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Master's Thesis

A BLOCKCHAIN TO TRADE ENERGY IN EUROPE: COST REDUCTION ANALYSIS

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ABSTRACT

The external cost per trade is gaining importance in energy trading companies as profitability is being reduced due to the increment of small volume transactions, at a reduced price and on a shorter term, with the expansion of Renewable Energy Sources as main driver in the background.

Blockchain, a relatively new technology which promises a realm of no transaction costs among other advantages, could help to mitigate this unprofitable development by removing some charges, mainly those paid to intermediaries, such as clearing and exchange fees, broker fees, access to an exchange, index agencies, OTC electronic platforms fees, etc.

This work aims to clarify the role that a blockchain could play in energy industry by focusing on wholesale energy trading and the costs that this technology could save to each type of market participant. A cost comparison between the German EPEX SPOT and a blockchain infrastructure which could provide the same level of service is developed in detail.

The expectation of the trading community is analysed thanks to a survey to the energy trading community. This poll tries to gather the opinion of experts on the many questions around the use of a decentralized ledger technology to trade wholesale energy.

Many of these questions are related to the compliance of this technology in current European Energy Markets Regulation. These rules are reviewed and analysed in regard of the application of blockchain in wholesale energy trading.

Finally, it is concluded that the use of the new technology in this field could be a cost efficient tool for energy trading companies provided that the regulation is adapted to fulfil its many requirements. The results of the survey go in line with the rest of this research.

Acknowledgement

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I would like to thank the respondents to the survey, who dedicated their time and experience to contribute to this research.

Finally, I would like to acknowledge the support provided by my family during the preparation of this Master Thesis. To my parents, Chari and Jesús, who are always present in spite of the distance. Specially to my wife, Cristina, who has been extremely supportive of me through this period and has made countless sacrifices to help me get to this point. My son, Jaime, from who I received the most important motivation which is his joy and love. Without them behind me, I do not believe I would be here today.

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1.1. Motivation

The European Union (EU) set ambitious targets in 2007 in order to tackle climate change challenges and to boost competition for green technology businesses operating in Europe: reduction of greenhouse gas emissions by at least 20 percent (or even 30% depending on further agreements) compared to 1990 levels, increment of the share of renewable energy sources (RES) to at least 20 percent of energy consumption, and energy savings of 20 percent or more by means of energy efficiency initiatives [COMM07].

As renewable penetration rises towards 20 percent and beyond and due to its intermittent nature, more significant changes in the energy system will be needed. The stability of the grid will suffer due to an increase in renewables, transmission operators will have to find new ways to integrate or use energy flows from the distributed grid. The design of the wholesale market will also be impacted while enabling a clean and secure energy transition.

Nowadays only suppliers, generators, traders and large direct consumers, a relatively recent novelty, are active in this market. In the near future, market rules will be adapted to allow new market participants to be active in the wholesale market. This will be the case of prosumers which would need to sell small volumes of energy many times during a single day in order to adapt to their renewable energy generation assets and changing consumption. But even today, with increasing tightening margins the reduction of the cost per trade is paramount to make classical trading houses economically sustainable.

In the coming years, the integration of variable renewable energy sources (VRES) and the access to any participant, no matter its size or nature, to energy markets will be accomplished through the deployment of new technologies across the energy value chain.

A rather new technology as blockchain could function as a digital enabler of this shift to decentralization and distributed energy generation. Blockchain allows transactions to be recorded between two parties efficiently and in a verifiable and permanent way. It can also be programmed to trigger transactions automatically with the help of smart contracts. Blockchain projects deal among others with radically speeding up transactions and cutting costs by establishing trust and transferring value without the involvement of traditional intermediaries. The main advantages of the technology can be listed as follows: disintermediation (enabling lower to neglectable transactions costs) and process integrity (reduction of counterparty risk given that the value is transferred immediately), empowerment of prosumers, high quality data (incorruptible), durability and reliability (the records are almost impossible to be hacked), transparency and immutability, simplicity for new services, standardization and faster transactions.

An IT infrastructure based on blockchain could allow participants in the energy wholesale markets to trade power and gas in a decentralised way where central market roles such as brokers, exchanges, clearing houses, settlement operations, etc. are not needed any more.

Operating a distributed system is potentially more affordable than operating a central platform like that of a power exchange given that the classical organization structure is not needed any more: management, market control, market supervision, regulation, legal, market support, compliance, IT, sales and marketing, business development, etc.

In this peer-to-peer trading scenario with no market operator in the middle, transparency is assured because the price signal is shared by all participants while their identity is not revealed thanks to the technology and the security it provides by design.

1.2. Problem Description

In the past, energy-trading companies were focused in a low- to mid-volume business with appealing margins while investment banks with a different nature of business at its core were focused on equity, fixed-income, and foreign-exchange trading which are a high-volume but low-margin one. The relatively higher cost per trade was not a big problem for energy-trading companies, there was not an overwhelming incentive to be more efficient in all processes involved from front office (trading), middle office (risk management), back office (settlement), IT and all other areas involved.

However, in the current time, with low margins and lower traded volumes considering energy derivatives and spot markets, efficiency is gaining importance with the final goal of reducing the cost per trade and keep being profitable.

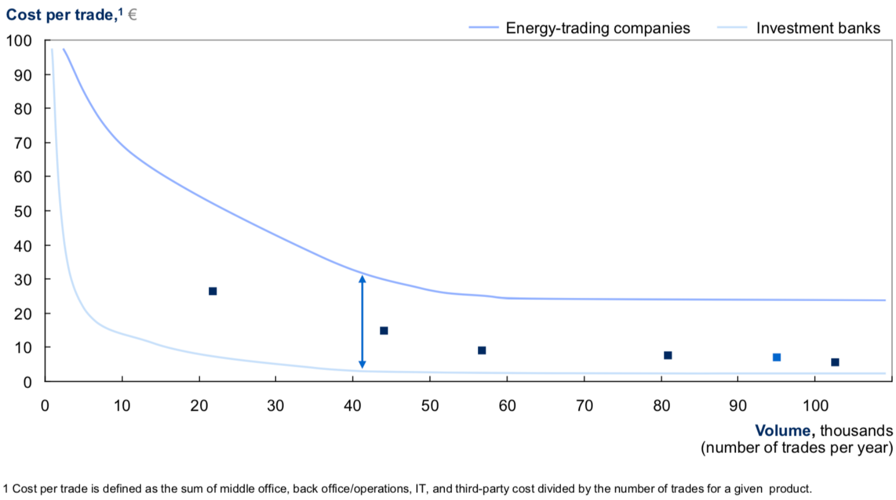

Figure 1 Cost-per-trade for energy-trading companies and for investment banks. Source: [HEIL13]

According to [HEIL13] there are five areas of complexity that could be improved in order to boost efficiency and consequently reduce internal cost per trade:

- **Product and commercial complexity:** sales and origination is one of the areas with more potential for optimization by using standard contracts instead of thousands of non-standard contracts which jeopardize profitability and increase operational risk by adding process and compliance costs.
- **Support and control complexity:** review processes in back and middle office by automating and standardizing as much as possible.
- **IT complexity:** reduction of IT complexity by consolidating systems and being sure which projects really add value to the company.
- **Organizational complexity:** overly complex organizational structures often generate unnecessary layers or overlapping activities, leading to slower decision-making processes. A simple organization with empowerment and clear responsibilities may bring more value to the company.
- **Location complexity:** a rationalization of locations must be endured in order to reduce operational cost and legal complexity.

However, not only the internal cost per trade must be taken into account in searching for efficiencies. The external costs are among others the clearing and power exchange fees, broker fees, trader admissions, index agencies, electronic platform fees and other service. These costs can also provoke in the short term that the energy trading company is not profitable any more.

Hence, new strategies and tools must be enquired in order to ensure the survival of the organization, not only tackling the problem of internal costs but also encouraging to reduce the external costs of trading.

1.3. Objective

The main research goal is to know if a blockchain infrastructure could replace the classical wholesale market model, not only the one based on power exchange but also the classical OTC with its many intermediaries. The study will be focused on Germany and on current wholesale market participants. From the results it will be distinguished whether the conclusions can or cannot be translated to other European markets.

Therefore, the following questions will be answered:

1. Is this new infrastructure feasible? To answer this question, two new group of sub questions arise:
    a. Cost analysis of the new infrastructure in comparison to the existing power exchange focusing on transaction costs:
        - Could this new infrastructure be more affordable for classical wholesale market participants?
        - Will the renewables expansion impact the need for a more affordable mechanism to trade energy due to tightening margins and increment of traded volume?
        - What would be the effect of this new infrastructure on end consumers?
        - What business model should be implemented so the new infrastructure is more attractive to participants?
    b. Marketing research:
        - Would this new system be accepted by current wholesale market participants?
        - Are the participants ready to embrace this disruptive change?
2. What aspects must be resolved before implementation? To answer this question, the following sub-questions arise:
    - What type of regulatory changes would be needed?
    - Is it necessary to develop a new regulation?
    - Are there any other issues and limitations?

1.4. *Description of the Methodology*

The assumption for a distributed blockchain infrastructure is that the external cost of trading must be considered but it would be much lower than the traditional marketplace costs. Therefore, the following methodology will be followed to compare prices between the classical model and the new infrastructure based on Power Markets operating in Germany but with the sufficient standardization to be applied to any other European

Market:

1) Cost analysis research:
   - Cost analysis of the classical central wholesale market model, specifically the German EPEX SPOT.
   - Classification of wholesale market participants depending on volume, number of transactions and products into three different groups: small, medium and large.
   - Cost distribution according to the previous classification.
   - In the classical central wholesale market validate through correlations if there is an increment of the amount of transactions due to the rise of VRES production.
   - Cost structure of the new infrastructure: pricing for using the infrastructure should be based on flat annual fees instead of variable MWh-based fees or per-transaction fees. This cost reduction depends on the number of markets where a participant is active, the traded volumes and the total number of transactions. Small participants will be able to take part in it because the platform cost should be affordable for them. The cost structure will be computed taking into account the following Capital and Operative Expenses accounts (CAPEX and OPEX):
     - Initial development costs (consortium effort).
     - Operating costs.
     - Maintenance costs.
     - Support costs.
     - Evolutionary development costs.
     - Legal consulting.
     - Governance costs.
     - Etc.
   - Business model: a business model to develop this infrastructure will be discussed taking into consideration that such an infrastructure with blockchain at its core can disrupt existing business models: power exchanges, brokers, clearing houses, market indexes. The main hypothesis is that the charge for using this infrastructure will be based on a flat rate depending on the market participant size instead of the classical volume and transaction fees.

2) Marketing research: acceptance by users

A quantitative marketing research will be conducted to validate the industry acceptance of this initiative following this process:

- Initial contact of potential end customers, that is, members of energy trading companies.
- Research brief.
- Research proposal.
- Data gathering.
- Data analysis and interpretation.
- Report and explanatory results.

The results will clarify if this infrastructure is economically viable and can succeed in the new energy economy.

3) Analysis of the regulatory impact

An understanding of the regulation which applies on current wholesale markets will be reviewed, mainly EMIR (European Market Infrastructure Regulation), REMIT (Regulation on Wholesale Energy Market Integrity and Transparency) and MiFID II (Markets in Financial Instruments Directive). The potential regulatory impact will be discussed as well as which regulation should be adapted or reinterpreted given the features of the new infrastructure.

1.5. Document Structure

In chapter 1 an introduction of the problem is stated. It also comprises the description of the motivation that substantiates this work as well as the objectives and the methodology employed that will be used to achieve them.

The European wholesale power market is described in chapter 2 with a special review of the spot and OTC markets. This review will help understand how the new blockchain technology could disrupt the centralized market model as well the economic theories that underlies this shift. The blockchain technology will be explained as well as its different types. Although blockchain is at its early stages of development, several case uses in the energy industry will be described. From a theoretical perspective, the potential improvements to the value chain of the energy trading company will also be considered. Ending the chapter, a review of the industry's expectations in relation to the blockchain will be documented.

The cost analysis of a traditional power market, specifically a spot power exchange, and the new technology potentially replacing it, will be presented in chapter 3. Furthermore, a classification of market participants and a business model where those will be able to join the platform by paying flat rates instead of volume and transaction based fees. The impact of renewables in these markets will also be discussed. The conclusion of this chapter will clarify whether the new technology can reduce costs to market participants.

In chapter 4 the results of the electronic survey to employees of the main energy trading companies of Europe will be presented. This analysis will shed light on the willingness of the industry to accept the new technology and confront the opinions on how a blockchain could improve processes and efficiency in the energy trading business and to the electric system as a whole.

