator would automatically lose their stake, which serves as a deposit. Additionally, PoS algorithm, chooses validators according to their stakes, with the idea that the higher your stake is (or deposit) in the system, will drive participants to behave in a correct way to preserve their stake.

Proof of Authority (PoA)

Proof of Authority (PoA) is a consensus protocol that derived from PoS, it is currently being used by the Energy Web Foundation's development "D3A" and will allow approximately 1,000,000 transactions per second *(Smole, 2018)* and it is based on the participant's "reputation", rather than an economical stake. This is a very interesting Consensus Protocol that is also being used by other companies like POA Network, Kovan and 2 Ethereum testnets *(POA Network, 2018).* In the energy market place, as above mentioned, this is vital and could be a potential efficient solution to be applied in Public blockchains. One of the interesting things that this consensus protocol offers is that as opposed to most public blockchains where the participants' identities are unknown (raising questions of who they really are and if they are trustworthy), this protocol knows the identities of the participants, but still allows anonymity. In the energy sector, this is a very important factor. Although public blockchains are great, when it comes to energy transactions, participants must be reliable. This solves an important trust problem for energy applications aiming to use public blockchains.

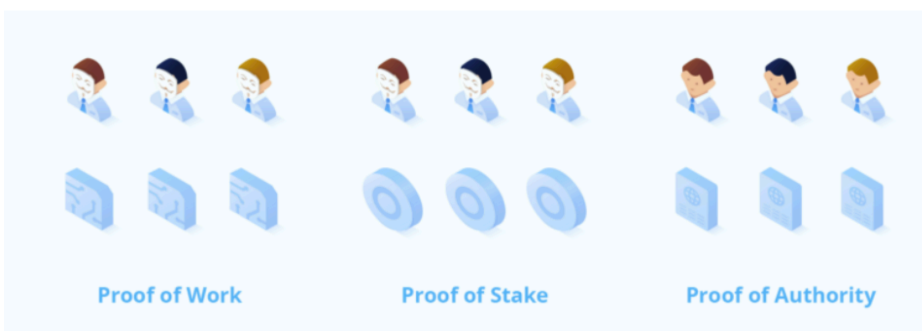


Figure 18. Identity differences in PoW, PoS and PoA. *(Source: Medium.com)*

4.2.3 How to further optimize the efficiency of P2P electricity trading system and its participants

IoT and Demand Response Management

One of the biggest concerns when we talk about blockchain is the exorbitant amount of electricity a public system requires due to mining, which will be described further in this paper. Therefore, besides the correct selection of the consensus protocol that will be used, it is also important to make the nodes efficient, in other words, making the Prosumer household more efficient too. This will result in an even more efficient node, thus making the entire system a lot more sustainable.

In order to do so, there are several commercial options available that could be utilized in the building or household. This is where ***IoT*** in the energy efficiency of buildings takes place. By choosing smart and energy efficient systems and appliances at home, not only can energy consumption be reduced, but it can also be managed correctly. Today, smart computers that allow not only precise metering measurements but can also communicate with other systems within the network are the key resource to demand response.

Demand response is the ability to change the consumption in a node or household, in order to match the demand on the grid. In other words, ***demand response management*** allows the communication between the Balancing Operators, DSO and the Prosumer and/or consumer (more accurately the customer's smart computer or meter) in order to further optimize the grid balancing. By doing so, the benefits go both to the utility as well as the customer; the consumer benefits from lower prices at which he can connect his devices (e.g. electric vehicle), or disconnect when prices are very high. On the other side, the Utility companies receive accurate and real-time consumption and production information, which allows them to better balance the grid. Additionally, the utility sector also has the benefit of using this communication platform in order for them to balance the market prices; when there is an overproduction of electricity and no one uses it, the prices become cheaper and sometimes fall under the line where utilities have to pay users to get ride of the excess electricity. Therefore, this problem can be solved by communicating and working together with the consumer, to get benefits on price if they use the electricity on these specific moments. This communication can be manual or automatically managed by the Smart computer (through several pre-settings) in order to automate it. *Figure 19* explains shows the communication paths between the different smart appliances and systems with the demand response software (smart computer) and how the information gathered reaches the DSO in real-time.

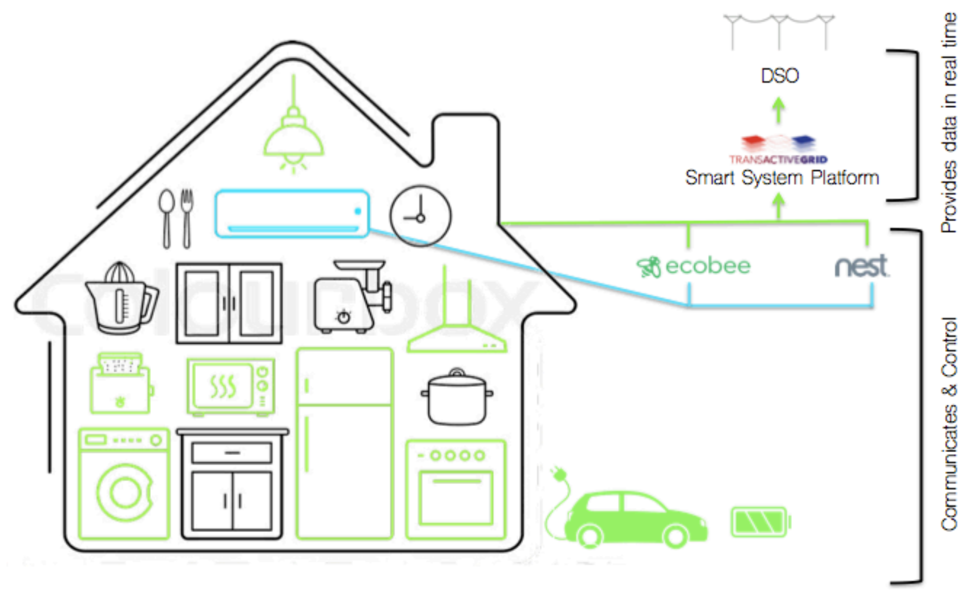


Figure 19. The way demand Response Management software and smart systems/appliances communicate. *(Own Figure)*

Energy IoT oriented P2P Systems:

The implementation of IoT in Blockchain systems can allow easier interaction between the applications and the physical appliances. A perfect example is LO3's TransActive grid, a computer that measures energy production and consumption in any given building or household and acts as a smart meter while also being capable of providing IoT solutions to all smart devices in the household. A number of other IoT oriented devices and applications can further optimize the system, making the entire system more efficient and value-oriented.