The regulation which would apply to the new infrastructure will be examined in chapter 5. Power trading businesses in the European Union must conform to the regulation currently in force, mainly EMIR, REMIT and MiFID II which will be analysed in relation to the potential compliance issues that could result from implementing a blockchain to trade energy.

Finally, in chapter 6 the main conclusions of the study will be compiled and new fields of research in this matter will be proposed.

2. *The Traditional Power Market Model and a Blockchain to Trade Energy*

Chapter 2. Index

2.1. INTRODUCTION

In order to properly understand the potential benefits of the use of blockchain technology in wholesale power trading, first of all, a thorough review of the existing model must be taken with special emphasis on the spot and over-the-counter markets. Then, a brief review of the possible future designs of European Energy Markets is discussed with the goal to tackle higher amount of energy produced with renewables sources. For this purpose, the EU Winter Package will be used as the central hypothesis.

The main part of the chapter will be devoted to explain the blockchain technology, its many types and what benefits could bring to the energy industry, specifically with the implementation of this technology to improve or replace existing business models. A brief compilation of existing proof of concepts and initiatives in the electric power industry with blockchain at its core will be presented in order to place the use case of power trading in context. The 1937 Coase Theorem will be linked to the main potential benefit of the blockchain, that is, to reduce transaction costs in energy trading. Finally, an examination of the already released surveys questioning the industry about blockchain will be presented. This last section will be used to compare the results of the survey contained in chapter 4.

2.2. ELECTRICITY WHOLESALE MARKET

The wholesale market is comprised of the commercial transactions made by the demand and the supply of energy and the services needed by the System Operator (SO) to balance the system, mainly through the so called ancillary services and the operating reserves. These transactions are organized around a sequence of consecutive markets starting in a long term horizon before physical delivery to near real time operations when trading stops and the SO control the whole system, what is called the gate closure. The centralized trading takes place in the framework of a Market Operator (MO) [BATL13]. The MO is the intermediary of any transaction, that is, if a counterparty sells energy the MO is the buyer and vice versa. This allows all the counterparties to remain anonymous and reduce credit risk being the MO the only counterparty.

In Europe these markets follow this sequence:

- **Long-term markets**: offer hedging mechanisms for producers and consumers and are also used by arbitrageurs and speculators who increase market liquidity.

- **Day-ahead markets (DAM)**: the market participants with energy demand or supply not committed in a bilateral contract present their bids and offers in the day-ahead auction. The clearing of this auction takes place and the result is the preliminary schedule for the day after it has taken place. The volume of bilateral contracts is added and the SO approves if it is feasible considering the transmission network.

- **Intraday market (IM):** after DAM and starting in the same day of its celebration, the market participants can balance their position in the so called intraday market. This market can consist in one auction as in EPEX SPOT or several auctions as in Iberian OMIE with six sessions. Besides, there is an intraday continuous market where like in the case of Germany electricity can be traded for a delivery on the same day or the following day on single hours, 15-minute periods or block of hours. In June 2018, EPEX SPOT, GME, Nord Pool and OMIE along with TSO's from 12 European countries have started the XBID market to create a joint integrated cross-zonal market which allow market participants to trade out their intraday positions, not only with the national available Intraday liquidity, but also from the available liquidity in other areas of Europe [EPEX18] .

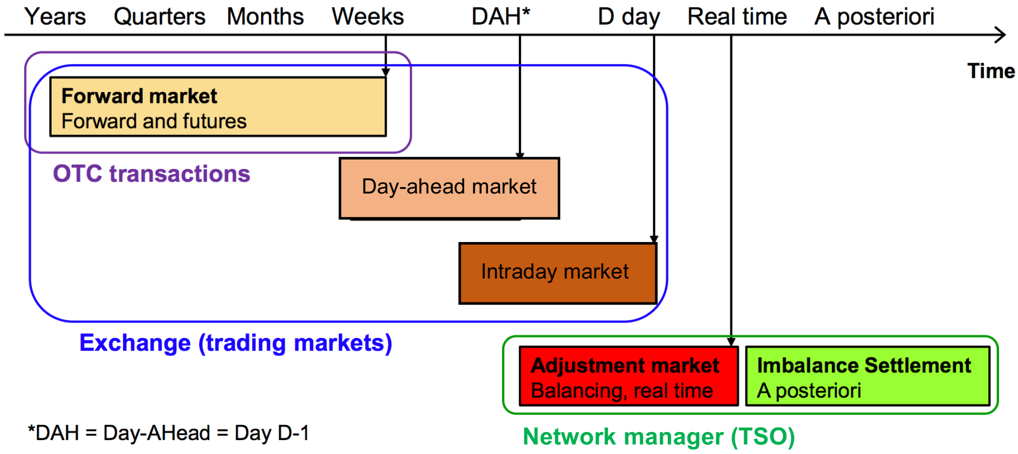

Figure 2 Electricity markets sequenced by maturity

Power Exchanges have a high level of standardization and only a set of products are traded. Automatization in these exchanges is high thanks to electronic platforms.

Another type of player in the electricity wholesale market is the clearinghouse which is usually connected to one or more exchanges and carry out the financial and physical settlement of energy transactions. They protect the system against counterparty default risk so if any participant defaults, the clearing house compensates the obligations of the troubled counterparty.

2.3. OTC MARKETS

In the over-the-counter market, each pair of counterparties reaches an agreement and concludes their trades independently revealing their identity to each other once the transaction has been executed. Generators and suppliers negotiate their contract terms outside an organized market and electric power is physically delivered [BATL13]. In this type of OTC, both parties assume the counterparty risk. This type of OTC is called bilateral or non-cleared. This flexibility makes the market less standard than the Power Exchange. The intermediaries that operate in this markets are the following:

- **Brokers**: organizations that link buyers and sellers applying a fee to each transaction. They do not cover the default risk of any of the counterparties involved.

- **Index agencies**: organizations that calculate the current market price for energy products, either on trading platforms or by contacting individual traders, and provide this pricing information to traders for a fee. Examples of these are Platts and Heren in energy and Bloomberg and Thomson-Reuters in markets in general.

Another important player in these markets are the **Standardization bodies** which specify the processes in energy trading. One of the advantages of bilateral contracts is that they can fit customized formats to match counterparty requirements. This also involves a disadvantage, because being the contracts less standardized they are more difficult to match with another counterparty. To enable these transactions, the European Federation of Energy Traders (EFET) standardize these contracts under the signature of a master agreement for the delivery and acceptance of electricity.

The other type of OTC is called cleared OTC, where cleared trades involve the imposition of a central counterparty. A third counterparty, that lies between the two counterparties to the trade, acting as counterparty to each original party, the Central Counterparty (CCP). The goal is to transfer to the CCP the counterparty risk held by each party to the trade.

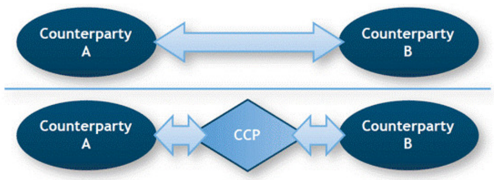

Figure 3 OTC bilateral (non-cleared) vs OTC cleared

In chapter 3, the evolution of EPEX SPOT and power derivative (EEX and OTC registered) will be analysed in the case of Germany.

2.4. Future of Power Markets in Europe. EU Clean Energy Package

In the past years, worrying symptoms of inefficiency have appeared in the European power wholesale markets, the following are some examples: falling wholesale prices while generation costs are rising, closures of relatively new plants, financial problems for utilities which however have to invest heavily in the transition to a decarbonized generation, the frequent existence of zero or negative prices, market reform request for introducing capacity mechanisms to keep supply security, complaints from retail consumers about constantly rising prices, etc. Electricity markets are designed to reflect and optimise the cost structures of the conventional technologies from 20th century electricity systems but are not suited to the electric system of the 21st century where new RES technologies receive support schemes from outside the market while older technologies can only recover its investment from the market [KEAY16].

The EU Clean Energy or Winter package is an attempt to tackle the aforementioned inefficiencies and provide regulatory tools to Member States to keep going in the energy transition. The European Commission focuses on three aspects in regard to the wholesale markets: deregulation of the energy market, bidding zones and capacity mechanisms [GREE18]. Let us briefly review each one:

Deregulation: promote further deregulation by removing some of the direct and indirect subsidies that are already in place. While subsidies are needed to support the growth of renewables and to reflect fossil fuel externalities, they distort the electricity market and may in the future cause electricity shortages if the new generation mix cannot match the demand. In line with the open market philosophy, it was first suggested that the priority dispatch scheme, a form of indirect subsidies that promoted renewable electricity over other sources, should be removed from the market as well. It is established to be cancelled by 2020 and only used by new renewable installations. However, in case of grid congestion after 2020, renewable energy providers will be the last to be shut down and will receive proper compensation. Additionally, to balance their market advantages, renewable energy providers will gradually have to pay the Transmission System Operator for the deviation in their projected generation. Other deregulations have been proposed as well, such as removing the price cap on electricity in order to increase the consumer response in times of shortage and shortening the trading time frame to improve market reactivity. This last proposal would be favoured by the use of new technologies as the proposed in this study to counterbalance the cost of increasing transactions that could trigger this market reform.

Bidding zones: creation of larger bidding zones drawn on geographical areas with a strong transmission network infrastructure. These new bidding zones would allow electricity to be traded freely, at a uniform price and without capacity allocation. By contrast, trade between different bidding zones would be restrained in an effort to avoid transmission congestion. Blockchain would be neutral to this reform.

Capacity mechanisms: generalize the use of these mechanisms, already introduced by several European countries, to encourage investment in flexible power plants, such as hydroelectric, gas or coal, in order to ensure supply, in a context where RES gain market share (and make traditional generation plants inviable). Capacity mechanisms remunerate electricity suppliers for the generation capacity they provide to the grid, in addition to the electricity they produce. Most of the time, this supply is ensured by gas or coal power stations. In a capacity market, regular power plants remain economically viable and can remain as backup units to meet peak demand, while in an energy-only market they would be shut down as non-viable. Finally, stricter rules will be applied on the capacity mechanisms, so they will be used as a last resort solution for countries. There will be a European wide monitoring of the electricity supply's security so any capacity mechanism will have to be based on European, and not only on national, capacity. This parallel capacity market could also be partly running on an infrastructure like the one described in the following section, so the energy and capacity markets can be coordinated in parallel.

2.4.1. PROSUMERS

Prosumers are consumers which not only withdraw energy from the network, but also produce and inject energy into it. Although they are considered mainly as consumers they participate in energy efficiency and especially demand response (DR) programmes so they can also be named as producers since they provide services that the market needs with a given retribution. The definition of prosumers often describes consumers or other agents that rely on smart meters and solar PV panels to generate electricity and/or combine these with home energy management systems, energy storage, electric vehicles and electric vehicle-to grid (V2G) systems [LAVR17].

The Winter Package also refers to prosumers as active consumers: “a customer or a group of jointly acting customers who consume, store or sell electricity generated on their premises, including through aggregators, or participate in demand response or energy efficiency schemes provided that these activities do not constitute their primary commercial or professional activity” [COMM17].

As stated in [LAVR17] digitalization will play a key role by lowering barriers to entry to consumers. Local communities and small start-ups will lead the development of energy and related social innovations, for instance by trading energy on P2P digital platforms as the one presented in the following section and by the participation in DR. A decentralized P2P trading platform with low fees for entry as the discussed in this study could potentially integrate these prosumers into the wholesale market. The blockchain technology could also be used to coordinate several blockchain infrastructures, for instance, one P2P platform for direct purchase and selling of distributed energy resources connected to a P2P wholesale energy trading platform.

2.5. Blockchain

In this section a description of the technology will be performed considering the different types of blockchain and the most suitable one to the energy business case under study. Other early uses in the energy industry will also be briefly discussed. The economic theories which justifies the use of this technology will be succinctly explained. Finally, a deeper description of the use of Blockchain in energy trading will follow with a closing section devoted to the expectancy of the business members regarding to the impact of this technology in the industry thanks to recent surveys enquiring the community.

2.5.1. What is Blockchain?

Blockchain is a distributed ledger technology (DLT) which was originally designed to be the public ledger of all Bitcoin transactions [SWAN16]. This ledger or data base distributed among participants or nodes, having each node an exact copy of this data base, is cryptographically protected and is organized in blocks of transactions which are mathematically interrelated to each other. The attribute of immutability allows that participants that do not trust in each other can agree on the state of the copies of the ledger in each node without the need of a central authority [TAPS17] [PREU17].

A blockchain is composed of the following elements:

- **A node:** it can be a simple PC or a powerful virtual server running in the cloud. With independence of its computational power each node must run the same software and protocol to interconnect them.

- **Standard protocol:** it provides a common standard to allow the nodes to communicate with each other, similarly to the TCP/IP (Transfer Control Protocol/Internet Protocol) which make possible the Internet.

- **A Peer-to-Peer (P2P) network:** each node behaves as an equal to each other, without a fixed hierarchy of servers and clients because each node acts as a client and server simultaneously. This type of network enables direct data sharing between nodes in any format. No single party can shut the system down because the rest of peers remain interconnected.

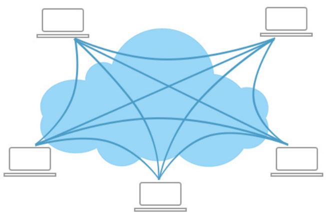

Figure 4 High level overview of a Peer-to-Peer network

- **Decentralized system:** in contrast to a centralized network where a central entity controls all information in a decentralized network all nodes control the network. This means that there is no hierarchy, at least in a public blockchain. However, in a private blockchain a kind of hierarchy can exist.

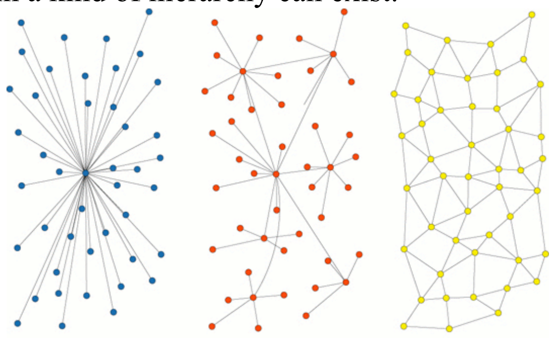

Figure 5 Network topologies: centralized, decentralized, distributed

A blockchain transaction consists generically in the following steps [FRØY16]:

1. **Transaction definition.** The sender creates a message and transmits it to the P2P network, which contains information on the value of the transaction and a cryptographic digital signature that confirms the authenticity of the sender, transaction, and receiver's address.
2. **Transaction authentication.** The nodes of the network receive the message and authenticate the validity of the message by decrypting the digital signature. The authenticated transaction is placed in a pool of pending transactions.
3. **Block creation.** One of the nodes in the network aggregates pending transactions in a block that contains consensual, replicated, shared, and

synchronized digital data. At a specific time interval, the node broadcasts the block to the network for validation.

4. **Block validation.** The validator nodes of the network receive the proposed block and validate it through an iterative process, which requires consensus from a majority of the network. This will be further discussed below in the consensus protocol paragraph.
5. **Block chaining.** If all transactions are validated, the new block is integrated into the existing Blockchain, and the new current state of the ledger is communicated to the network. Otherwise the block is dropped.

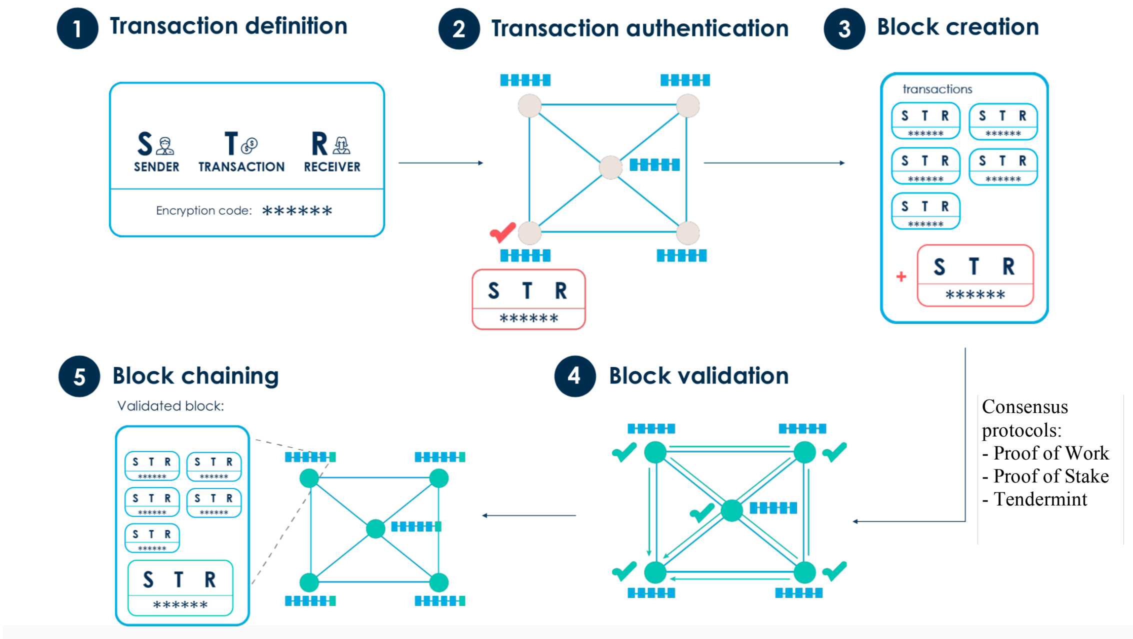

Figure 6 Generalized overview of a blockchain transaction [FRØY16]

The main characteristics of a blockchain are:

- **Cryptography:** generally, encrypting it is the process of converting ordinary information (called plaintext) into unintelligible text (ciphertext). In the blockchain, cryptography is essential to protect the identities of users, ensuring transactions are done safely and securing all information and storages of value. Therefore, anyone using blockchain can have complete confidence that once something is recorded, it is done so legitimately and in a manner that preserves security.

- **Blockchain ledger**: it is a ledger designed to record the data of participants. All nodes have the same rules and protocols so a block can be validated and join the chain of blocks when accepted by those rules. This removes the need of a central authority.

- **Consensus protocols**: provide an irrefutable system of agreement between various devices across a distributed network while avoiding the hacking of the system. The most common consensus protocols are the following:
    - **Proof of Work (PoW)** is the validation of the work and corroborate that it is correct. This is the way of consensus to make sure the authenticity of

the chain is good. Miners validate new transactions and record them on the blockchain earning a reward after having solved the complex mathematical problem or PoW. Its main drawback is that it requires more electric power and powerful computing hardware which is expensive and in the long term inefficient.

- **Proof of stake (PoS)** is an alternative way of verifying and validating the block. The creator of the next block is determined by a randomized system that is, in part, dictated by how much of that crypto asset a user is holding or, in some cases, how long they have been holding it. Instead of computational power, as is the case of proof of work, the probability of creating a block and receiving the associated rewards is proportional to a user's holding of the underlining token or cryptocurrency on the network.
- **Tendermint** is an open-source project to address the speed, scalability, and environmental issues of Bitcoin's Proof-of-Work consensus algorithm. It uses BFT (Byzantine fault-tolerant consensus) algorithm which enable that two nodes can communicate safely across a network, knowing that they are displaying the same data.

2.5.2. Types of Blockchain

There are three types of blockchain: public, federated and private.

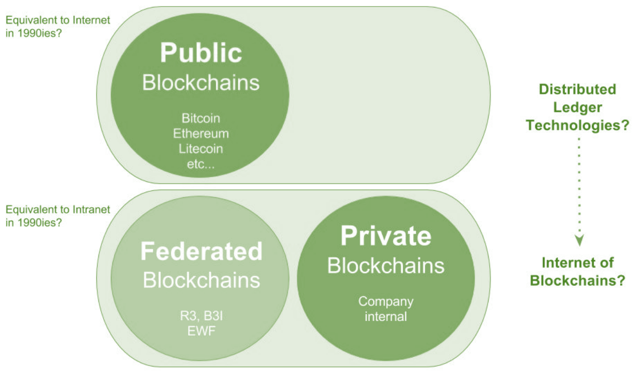

Figure 7 Types of Blockchain. Source: [BLOC18]

Let us briefly review each one according to [BLOC18] and [PREU17] description:

- **Public**: open source and not permissioned what means that anyone can participate without permission. Examples of this are Bitcoin, Ethereum or Litecoin. Its main characteristics are:
  1. Public, anyone can download the code and start running a public node on their local device, validating transactions in the network.
  2. Decentralized, anyone in the world can send transactions through the network and expect to see them included in the blockchain if they are valid. There is no hierarchy.
  3. Open, anyone can read transaction on the public block explorer. Transactions are transparent, but anonymous or at least pseudonymous (because their address can be traced).

	Public No centralised management	**Consortium** Multiple Organisations	**Private** Single Organisation
Access	**Open read/write**	**Permissioned read and/or write**	**Permissioned read and/or write**
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
Identity	• **Anonymous** • **Pseudoanomymous**	**Anonymity can be defined per design**	**Anonymity can be defined per design**
Transaction Approval Frequency	**Long** Bitcoin: 10 min or more	**Short** 100x msec.	**Short** 100x msec.
Asset	**Native Asset**	**Any Asset**	**Any Asset**
Capacity to disrupt traditional business models	**Disruptive** Disruptive in the sense of disintermediation. Unclear what the business models will be	**Cost Cutting** Can radically reduce transactions costs. Extreme cost cutting opportunities. Less data redundancy, higher transactions times, more transparency	**Cost Cutting** Can radically reduce transactions costs. Extreme cost cutting opportunities. Less data redundancy, higher transactions times, more transparency

Table 1 Types of blockchain and its attributes. Source [BLOC18] and own elaboration

- **Federated**: operate under the leadership of a group. Examples of this type are R3 (Banks), Energy Web Foundation and Enerchain (Energy), B3i (Insurance). It has the following characteristics:
  1. Private and closed, as opposed to public they don't allow any person or entity with access to the Internet to participate in the process of verifying transactions.
  2. Anonymity, they provide more transaction privacy which can be modulated by the design of the blockchain.
  3. Consensus, it is controlled by a pre-selected set of nodes; for example, a consortium of 15 financial institutions, each of which operates a node and of which 10 must sign every block in order for the block to be valid. The right to read the blockchain may be public, or restricted to the participants.

- **Private**: write permissions are kept centralized to one organization. Private blockchains are a way of taking advantage of blockchain technology by setting up groups and participants who can verify transactions internally. This brings the risk of security breaches like in a centralized system, as opposed to public blockchain secured by game theoretic incentive mechanisms but keep the security advantages of the cryptographic design of a blockchain. Example of this: Monax and Multichain.

2.5.3. Benefits of Blockchain

Blockchain brings technological and economic benefits due to its nature. These will be discussed briefly in this paragraph as a recapitulation of what has been presented:

- **Transparency**. All network participants share the same data as opposed to individual copies. That shared version can only be updated through consensus, what makes data more accurate, consistent and transparent than in traditional systems.

- **Security.** Every sequence of a transaction has an ingrained security architecture: from consensus before recording until encryption of the transaction and association to the previous one. This, along with the fact that information is stored across a network of computers distributed in different locations instead of on a single server, makes it very difficult for hackers to compromise the data.

- **Traceability**. When any asset is recorded on a blockchain, there is an audit trail that shows where it came from and every stop it made on its journey. This historical transaction data can help to verify the authenticity of assets and prevent fraud.

- **Efficiency and speed.** Blockchain has the potential to automate traditional paper based processes what allow transactions to be completed faster and more efficiently. Since record-keeping is performed using the same data layer, no reconciliation is needed any more. Clearing and settlement can take place much quicker because everyone has access to the same information, trust is established among participants and therefore, there is no need of intermediaries in those processes.

- **Cost reduction.** As stated in the introduction, many businesses, like that of trading energy companies, have a priority goal of reducing costs. The intermediaries in this type of network are not needed anymore because everyone can trust in his peer thanks to the blockchain.

2.5.4. Coase and the Blockchain

Professor Ronald Coase proposed in 1937 the model that underlies the Blockchain Economy. One of his main arguments [COAS37] was that there is a dynamic tension between those functions a company chooses to perform internally and those functions that it would choose to contract for externally. That is the same as to question, why do companies exist or why should a firm hire employees instead of contracting tasks. A company exists because it is cheaper to do some transactions within a company than outside. Corporations are vehicles for creating long-term contracts when short-term contracts require too much effort to negotiate and enforce. Blockchain has resurfaced this theory by considerably reducing transaction costs because it facilitates contracting in both the short and the long term.