Recommended additional devices that Prosumers in a Blockchain P2P electricity trading system should include

Smart thermostats systems:

Ecobee4 and Nest thermostat E are 2 of the best thermostat systems that are currently available on the market and are widely used in the United States and spreading across Europe. These smart thermostats with a price ranging from €169 (Nest Thermostat E) - €249 (Ecobee4), can be a great aid for smarting the system up. They have the ability to control the temperature at home or office and in some cases some other appliances related to temperature control (e.g. the activation of a fan). They also include other features like connectivity with Alexa, in order to send instructions to the system and automatically control it.

Smart Computer / Controller:

TransActive Grid by LO3 is one of the systems (hardware and software with a connection to a Blockchain based platform) that have the ability to control appliances at home (e.g. lights, kitchen appliances, EV charging and even the Ecobee/Nest thermostat systems). Furthermore, it has the ability to act as a smart meter, measuring electricity production and consumption in a household. The system also has the ability to communicate with other nodes through its blockchain-based platform and send information of production and consumption to the balancing operator or DSO.

Another smart device designed for home energy efficiency is Verv, a Smart House computer with similar functions to LO3's TransActive Grid, but can trace specifically where the consumption comes from (if it's a kettle or a light). This information is particularly important, since the homeowner can monitor which devices use more of the electricity and can manage when to turn them on.

Battery Storage System:

In order to be able to store electricity when it is generated and be able to distribute it or use it when there is demand, it is paramount to have a Battery Storage System. The battery storage system, as previously mentioned in one of the current models for P2P electricity trading, can be owned by a single prosumer or shared by 2 or more prosumers. The benefits of having a storage system includes having supply back-up in case of emergency (e.g. blackouts), allows the prosumer to manage how the electricity is used (if it is self-consumed, if it goes to a consumer or the grid), being able to store electricity when prices are low, and selling it when they're high and enabling demand response with the grid. The size of the battery storage system will depend on the system. For example, if a single prosumer with a 10 kWh PV rooftop system invests in a battery storage system, a 10 kWh Battery storage is ideal. However, if a battery storage system is shared by several prosumers the capacity has to be increased. The option for shared battery storage systems for small communities is becoming popular, since the participants can divide the investment required but share the benefits. However, negotiations among them need to be clear and specific, since there will inevitably an uneven use of it by each.

Some of the most popular battery storage systems go from Sonnen's Eco Lynx with a capacity of 16 kWh, which has an average price of €19,618 and a lifetime of 15 years to Tesla Powerwall 2 with a capacity of 13.5 kWh, an average price of €5,076 and an unlimited 10-year warranty. *(Energysage.com)*

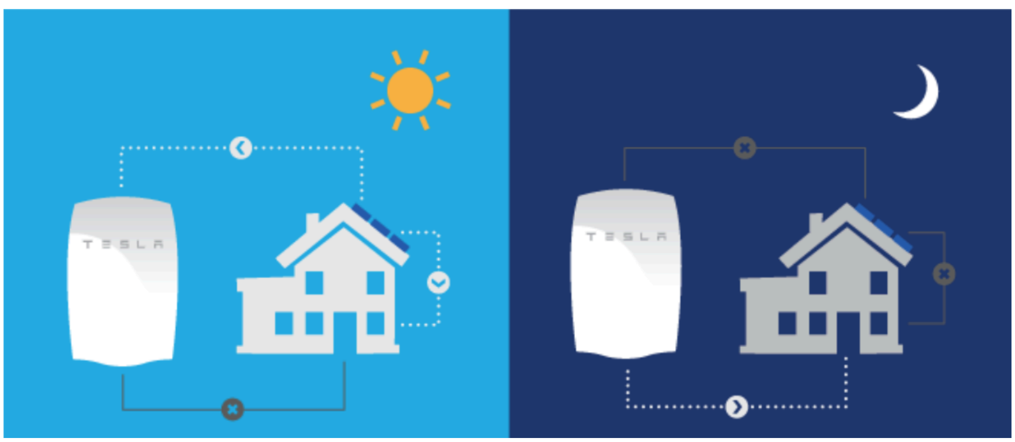


Figure 20. How a Battery Storage System works. *(Source: energysage.com)*

Block Storage Node Requirements:

A Block storage node, is the participant or node that will store information on its hardware. Today one block is approximately 1 MB and the blockchain (for Bitcoin) is currently about 20 GB. However, the blockchain grows exponentially, therefore, when considering the disk capacity for each node, it'd be better to think of the future and consider at least 50 GB in the computer.

The recommended requirements for Bitcoin Core as an example of the requirements for a node are shown in *Figure 21*.

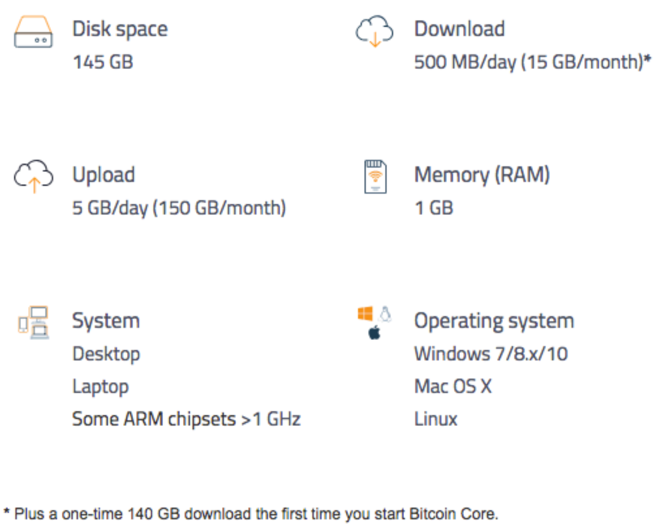


Figure 21. Minimum recommended requirements for Bitcoin Core installation. (Source: Bitcoin.org)

4.2.4 Benefits of the application of a Blockchain P2P Electricity trading system

Cybersecurity concerns to electricity. One of the most important aspects that provide blockchain is reliability on the information. The method it uses to validate new transactions (consensus protocol), based on specific cryptographic puzzles that change continuously, it provides with an unprecedented level of security. The importance of cybersecurity in the reliability of the grid is paramount; by simply observing our surroundings in our day to day, we can confirm that the need for energy in all of its forms, but specially in electricity, is of utmost importance. One day without electric power can lead to chaos in our modern world. A longer period could have negative effects and bring potential threats to a country or region that range from health to economical instability.