Thanks to technology advancements mainly on telecommunications, specifically the Internet, the cost of outsourcing has lowered along the previous years. However, transaction costs still represent a huge chunk of the costs of doing business and when managing highly complex projects it's always easier to cooperate in person and face-to-face. Now with the Blockchain, the drop in transaction costs are going allow to more companies outsourcing to the market. The money saved can be reinvested to spur further economic growth. The new technology is also a long term menace for big companies based on traditional economies of scale which do not adapt to the new paradigm. They will have the complexity of size without the advantages of scale.

Coase also formulates in his theorem [COAS60] the economic efficiency of an economic allocation in the presence of externalities. His theorem states that if an externality can be traded and there are sufficiently low transaction costs, bargaining will lead to a Pareto efficient outcome regardless of the initial allocation of property.

The biggest issue is around negative externalities as they cannot can be addressed simply through price discovery mechanism between producer and consumer. This is why governments and courts exist.

Establishing trust is in itself a transaction cost, but transactions improve when trust is managed by the system and not by mediators, that is, a blockchain.

2.5.5. Use Cases for Blockchain in the Energy Sector

This section is dedicated to briefly account for the numerous cases of use of blockchain in the value chain of the electric power business.

Since 2016 there have been an exponential growth of energy companies investing in start-ups and projects related to blockchain with the sector having spent $300 millions [BLOO18].

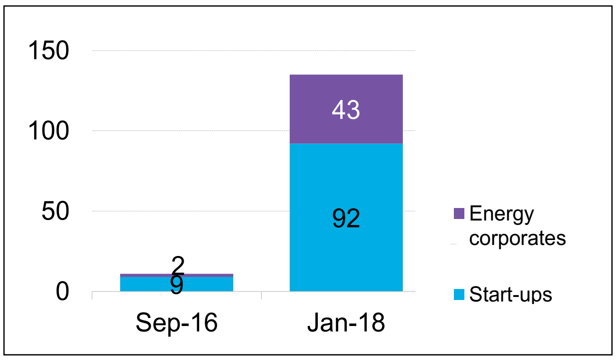

Figure 8 Active companies in Blockchain energy related. Source: BNEF

All the following cases will refer to a permissioned blockchain and accounts for the application of blockchain in the energy business:

- **P2P platforms for distributed energy generation.** The prosumers can buy and sell directly their energy (mainly from solar PV panels) in a platform powered by blockchain and without the participation of any intermediary. This kind of platforms could also be used to directly sell the generation of plants to end consumers. Examples of start-ups developing these solutions are LO3 Energy, OmegaGrid, Powerledger or Axpo's Elblox [LO3E18], [OMEG18], [POWE18], [ELBL18].

- **Wholesale trading**. Main applications are an alternative to non-organized markets as a replacement to the OTC brokers, direct access to the wholesale market without intermediaries and an alternative to organized markets as the power exchanges. This is the use case under study and will be developed in the next section. Example of this are: Enerchain, Drift, BTL and Grid+ [ENER18], [DRIF18], [BTL_18], [GRID18].

- **Distributed energy resources (DER).** Management of flexibility with DER for instance in demand side response (DSR) programmes. It could also be used to manage flexibility for the whole system but in a decentralized way. The main start-ups working on this area are: Electron, OmegaGrid, LO3 Energy and Power ledger [ELEC18], [OMEG18], [LO3E18], [POWE18].

- **Backoffice.** Improvement of efficiency and cost reduction in backoffice operations, for instance in the following applications: confirmation process in wholesale markets, regulatory compliance and billing. Main players in this area are BTL and Enerchain [BTL_18], [ENER18].

- **Electromobility.** Digital platforms with blockchain as their backend to facilitate the transactions between charge points operators and electric vehicle owners. Among others, there are applications for clearing in a decentralized platform all transaction between charge point owners and users. Another example is the management of contracts between producers and consumers and the management of billing. Start-ups working on this area are Share&Charge, Oxygen Initiative, Car eWallet and Everty [SHAR18], [OXYG18], [CAR-18], [EVER18].

- **Assets recording**. Records in smart-meters of electricity and gas and production of DER. Some examples are Electron and Enledger [ELEC18], [ENLE18]

- **Logistic traceability**. Automatization of logistic processes, for instance for the trading of commodity shipments. An example of this would be the consortium of companies with Equinor, Shell and BP among others.

- **Energy related cryptocurrency**. Generation of tokens which will be traded in markets associated to the energy business. Some applications are the creation of a cryptocurrency linked to the production of renewable energy, crowd-funding through initial coin offerings (ICO) the new renewable generation facilities and token generation related to energy efficiency. The start-ups or foundations active on this are Energimine, the Sun Exchange, Solarcoin and WePower [ENEG18], [SUNE18], [SOLA18], [WEPO18]

Next section will be focused on the application of blockchain in the wholesale energy trading.

2.5.6. A Blockchain Infrastructure to Trade Energy in the Wholesale Market

The research carried out in the chapter 3, cost reduction analysis, and chapter 4, survey on the acceptance of this new virtual facility, is based in the use of the infrastructure that will be discussed in this paragraph.

It could be foreseen that such an infrastructure could appeal energy trading companies to trade the most part of the power they nowadays operate in classical organized markets like power exchanges and OTC electronic trading platforms once its use is completely widespread among the electricity value chain.

This blockchain as envisioned in [MERZ18] could in the short term support current processes in the context of energy trading rather than replace them which could take more years. The form this infrastructure would have at the beginning is a facility to trade bilateral OTC. Beyond the cost reduction, standardization would be the most important advantage because this blockchain would force every participant to record their transactions in the same format. Here, the blockchain would act as a communication layer devoted to distribute data.

In this new infrastructure the lifecycle of a trade would be impacted in different levels. The trade process can be divided into three stages: pre-trade, execution and post-trade. Let us briefly review these stages and take into consideration the applicability of a blockchain on them.

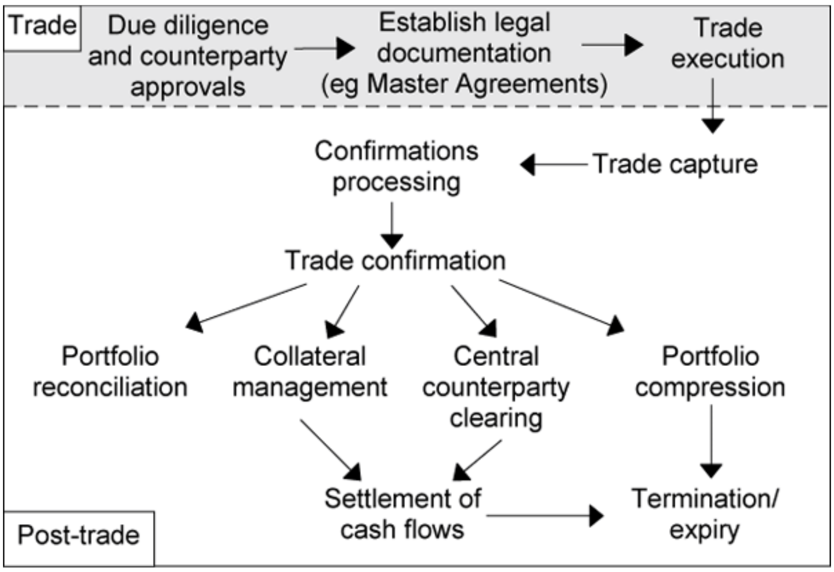

Figure 9 Life Cycle of an OTC Derivatives Contract

In the **pre-trade** stage where traders decide their strategies and send their orders to the markets according to [SANT16] for OTC bilateral a blockchain would be applicable because the cancel/update rate is relatively low considering the immutability nature of the blockchain. However, applications to other markets like the classical power exchange will also be considered as blockchain technology evolves and transaction frequency rates are reduced to the minimum. These efforts can be found in [ENER18]. Furthermore, blockchain could be used as the common data base for information of counterparties, so every counterparty only has to upgrade the information regarding to itself, such as name, social and fiscal address, etc. Another application would be the decentralized OTC bilateral credit matrix so once a trader inserts an order in the infrastructure only another trader with an agreement to trade with the former and no bilateral credit limit breach could aggress that order.

In the **execution** stage where traders agree on a price, the advantages of using blockchain are even brighter given that the intermediaries, that is, brokers and electronic platforms, would not be needed any more. Furthermore, as stated in [MERZ18] this blockchain could facilitate the creation of exotic products not available anywhere else with any given period of delivery. That is because the counterparties would agree in customizing these new products according to their needs.

Finally, the new infrastructure would also bring several opportunities in the **post-trade** stage which can be divided in the following sub processes: trade capture, confirmation, collateral management, settlement, nomination and regulatory reporting.

The first action after having executed the deal is its **capture**. Here, thanks to the standardization that blockchain provides, it could easily be acquired by the company's Energy Trading and Risk Management (ETRM) software. This is feasible because the trade is already in the blockchain and could automatically be linked to the ETRM with no human intervention.

The trade **confirmation** between counterparties is also benefited by the blockchain. This process consists on confirming the physical terms of the transaction (volume, price, etc.). Given that all counterparties share the same blockchain, confirmation can automatically be done because there is no need of further intervention by counterparties, this process could even be neglected.

Collateral management is used in bilateral OTC to diminish the counterparty risk that participants experience from deal execution until maturity because of market volatility or problems that could arise in a counterparty not able to fulfil its duties, it is the way to protect counterparties against non-payment. It consists on the transfer of collateral between counterparties according to mark-to-market position valuation and the terms of the credit agreement between them. This transfer of value could also be done in the blockchain infrastructure under study but its advantage is diminished because of the need to immobilize capital in the infrastructure to attend the collateral movements.

The bilateral OTC transactions are settled bilaterally between the counterparties. The **settlement** of a transaction requires that each party obtains what was contracted for, usually cash for one party and the contracted good for another, and at the time expected, that is invoice and payment. The financial settlement can be difficult because normally is indexed to prices like energy commodities and varies depending on the taxes of the country of the company settling the operation. The blockchain could also help in this process as commented by [MERZ16] because the payment could be an input of the ledger, that is, that the payment takes place in the blockchain transferring value from one counterparty to another. Nevertheless, this has also a big disadvantage because participants would have to allocate a large amount of financial resources in those accounts to allow the deals to be settled at any given time.

If the deal contains physical delivery the counterparties must **nominate** their new positions to the Transmission System Operator (TSO), responsible of the balance between generation and consumption. Both counterparties send the new scheduling and is accepted if the format is correct and if both send the same information. With a blockchain, the TSO could operate a node [MERZ16] and listen to all new transactions so the new positions are known by every party and no extra process is needed. This would bring less operational risk and reduce costs on operations and IT.

Finally, regulatory reporting could also be included in the scope of an energy blockchain. Counterparties must report their transactions with the requested level of detail to regulatory bodies in Europe in order to avoid market abuse and any other malpractice. The regulatory bodies as in the case of TSO's in the nomination process could also operate one node to analyse transactions given that all relevant information will be in the blockchain. This could save many internal costs to the counterparties, making the existence of intermediaries like trading repositories (TR) redundant (platforms where the counterparties send their information according to the regulation in force).

2.5.7. Expectation of the Energy Trading Community in the Blockchain

Before ending this chapter, a brief examination of the published surveys related to the potential use of blockchain in the energy business will be performed, mainly [BURG16] and [INOU18]. Although the questions in each survey differs, it will be used as a benchmark for the results of the marketing research presented in chapter 4 of this work.

First of all, let us clarify that the respondents in [BURG16] are German energy executives from the German Energy Agency (DENA) network as well as European School of Management and Technology (ESMT) alumni who work in the energy sector or energy-related industries (70 respondents) and respondents in [INOU18] are professionals of the industry with knowledge of the wholesale market and blockchain, they work at energy companies, software developement, advisory firms, public agencies, research institutes and academia (24 respondents).

In [BURG16] more than one quarter of respondents work for an electric utility with more than one fifth for a service company. More than two thirds of the respondents work for a company with more than 500 employees, and more than two thirds are aware of Blockchain in the Energy Industry. Almost half of the participants have not planned any project regarding blockchain. Note that this survey is almost 2 years old, so the same question today would probably be answered in a different way. A big majority (60%) concedes that Blockchain will advance in the energy sector.

When questioned about potential use cases there is a cluster classification in [BURG16] between process optimization and platforms and markets. In process optimization the use case with more potential is considered to be billing, followed by sales and marketing, automation, metering and data transfer, electromobility, communication, grid management and finally security. In platforms and markets, the use case with more potential is P2P trading followed by trading platforms and decentralized generation.

[BURG16] concludes that in its current development stage, the technology does not necessarily have a competitive advantage, compared to many other software platforms that can equally deliver on reducing costs. Establishing Blockchain as the dominant transaction technology might be more difficult in existing markets than in new markets where new applications do not yet exist, for instance in the case of Smart Meters in some EU countries and EV charging.

Coming back to [INOU18] when questioned what are the main benefit of applying blockchain in energy trading the answer with almost 90% of the votes was “reduction of transaction costs such (e.g. broker fees)” which is coherent with the focus of this study. The most voted benefits that follows are “possibility to innovate and create new products and market places” (50%), “optimization of post-trade processes” (46%), “reduction of entry barrier for smaller players” (37.5%), “increase in transparency and traceability” (33.3%) which could be grouped with the goals of decentralization and digitization and “high availability and resiliency with low redundancy” (17%) and the least voted benefit “immutability of records” (12.5%) which can be grouped as inherent characteristics of a blockchain.

Asked about the compliance of blockchain with the current European regulatory framework [INOU18] three quarters asses that the new technology can be compliant with the current rules and one third believes that it depends on the use case. Requested about the main regulatory limitations to implement the infrastructure, conflict of interest is the most voted one, a challenge that should be addressed by proper governance of the blockchain. The next most voted issues are uncertainty about applicable jurisdiction and possible changes in the regulatory framework soon, what put the weight on the regulator’s decision to confront and accept digital innovation.

The creation of specific rules to foster test projects by reducing uncertainty around early developments is the most voted answer to the question about the position of regulators with two thirds of the answers.

P2P trading platform (trade execution) is the blockchain application that the most of the respondents consider to be the first commercially deployed (62,5%) followed by post-trade processes (25%), what can be justified for the progress of the initiatives in place.

For P2P platform to be deployed the respondents consider that the main challenge is create liquidity (attract trading volume from existing markets followed by governance among participants, regulation and integration with existing systems and processes. Future blockchain projects for electricity wholesale is considered to be operated and managed by a balanced mix of incumbent players, trading companies and new players (40%), followed by only trading companies in consortium (26,7%) and by only new players as tech companies (26,7%) and none by only incumbent players (brokers). Enquired about the likelihood of blockchain P2P infrastructure replacing all other marketplaces, respondents are divided between likely (40%) and unlikely (40%). Finally, almost half of the respondents disagrees or strongly disagrees with the statement that is currently possible to remain fully anonymous in the blockchain while 40% agrees or strongly agrees. However, there is confidence in future developments for securing anonymity (57%).

For the application of blockchain only in post-trade processes, the main challenges are considered to be regulation and integration with existing systems and processes, followed by governance among participants, shift of liquidity, technical developments and lack of clear business case. The post-trade processes more benefited by the new solution would be settlement, invoice and payment (50%) very suitable for spot instruments but not so for financial instruments which could rise the credit risk, equally followed by confirmation and collateral management with no votes for nomination and regulatory reporting. However, respondents assess very likely (50%) a scenario where regulators check information directly from the blockchain. An editable blockchain, what is by definition contrary to its immutability nature, is considered by 33.3% of respondents to be essential for its implementation for post-trade processes. However, errors in the blockchain could be fixed by undoing positions in a mechanism to be defined.

3. *Economics of a Blockchain to Trade Energy*

Chapter 3. Index

3.1. Introduction

There is not official data about the initial investment required to develop a blockchain infrastructure because the company leading the project considers that this information is a strategic asset and therefore will not disclose it. For this reason, the capital and operating costs of such an infrastructure, in other words, support, maintenance, minor software enhancements, cloud computing expenses, etc. must be studied to determine how much a blockchain infrastructure would cost. However, an attempt to determine the possible cost structure of this development will be described in the following sections. But first of all, the costs of a traditional central market will be computed so an effective comparison between the centralized and the distributed model in terms of costs can be carried out. For the central market model, the spot market will be studied from the perspective of the transaction costs the energy trading companies fall into to join and participate.

Besides, a cause and effect relationship between the renewable capacity expansion in the last years and the increment of transactions will be conducted. A shift from a futures market to a spot and real time markets will also be discussed and inside the spot market the evolution between the day-ahead market and the intraday market.

3.2. Computation of Costs in a Traditional Physical Power Market

For comparison and simplification purposes let us assume that the new blockchain will be used only in the spot market of Germany although as discussed in a previous chapter the infrastructure could be used to trade any power and gas product in any country spot or forward. Furthermore, OTC markets transaction costs will not be included in this study so the fees of brokers, electronic trading platforms and OTC clearing facilities will not be considered.

In this paragraph the costs from the market participant perspective will be computed because they will be used as the benchmark for the success of the blockchain infrastructure.

The data used in this research has been retrieved from EPEX SPOT for the market zone of Germany and is dated on year 2.016 [EEX_17].

EPEX SPOT is held by EEX Group (51%) and Transmission System Operators.

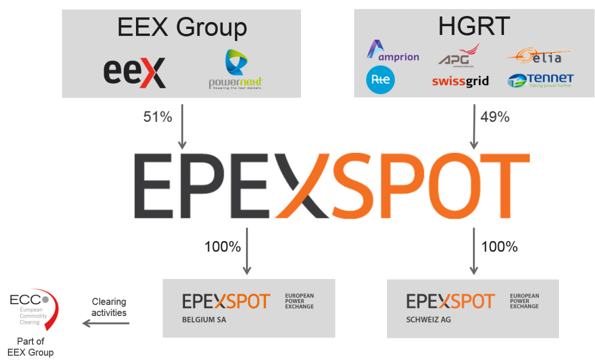

Figure 10 EPEX SPOT Shareholder Structure [EPEX18]

As mentioned before the spot market consist on a day-ahead market and intraday market. EPEX SPOT operates day-ahead and intraday power markets for Germany/Austria/Luxembourg, France, the United Kingdom, the Netherlands, Belgium and Switzerland.

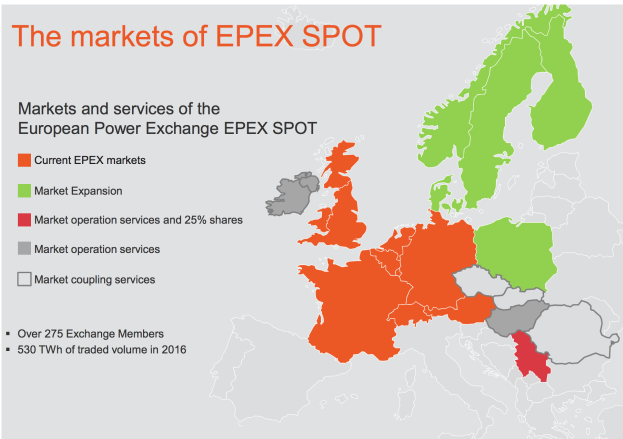

Figure 11 The geographical markets of EPEX SPOT [EPEX18]

The following volumes were traded on this market with the following share for Germany:

Volume (TWh)	2016	Share	2015	Change
Day-Ahead markets	474	89%	472	0%
Germany Day-Ahead	235	44%	264	-11%
Intraday markets	62	12%	53	17%
Germany Intraday	39	7%	37	5%
Power Spot	535	100%	524	2%

Table 2 Power Spot trading volumes 2015-2016

While the monthly evolution for day-ahead trading:

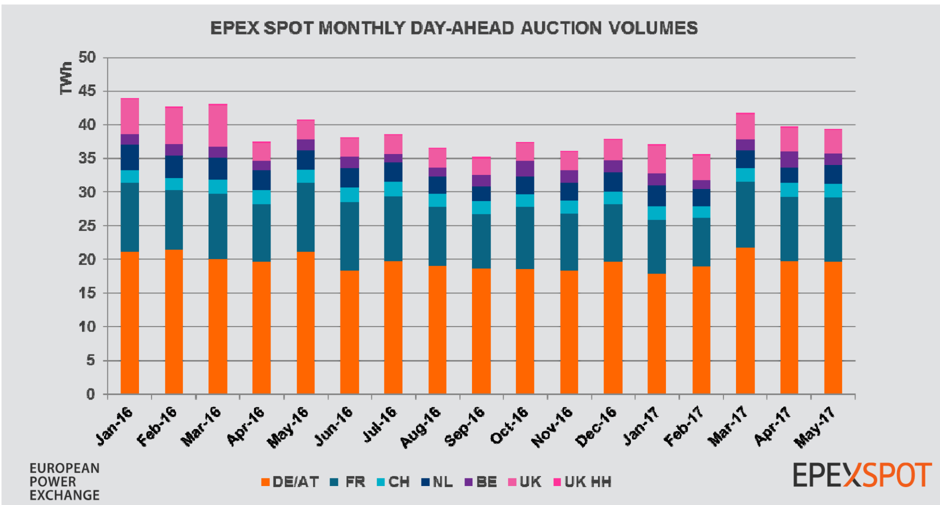

Figure 12 EPEX SPOT Monthly Day-Ahead Auction Volumes (2016-2017) [EPEX18]

And for intraday trading:

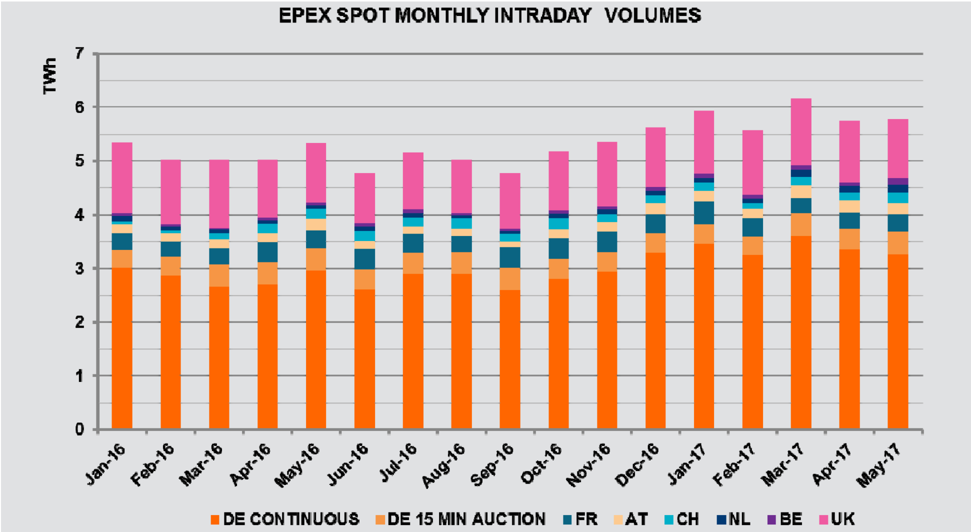

Figure 13 EPEX SPOT Monthly Intraday Volumes (2016-2017) [EPEX18]

The sales revenue of EEX Group per Power Spot business area was of 67.53 M€ or 29% of total revenues:

kEUR	2016	Share	2015	Change
Power Derivatives	87,206	37%	60,006	+45%
Power Spot	67,534	29%	63,393	+7%
Natural Gas	32,846	14%	21,132	+55%
Market Data Services	5,019	2%	3,745	+34%
Environmentals	2,479	1%	1,590	+56%
Clearing Services	1,727	1%	1,964	-12% [2]
Global Commodities	501	0%	1,157	-57%
Agriculturals	326	0%	217	+50%
Other revenues:				
Annual fees	14,152	6%	12,161	+16%
Technical connections	8,790	4%	7,926	+11%
Services to third parties	5,488	2%	4,306	+27%
Refunds of project costs	3,754	2%	4,960	-24%
Fix revenues from market-coupling	2,962	1%	4,055	-27%
Others	1,373	1%	3,811	-64%
Sales revenue	234,158	100%	190,424	+23%

Table 3 Sales revenue per EEX business area [EEX18]

Therefore, it can be roughly computed the following share of revenues per spot market, pondering by the volume traded in Germany:

Market	Sales revenues (k€)
Day-Ahead Germany	29,664
Intraday Germany	4,923
Total German Spot Market	34,587

Table 4 German Spot Market Sales Revenues. Own elaboration

It can be concluded that market participants which were active in the Power Spot Market of Germany during 2016 spent almost 34.6 M€ in EPEX SPOT.

3.3. CLASSIFICATION OF MARKET PARTICIPANTS

In this section, a classification of the market participants will be done according to their size, their average number of transactions and average expenditure considering different costs. The companies will be classified in three groups according to its activity: large, medium and small participants. With this information it will be possible to compare the average expenditure of each company in a Central Market to that on a decentralized Blockchain enabled platform.

First of all, let us consider the membership structure of EPEX SPOT as a whole. It is largely dominated by Utilities and Energy Trading Companies, which represent more than half of the Exchange's members (60%), with Municipal and regional suppliers representing overall about 83% of EPEX SPOT members.