DERs actively support the grid reliability. Due to their higher resilience to external threats (e.g. climate driven) perspective, to the benefits of having a decentralized system. By having many smaller scale decentralized systems connected in one big grid, the risk of entire blackouts and damages to the grid can be prevented; taking the eggs in the basket analogy, by not having all of the eggs in one single basket, the risk of the eggs being broken is lower.

Open energy markets and customer participation inclusiveness. As previously mentioned the increase of the consumer acting as a producer in the electricity sector has increased dramatically on the last decade. Due to transparency of data embedded in blockchain-based systems, markets where everyone can participate and share such data can be created. This allows customers to participate and trade electricity in markets that were reserved in the past for big players.

Giving customers/prosumers a choice. The customers have a choice to remain customers or become prosumers and decide who do they want to buy electricity from. Prosumers can now trade electricity with other customers/prosumers and furthermore, they have the liberty of deciding the price they want to sell electricity for, and consumers can decide what maximum do they want to spend for electricity.

Promotes the use of clean energy. In a world where 81.4% of the world primary energy production still comes from fossil fuel sources *(IEA, 2017:6)*, it is important to embrace every opportunity to allow renewable energy sources to thrive and become the main source of electricity. Blockchain in the P2P electricity trading system, by the nature of the prosumers themselves, allows the trading between them, ensuring the production and trade of clean energy.

New Business models in the energy sector. The energy sector is one of the oldest systems worldwide, the infrastructure has now become obsolete. The resilience of the grid itself is becoming an issue for balancing operators and there is a need to properly control the electricity flow as well as the consumer's behavior. The use of blockchain allows new energy business models that can allow the entire system to slowly but steadily upgrade. The increase of new business models for the electricity sector is being noticeable specially in the energy markets.

Entrepreneurship. The blockchain revolution has also opened many opportunities for entrepreneurs and innovations. Every day, new Start-ups with great ideas solving the current energy market, regulation and trade challenges within it are rising to create new niche markets and create new opportunities. These start-ups characterize specially by the use of edge technology to solve this issues and highly motivated founders that are prepared and show leadership.

Thrives Innovation. As we all know, technology grows exponentially. This means, that in order to create a smart phone, many other technologies were created first. Each of these technologies, allowed many other technologies to thrive, which means one technological breakthrough, leads to exponential use cases and applications. We saw this when the Internet was created and how it evolved. Now we see it with blockchain; how one good base technology led to many different applications in different areas.

5.2.6 Technical Limitations and Challenges to the application of Blockchain in the P2P electricity trading system

There are 2 main challenges currently affecting the scalability of Blockchain systems: Number of transactions and the time for processing/validating new transactions. These challenges have been studied since the beginning of the blockchain revolution and while some of them have been tackled, others are still being researched.

Number of Transactions per second and time processing:

One of the biggest problems for scalability in any system, is the ability to perform a high amount of transactions per second. This is basic in any system expansion. The main reason behind the importance of mass transaction or production is the cost reduction. As the economies of scale have taught us, production costs tend to be reduced as the quantity produced goes up. If we wanted to use a blockchain system for 1 single transaction every day, the production of the entire system, electricity used, hardware and software necessary, etc. would make that single transaction massively expensive. However, as the number of "production" or in this specific case transactions increase, the entire system's production costs are divided among all of the transactions, thus reducing costs per transaction.

Most Public blockchains use PoW (e.g. Bitcoin) as their consensus protocol. The problem with PoW, is that it only allows a very small number of transactions per second, which makes it hardly scalable. While PayPal manages 193 transactions per second (t/s) and Visa can manage 1663 t/s, cryptocurrencies with PoW like Blockchain only allows 7 t/s, and in a better scenario Ethereum with 20 t/s. The main reasons behind this abysmal difference are the time it takes to add a transaction to the blockchain and the time it takes to reach consensus. As previously mentioned, PoW uses a "competition" work form, in order to make its nodes more reliable. However, this competition is the main reason why the costs are so elevated in PoW, since nodes keep their computers running 24/7 to increase their chances of obtaining a reward. This competition style also takes a longer time for validating transactions, which makes the entire validation system slower. Additionally, miners in public blockchains using PoW use a Miner's fee (Bitcoin), which usually refers to a "cost" of computational efforts in order to process the transaction. The faster you want the transaction to be processed the more it costs, therefore, someone looking for lower fees will wait for their transaction to be processed from 10-45 minutes in some cases. *Figure 22* shows the median confirmation time it takes for a block or transaction to be added in the public ledger or blockchain. *(Blockchain.com, 2018)*

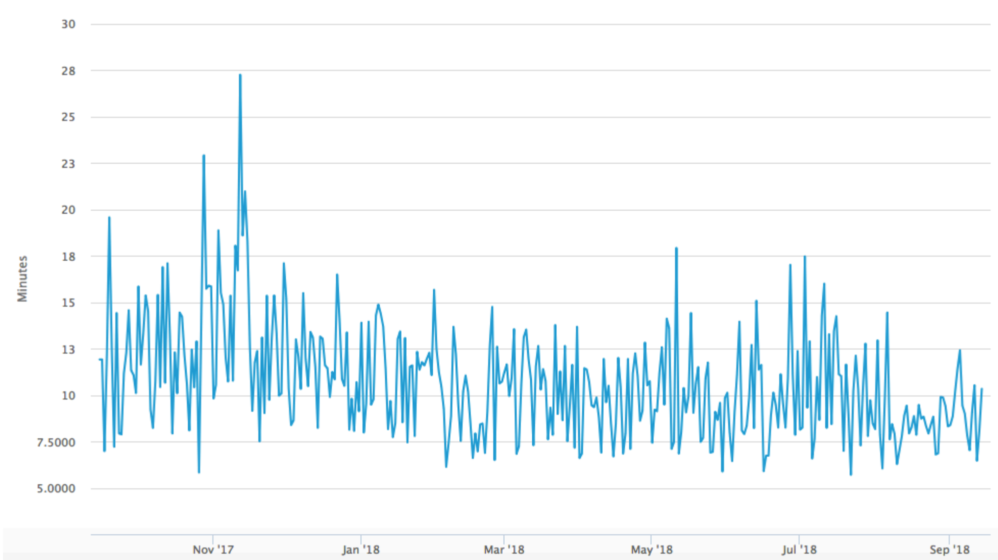


Figure 22. Median confirmation time for Bitcoin. *(Source: blockchain.com, 2018)*

Possible solutions

As previously described, the suggested solution to reduce the energy consumption of a blockchain system is by choosing a consensus protocol that requires low energy power (e.g. PoS or PoA).

5.3 Required Legal Framework

In order for Blockchain in the energy sector to thrive, an appropriate legal framework is required. As it happened when the internet was created, when a system that is completely new, groundbreaking and disruptive, the aim of legal entities is to ensure the security, transparency and the integrity of transactions and participants in the system. These legal frameworks should protect the participants without limiting the system in a negative way, but help it thrive and develop, which is not always the case in some countries. The question also arises if regulations and taxes are implemented, will the prices remain competitive? Some of the regulations that any country where blockchain is being implemented should consider are listed below.

Regulatory Challenges and Limitations

Regulation for Prosumers as energy producers (electricity generation aspect):
Prosumers are energy producers, and thus need to undergo several requirements to be able to produce and send electricity to the grid. Power Firstly, there needs to be a definition of the range of electricity that a Prosumer can generate. According to the International Energy Agency (IEA) a residential Prosumer is considered anyone who produces electricity under 10 kW *(GfK Belgium Consortium, 2017).* However, there needs to be a standardized definition of a prosumer and their production limits that would separate them from small energy producers.

Parameters for interoperability for Prosumers (frequency):
Frequency is a very important topic in Grid balancing and stability. This is a very important topic that needs to be addressed and considered. Therefore, regulations on the specifications for the electricity fed into the grid by prosumers,

in order to maintain this balance and ensure the integrity of the entire electric system.

Regulation for prosumers to trade electricity (commercial aspect, license fees):

An important challenge to be considered is how the law will regulate Peer-to-peer electricity trading, since there is indeed a product (electricity), a seller (prosumer) and a client (consumer), and a payment (cryptocurrency), therefore making a transaction. As any other commercial entity, law needs to consider this type of transaction and be regulated, as there are regulations for Power plants and other energy producers. The ideal framework would take into consideration that the product being traded is "regional" and in small quantities, which should be considered in order to establish an appropriate taxation or regulation. Additionally, other

Regulation to tax the traded electricity:

Electricity is a product, and as a product there needs to be an existing legal framework in order to determine if as a product electricity traded in small quantities should be taxed (e.g. adding VAT).

Regulation for prosumers to ensure the correct use of the network and safety regulations:

As energy producers (even in a smaller scale) a section that considers the safety regulations that energy producers need to undergo in order to ensure the safety of the system and surroundings (e.g. specific safety installation and emergency procedures and guidelines) as there is for larger production plants, but tailored specifically to the prosumers' installation size and capacity. Additionally, the appropriate framework to determine the specific obligations and use guidelines for the Grid (when sending electricity to the consumer or the grid itself), in order to ensure its integrity.

Grid fee for prosumers:

As mentioned in the previous point, when setting the obligations of the Prosumer for the use of the grid, a specific fee (if applicable) need to be defined (e.g. a scheme where there are fee ranges that vary depending on the Prosumer yearly production and trade forecast).

Regulation to determine a sanction in the case of byzantine failure in a system:

Blockchain's most important feature is the fact that it can create trust in a trustless world. Therefore, when a blockchain is created, a legal framework should be created around it to ensure the trust remains. Therefore, specific penalties within a system should be legally backed in case if a byzantine failure.

Regulation to ensure the "unknown" nodes or users are not illicit:

Trust in a trustless world is ambiguous in Blockchain. In one hand, some consensus protocols allow absolut anonymity, which may lead to allowing unknown entities (who could have illegal backgrounds) to do financial, trade and other transactions, in many cases it could be used for money laundering or other illegal activities. Therefore, an appropriate legal consideration should allow users and nodes to maintain their anonymity to the rest of the participants, but the system should know their identity in order to ensure that the node that is being trusted in the system is a legal participant.

Regulation for energy consumption from Blockchain: European:

In order to be sustainable and energy efficient in the long run, a regulation for energy consumption in public blockchains needs to be considered. In 2018, the European Commission is considering ways to control Blockchain applications that require Mining (POW), due to the excessive amounts of electricity required for this type of consensus protocol. Although no legal basis exists to ban it, it is evident that the concern for electricity consumption is rising, and in the future it will probably be controlled. Therefore, a framework on electricity use should be considered especially for Blockchain energy applications since we aim for sustainability.

5.4 Social and Ecological Appraisal

Social Appraisal

From the social point of view, the implementation of blockchain systems enable individual consumers and producers to trade electricity in a semi-autonomous way. This freedom of independence allows new markets to grow and promotes competition and thus quality of the products offered by current energy suppliers.

This means that in the future, with the rise of prosumers and the awareness of clean energy from the consumer's side, utility companies will have to provide clean, feasible, quality and competitive products for consumers.

Additionally, the empowerment the individuals receive from these technologies, Peer-to-peer electricity trading in microgrids also has the potential of bringing electricity markets to remote areas where there is currently an unfeasibility for the grid to operate. Although a microgrid is still required, the benefit of not requiring a utility electricity supplier (which increases costs) would benefit smaller communities by bringing them access to electricity, which is one of the most precious commodities in modern times.