Other significant actors at the Exchange include banks and financial service providers, commercial consumers, and Transmission System Operator:

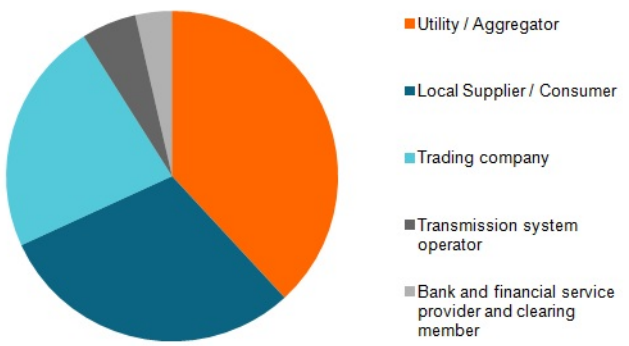

Figure 14 Membership Structure of EPEX SPOT

Let us review now the number of participants. According to [EPEX18] the number of EPEX SPOT Exchange Members active in Germany are:

Market	Number of participants
Day-Ahead	193
Intraday Continuous	194
Intraday Auction	102

Table 5 Number of active participants in EPEX SPOT Germany

Although members which participate in the day ahead market may not be the same as those in the intraday market let us consider that the overall number of participants are 193 for both Day-Ahead and Intraday Continuous and only 102 for the Intraday Auction. These assumptions will simplify the distribution of costs among participants.

According to the aforementioned classification, the membership structure of EPEX SPOT for members operating in Germany is quite similar to the EPEX SPOT as a whole which can be explained because Germany is the market with the largest weight in EPEX SPOT. The following figure shows the membership structure in German EPEX SPOT:

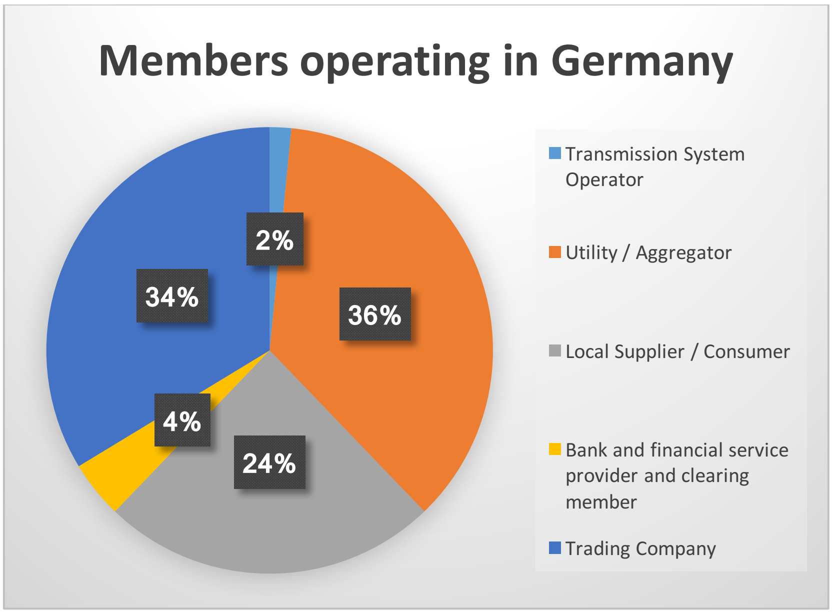

Figure 15 Membership Structure of EPEX SPOT in German Markets

Now let us review the relevant fees those members have to pay in order to join and operate in these markets (let us consider only direct members, therefore, there will not be Indirect Members trading indirectly thanks to another Exchange direct Member who would act as a Broker on the power exchange). According to [EPEX18] those fees are:

Concept	Frequency	Fees
EPEX SPOT entrance fees for Direct Member	One-time fee	25,000 €
Full membership: Day-Ahead Auction + corresponding Continuous Intraday Market	Annual fees	10,000 €
Intraday 15-min. Auction	Annual fees	5,000 €
Access via ETS Standard Access (up to 5 users and up to 5 portfolios) for Day-Ahead auction and 15-minute Intraday call auction	Annual technical fees	8,000 €
Access via ETS API read and write mode for Day-Ahead auction and 15-minute Intraday call auction	Annual technical fees	3,000 €
Access via ComTrader with an unlimited number of users for Intraday continuous market	Annual technical fees	4,000 €
Access via M7 API for the first application and for up to 5 users, if only active in one market area only for Intraday continuous market	Annual technical fees	4,000 €
Connection fees for M7 1 Mbit/s bandwidth dedicated line (average user)	Annual technical fees	24,000 €
DE/AT, CH Day-Ahead Auction	Volume based trading fees	0.04 €/MWh

DE Intraday 15-min. Auction	Volume based trading fees	0.07 €/MWh
DE/AT, FR, CH, NL, Continuous Intraday Market	Volume based trading fees	0.09 €/MWh
Trade Registration on the Continuous Intraday Market DE/AT, CH, FR, NL	Volume based trading fees	0,10 €/MWh
Order entering or cancellation by EPEX SPOT on the Day-Ahead and Intraday 15-min. auction market segment	Fees for Order Cancellation or Entry	50 € / per order
Order entering on the Continuous Intraday Market (when the member does not have access to the trading system for reasons outside of EPEX control)	Fees for Order Cancellation or Entry	200 € / per order
Order cancellation on the Continuous Intraday Market (when the member does not have access to the trading system for reasons outside of EPEX control)	Fees for Order Cancellation or Entry	50 € / per order
Trade cancellation on the Continuous Intraday Market at a member's request in case of a mistrade	Fees for Order Cancellation or Entry	3000 € / per order

Table 6 Sample of annual and variable fees [EPEX18]

There is a wider diversity of technical fees but only the mentioned above will be considered for the purpose of simplicity. The standard access to the markets (via ETS for Day-Ahead and ComTrader for Continuous Intraday) are compulsory as backup even if API's are used. The most of the companies have some automation or integration between their Trading Systems (ETRM) and the market platform, therefore both concepts, the standard access and the API must be considered for this computation.

Every type of revenue could be broken down applying the aforementioned fees and the traded volumes. The following table is an approach given that the exact fees every member pays according to its technical or operational needs cannot be known with exactitude:

Concept	Units	Revenues	Share
Day-ahead Germany	234,924,990 MWh	9,396,999.6 €	20%
Intraday Auction Germany	4,614,405 MWh	323,008.35 €	1%
Intraday Continuous Germany	36136179	2,529,532.53 €	5%
Rest of operations (trade registration, cancellation, etc.)		22,337,459.52 €	48%
Full Membership	193	1,930,000 €	4%
Intraday 15-min. Auction	102	510,000 €	1%
Access via ETS Standard Access	193	1,544,000 €	3%
Access via ETS API	193	1,158,000 €	2%
Access via ComTrader	193	772,000 €	2%
Access via M7 API	193	1,544,000 €	3%
Connection fees for M7	193	4,632,000 €	10%
Total		**46,677,000.00 €**	100%

Table 7 Revenues per market according to fees

It can be finally concluded that EPEX SPOT members spent €46,677,000 for operating in Germany during 2016 with 74% or 34.5 M€ accounting for variable fees related to volume and transactions and 26% or 12.1 M€ to fixed annual fees related to membership and use of EPEX electronic platforms.

Furthermore, the entrance fee for every member should be taken into account, not as a cost for the year on study but as an asset for each company. For all the members of EPEX SPOT operating in Germany it accounts for 4,825,000 €.

The classification will be done dividing the companies in three different groups: small, medium and large. The fixed costs will be shared by all 193 members equally which accounts to an average cost per member of 62,649.49€/year. Having considered the membership structure and recurrent costs in the market, let us classify the companies operating in this market according to the wholesale energy sales given that trading volumes are reported by only a few:

Type of trading company	Share of traded volume	Volume (MWh)	Members per group	Cost per group	Average cost per member (only variable costs)	Total average cost
Large	65%	179,189,123.1	8	22,481,550€	2,810,194€	2,872,836€
Medium	30%	82,702,672.2	121	10,376,100€	85,753€	148,395€
Small	5%	13,783,778.7	64	17,29,350€	27,021€	89,663€

Table 8 Market participant classification

The average cost each member has to pay varies dramatically comparing small and medium to large, a large company spends twenty more times than the medium one to participate in the SPOT market.

3.4. Impact of the Growth of Renewables in Trading.

In this section it will be studied the impact of renewables and if there is a cause and effect relationship between the increment of renewables and the change on the wholesale trading.

Then, the shift from futures markets to spot and real time markets will be reviewed, finally it will be discussed if there is an increment in the intraday market and a decrement in the day ahead market with a higher intermittent renewable generation capacity installed. For all these reviews, Germany will be the market under study.

First of all, let us examine the evolution of renewables capacity in Germany.

3.4.1. Evolution of Renewable Energy in Germany (2008-2017)

Germany has been installing new renewable generation continuously. The country has even been called as the world's first major renewable energy economy". Wind, solar and biomass are the most important technologies with offshore wind having momentum as more wind offshore farms are being commissioned. Germany had the world's largest photovoltaic installed capacity until 2014, and as of 2013, it is third with 43 GW. It is also the world's third country by installed wind power capacity, at 56 GW, and second for offshore wind, with over 5 GW. Therefore, the choice of Germany for studying the impact of renewable in power markets seems to be correct.

In the following table the evolution of renewable installed capacity is depicted:

	Hydro	Biomass	Wind Onshore	Wind Offshore	Solar	Total
2008	5,16	4,36	22,79	0	6,12	**38,43**
2009	5,34	5,59	25,7	0,04	10,57	**47,24**
2010	5,41	6,23	26,82	0,04	18,01	**56,51**
2011	5,31	5,8	28,58	0,08	25,43	**65,2**
2012	5,28	6	30,56	0,19	33,03	**75,06**
2013	5,44	6,7	32,97	0,51	36,71	**82,33**
2014	5,57	6,93	37,62	0,99	37,9	**89,01**
2015	5,47	7,17	41,3	3,28	39,22	**96,44**
2016	5,49	7,35	45,46	4,13	40,72	**103,15**
2017	5,49	7,39	50,91	5,26	42,98	**112,03**

Table 9 Evolution of Renewable Installed Capacity in Germany. Source: [ENEY18]

This rapid growth can be linked to the German Government commitment to fulfil the European Union environmental goals through the "Energiewende", that is, the transition to a low carbon, environmentally sound, reliable, and affordable energy supply. The legislative efforts started before 2010 but were impacted by the Fukushima accident in Japan in 2011 what moved the policymakers to remove the nuclear generation as a bridging technology to the zero emissions target.

The higher penetration of renewable generation has made possible to go from the 14,7% of the gross power production in 2008 to the 33,30% one decade later, that is, more than double in respect to the previous decade, and one third of the power produced nowadays in Germany.