Furthermore, P2P energy trading systems based on blockchain also promote clean energy, which has the impact of a healthier community, by contributing to the air quality of the community and reducing pollution from electricity generation, but also enabling local trade. Local trade has enormous impacts on the community, with many economical benefits that will be further detailed in the economical appraisal.

5. Ecological Appraisal

One of the most debated aspects regarding Public Blockchains in the electricity trading sector, is to discuss mining, due to it's high electricity consumption. When a Blockchain network is Public, it usually uses PoW as a consensus protocol, in which a cryptographic puzzle is given to the nodes and they compete to crack the code, in order to add a new block, gain cryptocurrencies or validating transactions. In order to do so, the computer serving as a node, needs to solve these "mathematical equations" which requires a high amount of computing power (electricity to work), since the computers are sometimes running these algorithms 24/7 to increase their chances of being the first to crack the puzzle. *Figure 23 (next page)* shows the PoW Energy consumption index chart with the use of Bitcoin from February 4 – August 21, 2018.

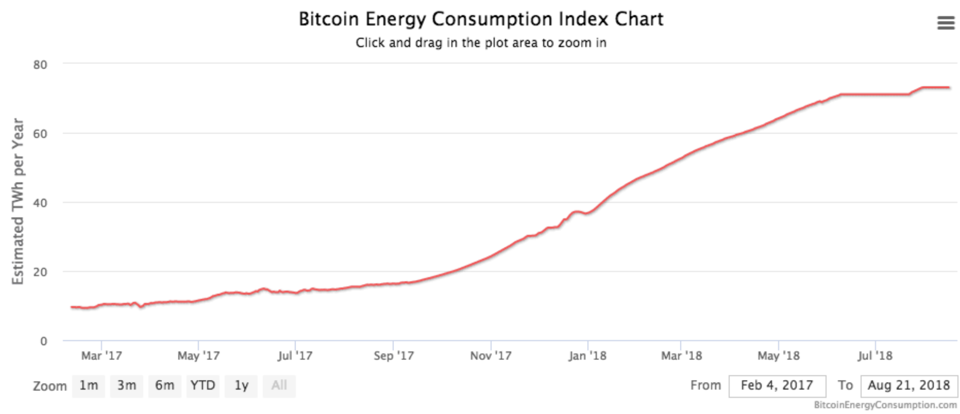


Figure 23. PoW Energy Consumption Index Chart. (Source: Bitcoinenergyconsumption.com)

Table 2 shows a comparison of the current estimated annual electricity consumption of 73.12 TWh used for Bitcoin mining, the revenues and cost of mining, among other interesting statistics. However, a very interesting comparison is the Number of U.S. households that could be powered during 1 day by the electricity used in one single Bitcoin transaction: 31.4 households (455.29 kt of CO2 per transaction). Furthermore, the annual carbon footprint estimated is 35,830 kt of CO2.

Table 2. Key Network Statistics for Bitcoin. (Source: Bitcoinenergyconsumption.com)

Description	Value
Bitcoin's current estimated annual electricity consumption* (TWh)	73.12
Annualized global mining revenues	$4,871,613,667
Annualized estimated global mining costs	$3,656,073,069
Current cost percentage	75.05%
Country closest to Bitcoin in terms of electricity consumption	Austria
Estimated electricity used over the previous day (KWh)	200,332,771
Implied Watts per GH/s	0.16
Total Network Hashrate in PH/s (1,000,000 GH/s)	52,203.00
Electricity consumed per transaction (KWh)	929
Number of U.S. households that could be powered by Bitcoin	6,770,506
Number of U.S. households powered for 1 day by the electricity consumed for a single transaction	31.4
Bitcoin's electricity consumption as a percentage of the world's electricity consumption	0.33%
Annual carbon footprint (kt of CO2)	35,830
Carbon footprint per transaction (kg of CO2)	455.29

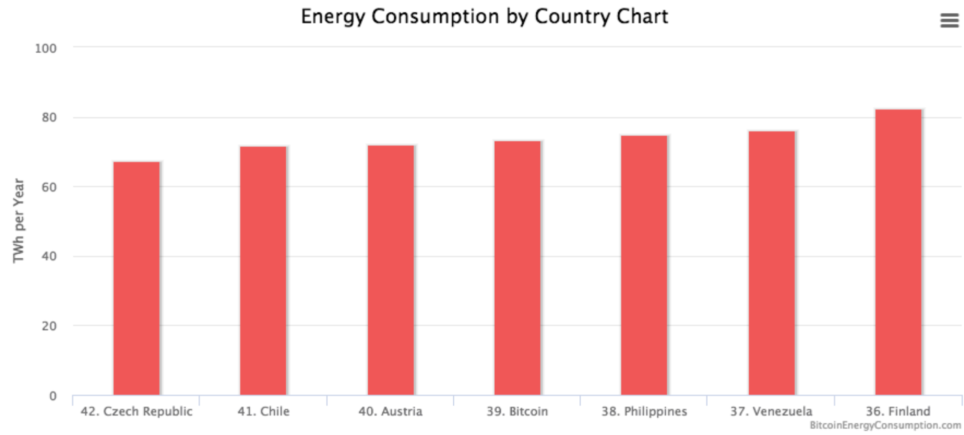


Figure 24. The overall Bitcoin energy consumption compared to other countries´ total consumption. *(Source: digiconomist.net)*

Figure 24 on the other hand ranks Bitcoin's total energy consumption due to mining and ranks it among some of the most energy consuming countries. In this comparison, we can observe that the Bitcoin total energy consumption has already surpassed the total energy consumption of the Czech Republic, Chile and Austria, and it can be estimated, that within a year, this energy consumption will increase exponentially.

Table 3. Examples of Recent Bitcoin ASIC Miner Machine types. *(Source: Joule, 2018)*

Machine	Hashrate (TH/s)	Power Use (W)	Power Efficiency (J/GH)
Antminer S9	14	1,372	0.098
Antminer T9	12.5	1,576	0.126
Antminer T9+	10.5	1,332	0.127
Antminer V9	4	1,027	0.257
Antminer S7	4.73	1,293	0.273
AvalonMiner 821	11	1,200	0.109
AvalonMiner 761	8.8	1,320	0.150
AvalonMiner 741	7.3	1,150	0.160
Bitfury B8 Black	55	5,600	0.11
Bitfury B8	47	6,400	0.13

Source: Bitmain, Bitfury, and Canaan.

Table 4. Estimated lifetime costs for an Antminer 59 under various lifetime assumptions and a production cost of US $500 (Assuming electricity costs US 5 cents per kWh). *(Source: Joule, 2018)*

Machine	Expected Lifetime (Years)	Estimated Production Costs (US$)	Lifetime Electricity Use (kWh)	Lifetime Electricity Costs (US$)	Total Lifetime Costs (US$)	Electricity Costs/Total Costs (%)
Antminer S9	2	500	24,037	1,202	1,702	70.6
Antminer S9	1.5	500	18,028	901	1,401	64.3
Antminer S9	1	500	12,019	601	1,101	54.6

When these figures are observed, it raises questions about whether or not it would be feasible or even sustainable to implement this system in a P2P electricity trading system. The reason in Bitcoin's specific case is, of course, the fact that mining and the value of Bitcoin in the market, is very lucrative, as it leads the cryptocurrency markets. Therefore it can be imagined that people want to participate and earn money from it. However, the energy consumption from Bitcoin comes from the consensus protocol that it uses. In other words, the energy consumption for P2P electricity trading systems can be abysmally lower, considering a different Consensus protocol.

A Feasible Solution for Public Blockchains

Recently In the Blockchain applied to the electricity sector, a higher acceptance has been adopted and being developed. With Ethereum's new platform Casper, which aims to use "PoS" as its consensus protocol, it is feasible to run a Blockchain based system, since PoS proposes a consensus where the validating nodes in a system are chosen through its "Power or wealth" within the system and not through the computing power race that PoW promotes. Another feasible solution has been previously described, PoA (Proof of Authority), which was born from the PoS concept and allows a larger amount of transactions per second at a much lower electricity consumption compared to PoW. *Figure 25*, gives a brief and simplified overview of the main differences between PoW and PoS.

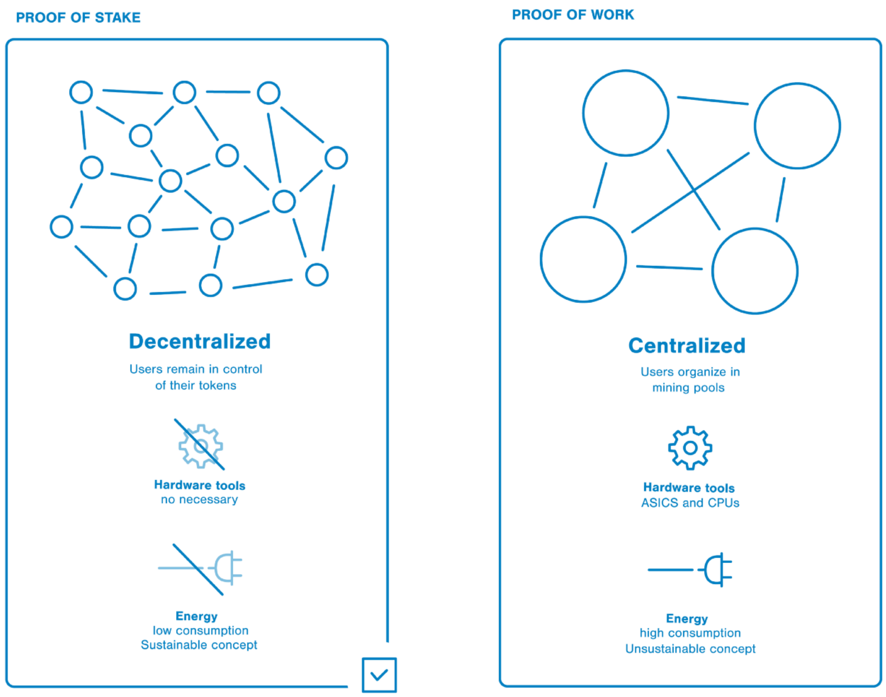


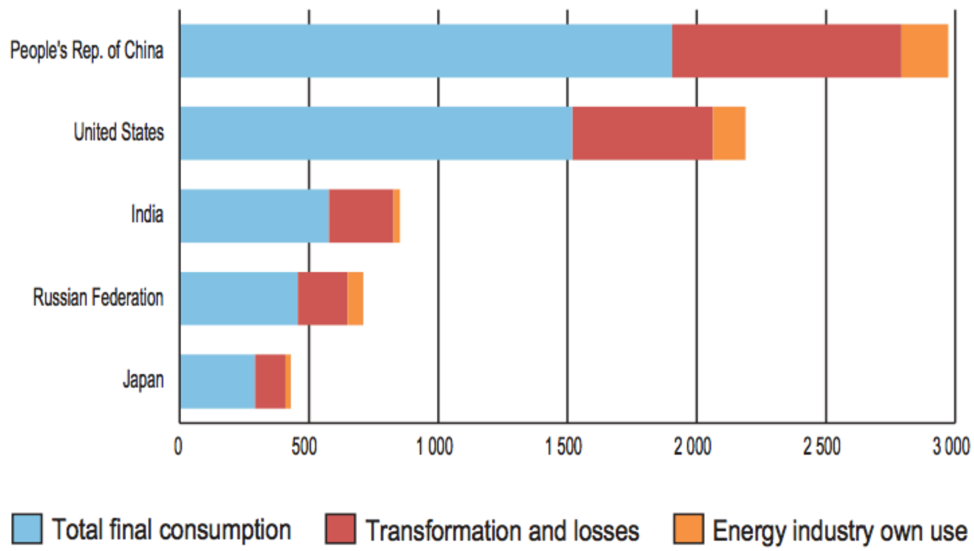
Figure 25. Main differences between PoS and PoW. (Source: Unidentified)