Let us review in the following graph the evolution of the different power generation by sources during the last 25 years:

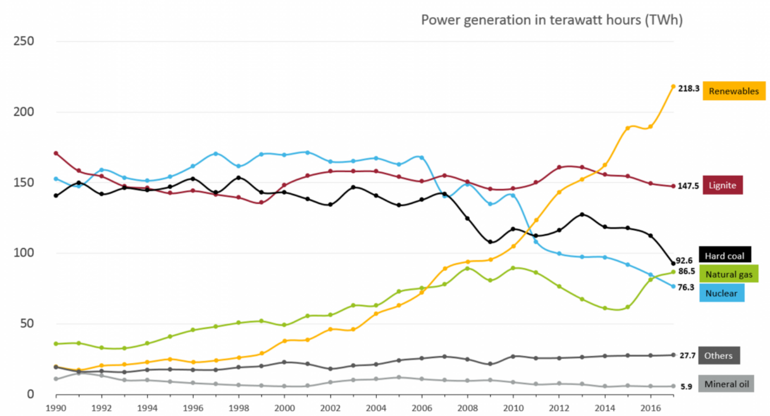

Figure 16 Gross power production in Germany 1990-2017, by source [AGEN18]

3.4.2. Trading Volume Evolution in EEX and EPEX SPOT (2008-2017)

Now, let us review the evolution of the futures market and the spot market during the last 10 years according to [EPEX18]. Note that the trading volumes in EEX include the power derivatives exchange and the power derivatives OTC (OTC registration) trading volumes while the EPEX SPOT includes the day-ahead market as well as the intraday market volumes:

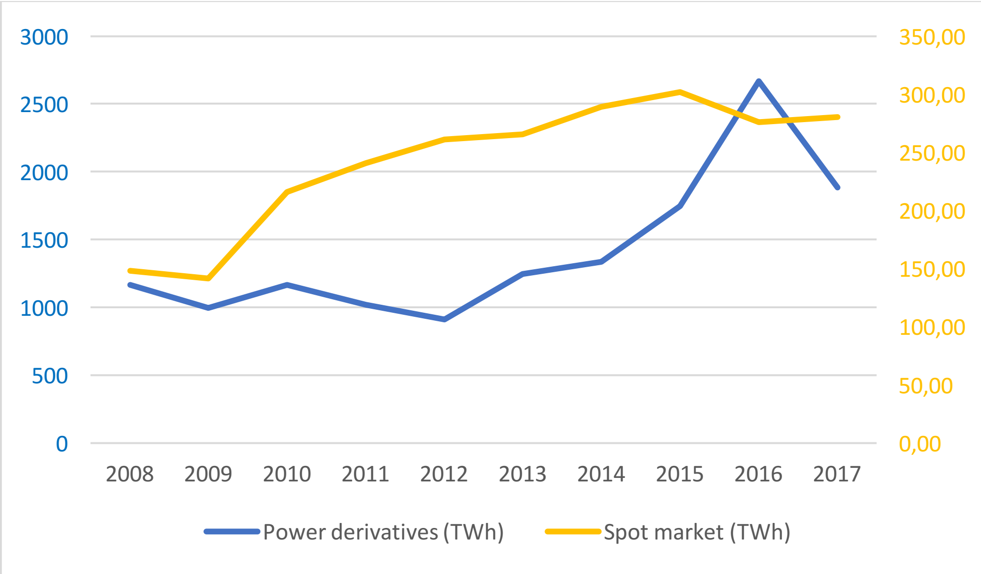

Figure 17 Evolution of trading volumes in power derivatives and spot market (2008-2017)

Although the intermittent renewable sources have expanded as seen in the previous paragraph the power derivatives market volume has grown only 61% during the last 10 years while the spot market volume has grown 89% in the last decade. This could be explained because the low marginal costs for solar and wind energy are sinking the prices of the wholesale market so trading shifts from the power derivatives to the spot market where power can be bought for a lower price. Nevertheless, the power derivatives market will still be needed in order to hedge against cloudy days, windless nights and dry hydrological years.

3.4.3. Trading Volume Evolution in the EPEX SPOT: Day-Ahead vs Intraday Trading (2008-2017)

Following the change from a power derivative to a spot market, it can also be confirmed that there is a trend of change from a day-ahead market to an intraday market as seen in the graphic below:

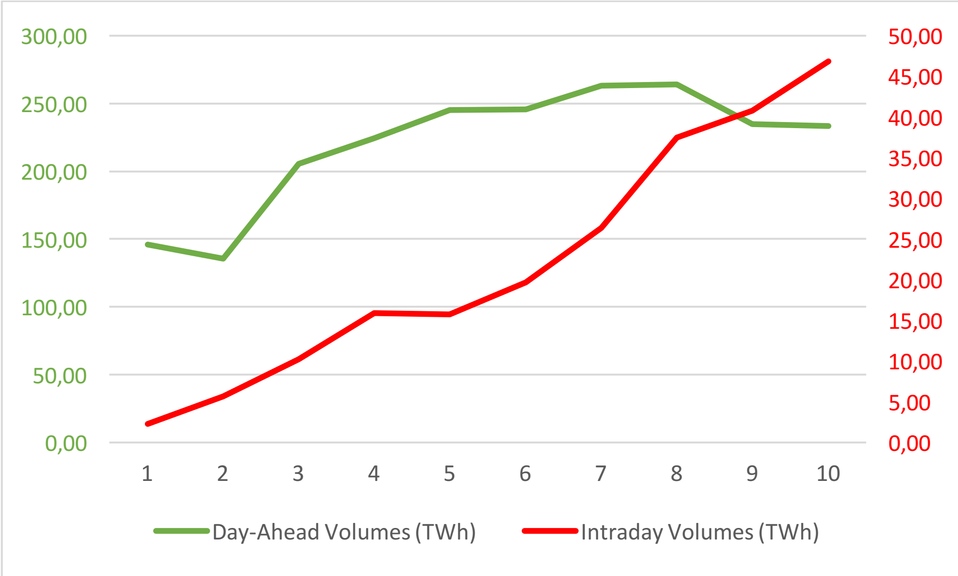

Figure 18 Evolution of trading volumes in day-ahead vs intraday (2008-2017)

Both markets have grown in the past ten years, but while the day-ahead market has only grown 1.5 more times, the intraday market has grown 20.5 times. This can also be attributed to the rise in renewables because power producers have to adjust their initial forecasts closer to the delivery of their energy.

This means that companies will have to pay more fees for participating in the intraday market which as seen in a previous paragraph is more expensive that the day-ahead market due to its volumetric fees and payment for event.

3.4.4. Correlation between Market Volume Evolutions and Renewable Energy Production Share

After having reviewed all the relevant historical series to this section: power capacity from renewable energy sources, market volume of the power markets under study, that is, derivatives and spot, and inside spot, day-ahead and intraday, it is time to compute their correlation coefficient.

The correlation coefficient is computed with the following formula:

$$Correl(X,Y) = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 \sum (y-\bar{y})^2}}$$

where $\bar{x}$ and $\bar{y}$ are the means of each series.

The following table depicts the historical series and the correlation coefficient between the gross power production share of RES and the market volumes:

Year	RES Share	Derivatives (TWh)	Spot (TWh)	Day-Ahead (TWh)	Intraday (TWh)
2008	14,70%	1165	148,23	145,94	2,29
2009	16,00%	994	141,26	135,60	5,66
2010	16,60%	1165	215,72	205,48	10,24
2011	20,20%	1018	240,45	224,55	15,90
2012	22,80%	911	261,03	245,27	15,76
2013	23,90%	1244	265,27	245,57	19,70
2014	25,90%	1336	289,30	262,92	26,38
2015	29,10%	1747	301,62	264,13	37,49
2016	29,20%	2665	275,68	234,92	40,75
2017	33,30%	1883	280,04	233,16	46,88
Correlation coefficient		0,71772351	0,86322969	0,752664538	0,978876834

Table 10 Correlation between RES power production share and market volumes (2008-2017)

As it was advanced in the previous subsection as more energy is produced with intermittent renewable technologies, the intraday market which can be used to balance previous positions in the day ahead market, has grown the most. The correlation coefficient of the volume traded in the intraday market and the share of energy produced only with renewable energy sources is very close to 1 (totally correlated): R=0,9789.

For the rest of correlation coefficients although not as high as with the intraday shows high correlation, the most significant one the spot market as a whole with R=0,8632.

It can be concluded that the expansion of renewables has a causality impact in the increase of the intraday and spot markets. Furthermore, another conclusion comes in hand to introduce the next section. If the volumes traded in the spot market and specifically in the intraday grows relentlessly, the costs of operating in these markets will also constantly grow. That is why a blockchain infrastructure could play an important role in diminishing the transaction cost of trading power and gas in the German and more generally in the European markets.

3.5. Cost of a Blockchain Infrastructure

A new autonomous infrastructure base on blockchain may be more affordable than operating a central platform like a power exchange. The classical organization structure is not needed any more: management, market control, market supervision, regulation, legal, market support, compliance, IT, sales and marketing, business development, etc. All the costs that have been studied in section 3.2 and 3.3 would disappear. But a new electronic platform based on blockchain for peer to peer trading must be developed from scratch to replace the incumbent intermediaries and this development has an initial investment cost and it will have a maintenance cost among others. Let us discuss how much would this infrastructure costs.

Peer to peer trading is the basis for developing this infrastructure. Some deals for power are closed bilaterally OTC as introduced in chapter 2, with the traders calling each other, sending emails, or using brokers as intermediaries. The power exchange is considered another intermediary. Therefore, all deals could be closed bilaterally without the need of any intermediary.

For a project like this to be successful, a set of potential end user companies must be involved from the beginning. This is because to perform any deal a trading partner is needed. Therefore, a consortium could be created to fund the project, as it was the case of Enerchain leaded by the German Software development company Ponton [ENER18].

Without aiming to replicate the costs of the aforementioned project, let us deduct a development cost based on the profiles of professionals needed to develop the infrastructure as well as other profiles needed to lead, coordinate and advise during the project.

There are several technical and organizational requirements to build this infrastructure. A group of professionals with the sufficient knowledge and coordination skills must be in place:

- Programmers with deep knowledge of coding.
- Knowledge of telecommunication networks and cloud computing.
- Knowledge of Open Source code that could be reused in this endeavour.
- Knowledge of the different types of blockchains.
- Knowledge of the Power Markets Dynamics.
- Knowledge of the Power Market and sector regulation.
- Entrepreneurial and leading skills to set the project right.

The technical resources will also be considered but have not the main weight on the cost structure:

- Personal computers.
- Cloud computing services.

The duration of the project will be set to 12 months. The following table summarizes the investment needed for the go live of such an infrastructure in terms of man-day:

Profile	Quantity (in man-days)	Estimated Cost/man-day (all taxes included)	Subtotal
Software developer	1575	288 €	453,600 €
Tester	225	288 €	64,800 €
Networking expert	225	298 €	66,960 €
Lead developer	225	480 €	108,000 €
Industry expert	450	528 €	237,600 €
Regulatory expert	150	480 €	72,000 €
Managing director	225	720 €	162,000 €
		Total	1,164,960 €

Table 11 Initial Investment to develop an Energy Trading Blockchain (CAPEX)

The members of the consortium should also provide technical and sector experience through the employees participating in the project but this will not be considered in the total cost of development of this project because the contribution of each partner is different and cannot be assessed in the same way. Anyway, as a whole, it could be computed that the consortium members as a whole would invest 1,600 man-days, what it could account for an expenditure of 500,000€.

The technical resources could also be computed as follows according to prices in [AWSE18] a popular cloud computing provider:

Concept	Quantity	Estimated Cost (all taxes included)	Subtotal
Personal Computers	11	267 €	2,933 €
Cloud Computing - Reserved Instances	6	1,085 €	6,510 €
Cloud Computing - Dedicated Host	2	15,000 €	30,000 €
Cloud Computing - Other costs	1	20,000 €	20,000 €
		Total	59,443 €

Table 12 Technical resources costs

Finally, the sum of both concepts accounts for **1,224,403€**, this is the figure for the whole project in the investment phase.

Now let us consider the recurring expenditure for this infrastructure once the platform has gone live on an annual basis. The recurring costs must contain the effort for maintenance, support and further development which could be outsourced to an already running specialized company with a level service agreement what means that the personnel providing service to the platform are not employed by the entity. A minimum management, regulatory advice and governance structure should in any case be considered:

Concept	Quantity (man- days or units)	Estimated Cost (all taxes included)	Total
Software developer	900	288 €	259,200 €
Tester	225	288 €	64,800 €
Support service	900	264 €	237,600 €
Networking expert	150	298 €	44,640 €
Lead developer	150	480 €	72,000 €
Industry expert	150	528 €	79,200 €
Regulatory expert	150	432 €	64,800 €
Managing director	150	720 €	108,000 €
		Subtotal	930,240 €
Personal Computers	8	267 €	2,133 €
Cloud Computing - Reserved Instances	3	1,085 €	3,255 €
Cloud Computing - Dedicated Host	5	15,000 €	75,000 €

Cloud Computing - Other costs	1	20,000 €	20,000 €
		Subtotal	100,388 €
		Total	**1,030,628 €**

Table 13 Infrastructure recurring cost (OPEX)

It is estimated that once the platform is ready, more cloud computing resources will be needed to ensure the performance of the blockchain network even not taking into account the participants' own resources. The recurring costs account for **1,030,628 € annually**.

3.6. BUSINESS MODEL OF THE BLOCKCHAIN INFRASTRUCTURE TO TRADE ENERGY

Starting from the results of section 3.3 with the classification of participants and having computed the potential costs of this infrastructure, an attractive business model has to be developed in order to accomplish two goals: on the first hand to develop the infrastructure and on the second hand to get the most of participants once it is operational to fund its operations and attract enough liquidity for a proper trading. The aim of this infrastructure is not to look after profits but to decrease the transaction costs of their participants, therefore, it will have to spend the resources its participants transfer to it.

Following the cost structure computed in the previous section let us consider that during the development phase only the large companies and half of the medium companies (let us call them medium A) are interested in the funding of the project, that is, 68 participants. If the investment costs are shared equally among these companies, each one should contribute with 18,006€. Given that the project should be funded with a little higher budget for incidentals and change of scope, let us consider that each participant will contribute with **21,000€**. These founding participants will not have to pay any license fees once the platform is operational, only partly contribute to the operational recurring costs.