5.5 Economical Appraisal

Larger Scale economical and energy losses impacts:

Electricity trade today needs to travel long distances from the producer to the consumer. This causes power losses in the trading sector, mainly through the lines and electric transformers. The economical impact of energy losses not only affect suppliers and the final cost of the product, but it also affect the consumer, since the increase in the price has to be borne by them. According to Costa-Campi et. al. based on Worldbank data, Spain had total energy losses of 8.9% in 2012, which resulted in € 1,160. Additionally, other countries in the same year showed similar losses, U.K.: 7.92%; Germany 3.94% and Austria 6.9%. *(Costa-Campi, et al., 2018)*

Figure 26 shows the top 5 countries by total energy supply, the red area in the bars show the energy losses (from transformation and others, which include



energy losses from supply as well). P2P electricity trading operating on a blockchain system has the possibility to reduce energy losses from transit through the grid. Since distances are much shorter, there are fewer losses in trading, thus making the trading processes more energy efficient under this scheme and helping build a healthier and smarter grid overall.

Figure 26. Top five countries by total energy supply TPES in Mtoe. (Source: IEA Key Energy Statistics 2017)

Small-scale economical impacts:

The activation of prosumers as a participant in energy markets has several economical impacts in different levels. The first one is that it activates and enables small producers to trade their products with small clients, thus activating smaller-scale local economies. This has a direct positive impact for prosumers, since they are now involved in an economical activity, boosting then their own participation in the market and earning money for it, thus activating micro economies. The consumer is also benefited economically in this aspect, since it can choose price ranges that he considers fair or affordable for him while having the security that the product they're buying comes indeed from renewable sources and a local provider.

Investment Costs for a Residential10kW PV rooftop System

Considering the average prices in Europe for Residential PV systems (about €1,100/kWp installed), we can assume that the cost of 10kW would be ranging the €13,500 (excluding VAT). Additionally, the installation of a storage system, which has an average cost of €5,076 (considering a Tesla Powerwall 2), the Smart computer like TransActive Grid, which price is still not available, as it has not been commercialized yet, but considering Verv's Smart Home Energy assistant price, we can assume a price range between €280 - €350. Therefore, the overall system per node (excluding installation costs and VAT) would cost in average around €18,856 - €19,000.

Shared PV Rooftop systems Investments:

A good option for cost reduction is sharing the investment of a PV system between 2 or more households interested in producing, self-consuming and trading electricity. However, in order for this to be feasible, a study of the average electricity consumption of each household needs to be undertaken in order to accurately choosing a system that will allow them to self-consume the electricity required for their activities and still have surplus electricity to trade. The benefit of sharing this investment, regarding the fact that the system may need to be bigger, is that economies of scale can be taken advantage of, since installation costs and prices for a larger amount of modules might be beneficial under this scheme.

5 PRESENTATION OF RESULTS

The presentation of results is presented in the form of a summary of what has been considered to be the best option in each of the sections described in this master's thesis and what are the suggested applications within the P2P electricity trading system based on a blockchain technology in order to improve the overall efficiency of the system.

An efficient blockchain P2P electricity trading system should be public to maintain the openness of the system and allow access to anyone who wants to participate in trading or buying electricity. However, is should use PoA/PoS as its consensus protocol, in order to allow a higher amount of transactions per second and reduce the electricity consumption. The use of smart contracts is vital in order to smoothen transactions; therefore it is important to feed the contracts with the correct information when creating them, in order to prevent mistakes.

Additionally, every node needs to be efficient as well, in order to optimize the entire network. Therefore, smart metering, home assistants and further required energy efficient devices should be implemented, in order for every node to have an efficient use within their household and allow the system and the nodes to be demand responsive to changes in the grid. Furthermore, the information provided to the grid is paramount. There cannot be a microgrid or any form of physical energy exchange without the grid. In order to use the grid responsibly, information should be sent to the DSOs and TSOs, in order to help them balance the grid and be able to forecast and cope with the rise of prosumers interacting with the grid. The use of a battery is highly recommended, since the generation of electricity usually takes place during the day, when there's usually not demand from households (although thee may be a demand from businesses). Nevertheless, trade is determined by demand, and demand depends on the consumer's needs, which may or may not be during the day.

Another important aspect to consider is determining the payment methods. The methods I consider to be easier and economically attractive are linking a currency with a cryptocurrency, in order to stabilize its value. The second option I consider to be interesting is the green certificates option, as long as they are not retained for long periods of time before selling them, since they depend on the renewable energy demand and may eventually lose value.

There is still more information to be calculated for the economical assessment, due to the fact that most of the projects being developed are still not commercial and their pilots have been mostly financed by different institutions in order to further learn and develop the technology. Therefore, it is quite difficult to put a specific price on how much each node will require to be part of the system. However, we can assume that the investment costs per node would be slightly higher to the cost of a rooftop PV Installation and a battery storage system (which are the highest expenses).

The results of the ecological appraisal show that the main reason why blockchain can be really expensive is due to mining, as it takes a massive amount of energy consumption. The solution for this problem is changing the consensus protocol from PoW to PoS/PoA. This will have a massive reduction in energy consumption in the system and is vital for the system to be as sustainable as possible.

6 CONCLUSIONS

After this extensive research that has taken approximately 6 months, I have heard many people speaking of blockchain applications that are not really applying blockchain technology; expressions such as "blockchain is a hype" have been in every discussion of blockchain. However, as any other disruptive technology, as it was the rise of the Internet, I find it to be a very interesting solution to allow decentralization in many different aspects of our lives.

The energy infrastructure today, has been created over time over decades and decades. The grid today and its balancing is so complex, with the rise of so many actors, from renewable energy sources, prosumers connecting into the grid. However, I think the only way to truly create "smart grids" is through interconnected decentralization. In other words, allowing local markets to produce and trade renewable energy in given areas (microgrids), but still with an interconnection with DSOs and TSOs in order to have a better communication, allow better planning and forecasting, becoming demand responsive consumers and to be able to unite in case of disasters.

Every disruptive technology has a greater purpose, either to allow free access to those who cannot afford paying for access, or to open sources and participate in order to create something greater. This is the opportunity blockchain gives us, not a hype, hypes cannot transcend. However, if we invest in projects, research and develop these technologies, the right applications will follow. Peer-to-peer electricity trading is the beginning of many changes that blockchain will enable in the electricity sector, and if we are wise enough to research and collaborate, this may be the beginning of creating smarter energy systems that are smart from the consumer to the TSO.

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GLOSSARY

Blockchain: A cryptographically secured distributed network, which shares data and transactions simultaneously throughout its interconnected nodes.

Bitcoin: A type of digital currency (cryptocurrency) that uses Blockchain as its driving technology.

Consensus Protocol: An encoded process in software by which nodes in the Blockchain reach a common agreement about a set of data. *(MIT TRE, 2018)*

Cryptocurrency (Token): A digital asset or currency resulted from solving a puzzle called mining in Blockchain, which can be exchanged in the same system. *(MIT TRE, 2018)*

Proof of Work (PoW or Mining): A consensus protocol used by Bitcoin and other cryptocurrencies. In order for a new block to be created, miners must calculate a hash for it that meets certain narrow criteria. The purpose of mining is to validate transactions (avoid double spending) or to create new validating blocks in the blockchain. *(MIT TRE, 2018)*

Proof of Stake (PoS): A consensus protocol used by Ethereum's Casper implementation, in which nodes can validate on the basis of their existing economic stake. *(MIT TRE, 2018)*

Proof of Authority (PoA): A consensus protocol used by the Energy Web Foundation, it is derived from PoS, but allows a larger amount of transactions (approximately 1,000,000) per second.

Byzantine Fault tolerance: The capability in a distributed system to bear a fault, without compromising the entire system. Such faults could come from a malicious, compromised or dead node which if not dealt with, could prevent the entire system from reaching agreement.

Smart Contract: First proposed by Nick Szabo in 1994, a Smart contract is a computer program operating within the Blockchain system, which is able to move assets from one account to another if the conditions encoded in it are met. *(MIT TRE, 2018)*

Hash: A cryptography function that turns any input of data into a string of characters that serves as a virtually unforgeable digital fingerprint of the data. *(MIT TRE, 2018)*

Double Spending: A transaction that uses the same input or data as an already broadcast transaction. The attempt of duplication, deceit, or conversion, will be adjudicated when only one of the transactions is recorded in the blockchain. *(Bitcoin, 2018)*

Crypto Economics: The study of economic interaction in adversarial environments. It is aimed to combine cryptography and economics in order to create robust P2P networks that can thrive regardless of corrupting attempts. *(Tomaino, 2017)*

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PoW	Proof of work
PoS	Proof of Stake
PoA	Proof of Authority
PoI	Proof of Identity
DAO	Decentralized Autonomus Organizations
IoT	Internet of Things
IRENA	International Renewable Energy Agency
REN	Renewable Energy

SoG-Si	Polycrystalline Silicone
DSOs	Distribution System Operator
TSOs	Transmision System Operator
P2P	Peer-to-peer
CSS	Central Storage System
TE	Transactive Energy
DER	Distributed Energy Resources
DC	Direct Current
AC	Alternating Current
HVDC	High Voltage Direct Current
Blockchain-P2P-ETS	Blockchain Peer-to-peer Electricity Trading System
dApps	Decentralized Applications
IT	Information Technologies
TPM	Trusted Platform Module
TEE	Trusted Execution Environment
SE	Secure Element
kW	kilowatt
kWh	kilowatt-hour
kWp	Kilowatt-peak
DLT	Distributed Ledger Technologies
SHA-256	Secure Hash Algorithm 256
ID	Identification

9 APPENDICES

Appendix 1. Experts Questionnaire Guide.

Experts Questionnaire

Blockchain in P2P for Electricity transmission

1. What is the main reason that motivates you to work on a Blockchain application for P2P electricity distribution?
2. What is your project about?
3. What stage is your project in? (E.g. Concept, Proof of Concept, Pilot, Partly Functional, Fully functional).
4. What does your project solve? Benefits or Problems tackled.
5. What type of Blockchain are you using in your P2P application? Public, Federated, Private? How does it work?
6. What challenges (technical, economical, practical) did you have to overcome, or are still trying to overcome?
7. In the technical side, what are the challenges of turning the concept into a reality?
8. In your Blockchain P2P energy trading system, how does the voltage balancing with the grid happen?
9. How will your Blockchain application help the energy and voltage balancing of the grid in a P2P application (for a Balancing Operator)?
10. How will you prevent excessive or uncontrolled electricity traffic in the microgrid area? Is the information of production / consumption within the microgrid sent to the TSOs?
11. How will the Balancing Operator be able to handle the electricity from Prosumers once the technology grows?
12. What sorts of algorithms are needed in the design of your Blockchain system?
13. Do you have a study for your system to understand the amount of electricity required (kW) to send 1kW of electricity in a P2P trading? Is it feasible? Do you have measurements?
14. What is an approximate on investment costs to build the Blockchain P2P Electricity trading system?
15. Is it feasible for a prosumer to participate in a Blockchain based P2P Trading system? How much does it cost for a participant?
16. What is the most expensive part on the process of making a transaction?
17. What is the most expensive component(s) when building the network? (E.g. software, expertise, smart meters and other components)
18. What capacity do the nodes (the computers) need to be able to store the information in the Blockchain? Do you need several external data storage devices (if so, who keeps them)?
19. Have you considered using a cloud system instead of computers to store the data (like the one offered by IBM)? Do you think this solution would go against

the "No-middle man" objective of the Blockchain (if so, to what extent? E.g. absolutely against it, necessary for the moment)

20. Do you think this concept would help reduce electricity consumption?
21. What regulations (legal frameworks) are required (regardless of the country) to allow/facilitate a Blockchain P2P electricity-trading system operates?
22. How are prices set in your P2P electricity-trading model?
23. What currency do you use to do the transactions? (Cryptocurrency, special energy coin)
24. How do you acquire this currency? PoW, PoS, other? Are you using an existing one (E.g. Ethereum)?
25. Advantages and Disadvantages of your application?

Appendix 2. Comparison of common Cryptocurrencies value.