The founding participants helping to develop this platform would have several advantages further from the savings which will be discussed in the following paragraph. The main advantages would be among others shape the platform, gain first-hand experience in the application of blockchain technology in the business, accelerate the creation of new trading products adapted to their needs, promote the image of the participant in the digitalization transition, etc.

Although a fair and rational share of the costs is sought so resources are properly allocated, the consortium should look for lowering the barriers of entry to small participants so the participation in the infrastructure is not limited to the member size and then as a by-product but key to new markets liquidity is assured. It should also be noted that the flat rate is based in the activity of the company, that is, medium companies will use the services provided by the infrastructure more intensively than the small companies, therefore, this type of companies will support the higher share of the OPEX.

Once the platform is alive two different mechanisms must be discussed to share the cost of the working infrastructure (**1,030,628 €/year**):

- **License or annual fee** for the rest of participants which did not join the consortium during the investment phase, the founding members are excluded from

the payment of an annual license and no access fee is requested for the new participants:
- Medium B companies:
  - 61 participants.
  - 10,000 €/year per participant.
  - Total contribution of this type of companies: 610,000 €
- Small companies:
  - 64 participants.
  - 500 €/year per participant.
  - Total contribution of this type of companies: 32,000 €.

- **Maintenance, support and further development**. Through this concept the rest of the recurrent costs must be funded annually. Considering all companies fund the rest of the infrastructure in the same way, that is, deducting the collected licence fees to the total operational costs:
  - 193 participants.
  - 2,500 €/year per participant. No distinctions.
  - Total contribution for this concept: 482,500 €.

The real need of extra funding for the operational costs is 2,014 €/year per company but the difference will be used for incidentals and extra needs. This accounts for a buffer of 93,872 €

The following table summarizes all the fees each company would pay and as stated at the beginning of this research they are fixed costs and not depend on the traded volume:

Type of company	Concept	Payment	Frequency
Large	Project funding	21,000 €	One-time
Medium A	Project funding	21,000 €	One-time
Large and medium A	Annual fees	0€	Annually
Medium B	Annual fees	10,000 €	Annually
Small	Annual fees	500 €	Annually
All	Maintenance, support and further development	2,500€	Annually

Table 14 Project initial funding and annual fees

3.7. Cost Comparison between a Centralized and a Distributed Market

Finally, the main results of this chapter will be summarized in the following tables, starting with the entrance fees for centralized markets and initial investment cost for the blockchain infrastructure:

	Members per group	Centralized Market	Blockchain Infrastructure	Cost reduction
Large	8	25.000 €	21,000 €	16%
Medium A	60	25.000 €	21,000 €	16%
Medium B	61	25.000 €	0 €	100%
Small	64	25.000 €	0 €	100%

Table 15 Entrance fees comparison

And now with the annual recurrent fees the even higher savings are shown:

	Members per group	Centralized Market (average variable cost)	Blockchain Infrastructure (flat rate)	Cost reduction
Large	8	2.872.836,24 €	2,500 €	99,91%
Medium A	60	148.395,38 €	2,500 €	98,32%
Medium B	61	148.395,38 €	12,500 €	91,58%
Small	64	89.663,58 €	3.000 €	96,65%

Table 16 Annual costs comparison

The companies that get the highest reduction in annual spending are the large ones with 99,91% lower fees. For the small one the cost reduction is quite significant because it is almost 30 times lower than with the centralized market. Furthermore, these small participants could take profit from other advantages like been able to trade smaller quantities as the standard in the centralized market (minimum volume increment of 0.1 MW and minimum price of 0.1 €/MWh). For all companies there are other advantages like been able to develop customized products for any particular need.

The traditional market operators could decide to change their business model and remove or drastically reduce variable fees and instead demand a higher subscription to the market, however they have a complex structure no matter how they collect fees, licenses or any other income: management, legal, sales, business development, IT departments among others would remain the same, so the overall costs would continue and will be uncompetitive compared to the blockchain infrastructure.

3.8. Conclusion

With the increment of renewable and linked to it the foreseeable increase of transactions in the intraday market and spot market in general, a new infrastructure with no variable but low fixed costs could replace the centralized market with all its related high costs. The large companies could be the most benefited in the first stage but a closer look reveals that the small companies, not only the existing ones but the future small players like small communities producing renewable energy, could be the most benefited of this new technology. It could also be concluded that the end consumers in the retail segment could also benefit given that the intermediary costs are reduced dramatically.

The study in this section has been focused in the power spot market in Germany but the new platform could be theoretically used in any power and gas wholesale market in any given country, therefore, the savings would even be higher than the one reflected on this research. The traditional market operator could not beat this business model because of their complex and costly structure.

4. *Marketing Research*

Chapter 4. Index

4.1. INTRODUCTION

This chapter is devoted to present the results of the survey that was designed to validate the acceptance of the new infrastructure by the industry. It consists on an analysis and interpretation of the answers sent by respondents and a conclusion considering all the facts under study.

4.2. METHODOLOGY

The marketing research, done in the form of a survey, had as a main goal to assess the acceptance of the new infrastructure by the energy trading community, the willingness of end users to shift to the platform enabled by the new technology and the barriers that could postpone or avoid its adoption.

The target population was professionals working in areas related to the wholesale energy trading with different profiles in a standard Energy Management department: IT managers, members of legal department, traders, heads of trading, heads of back-office, heads of middle-office, etc. All of them had some level of knowledge of blockchain technology and of its potential application in the wholesale energy trading. People working in energy management departments do not conform a big population, but those who have understanding of blockchain conform even a smaller portion of that community. Therefore, objective population is quite small and with a sample size of 50 people, it can be affirmed that there is an increase in confidence or precision in the estimates because the sample captures a larger fraction of the total population. As described in [FAHY12], the sampling method used in this survey is simple random, that is, the sample is drawn at random and each individual has a known and equal chance of being selected.

The survey method chosen was an online form which access was limited by email invitation. A covering letter explaining this research work goals and methodology was attached to the email invitation. The online survey is the most popular method because it is very cheap and anonymity is assured. Anonymity is key because of the nature of the questions and the identity of the respondents who could cooperate in blockchain projects as part of a consortium but are competitors and therefore, they must comply with competition law. This helps the respondents to answer honestly, knowing that there is no trace of their identity. That is why other methods like face-to-face or telephone interviews and mail surveys were discarded. The tool chosen to elaborate the survey and collect the results was a free account of [SURV18] which provides customizable surveys as well other paid services.

Following [FAHY12] recommendations, the questionnaire was designed taking care of the following criteria: clear and easy to understand questions without the need to reveal any clues regarding the respondents' identity or company so they are willing to provide an honest answer.

Thanks to the material collected in the previous chapters the survey was designed to confront those ideas and facts with the respondent's opinions. The questionnaire's construction was done following a logical flow and starting with three easy-to-answer questions that help to classify and relax the respondents and leaving the most sensitive question at the end. This classification could help to identify some trend between aggregated profiles and the answers to the relevant questions. There were two types of compulsory questions, multiple choice and ranking questions. This closed answers were chosen in order to help the respondents and avoid the risk of abandonment that can take place when questionnaires are too long and difficult to understand [DILL08].

The survey has been piloted with the supervisor. Once confirmed to be well designed it has been sent to the chosen sample and remained open for a whole month. The data sheet of the survey as well as the full list of questions and answers can be found at the Appendix.

4.3. Analysis of Results

After the survey was closed, 26 responses were collected which represents a 52% of the sample size and consequently it can be considered as representative of the population under study. This figure is quite a success given that the usual online response rates are much lower, ranging from 20% to 47% as stated in [NULT08] paper.

The analysis will be done in the same order as the questions in the online survey:

1. *What type of company do you work for?*

In order to classify and aggregate the respondents by type of company this question was formulated. As expected the majority, 61% of participants, are employed by an electric utility. This result coincides with the share of electric utilities and trading companies that was showed in 3.3 in EPEX SPOT that was 60%. Therefore, it could be concluded that this fact add significance to the results because the respondents are a representation of the industry. The next type of company with more representatives was Energy Service Companies followed by Oil & Gas Company and other.

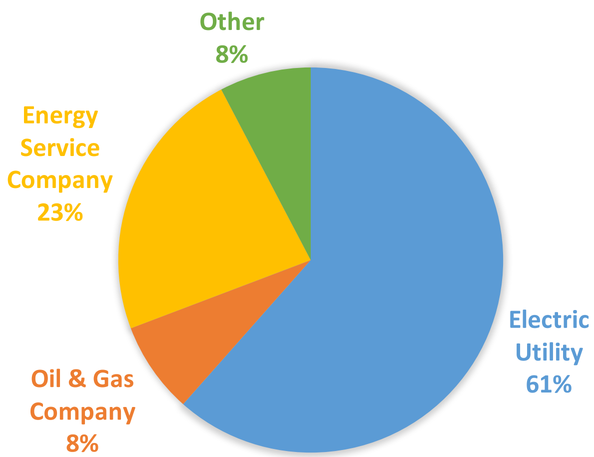

Figure 19 Type of company where employee works

In contrast to [BURG16] where the executives came all along the value chain in the electricity industry, this research is concentrated in respondents working in companies operating in the wholesale market, that is why in the former research there is a lower share for electric utilities.

2. How many people are employed at your company?

Of the 26 respondents, 85% of the respondents work in a company with more than 1,000 employees, 0 percent in companies with a range from 100 to 1,000 employees and about 15 percent in a company with less than 100 employees. It is highlighted that 72% of companies with more than 1,000 employees are electric utility companies.

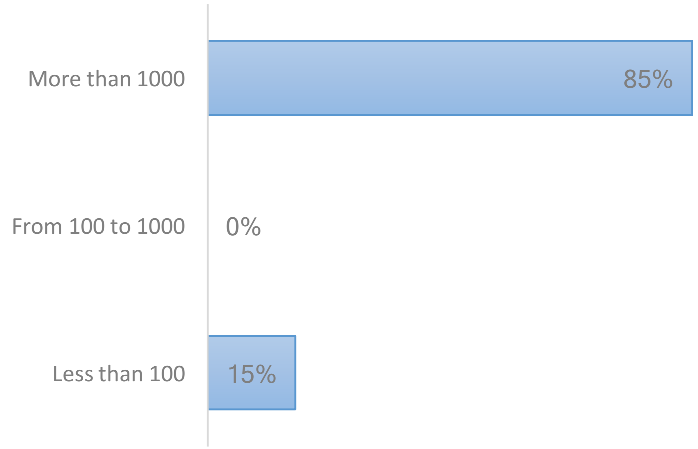

Figure 20 Company size of survey respondents

3. How deep are you involved in a Blockchain project?

This last classificatory question assess the level of knowledge participants have about blockchain and potential applications. None of the participants is unfamiliar with Blockchain technology, with the most part of the respondents, 62%, having a project related to Blockchain as a big part of their daily routine and with the rest having some contact to it.

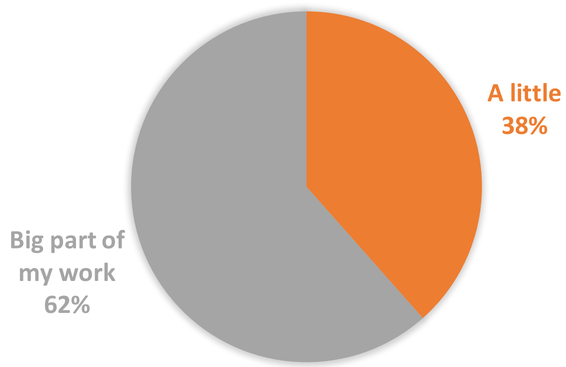

Figure 21 Involvement in a Blockchain project

This result set a clear classification of participants and confirm the sampling method, respondents are good representative of the energy trading business and have an average high level of knowledge of the new technology. Furthermore, it can be emphasized that 72% of those respondents having a blockchain project as a big part of their responsibilities work for a utility electric company. These last results can suggest that this type of companies leads the blockchain projects dealing with wholesale trading and dedicates the biggest share of resources.

This contrasts with the result in [BURG16] where only 69% of participants had awareness of blockchain and little more than the half planned to do a project with Blockchain. This can be explained with the passing of two years and the arrival of start-ups and other industry leaded initiatives.

4. *Could Blockchain change the way for the wholesale trading of energy?*

No participant thinks that Blockchain will not have any impact on wholesale markets however there is no certainty on the grade of that impact. 69% of the participants believe that blockchain could bring major changes to the market but with not high confidence. Only 31% of participants thinks without any hesitation that change is coming to the business due to Blockchain.

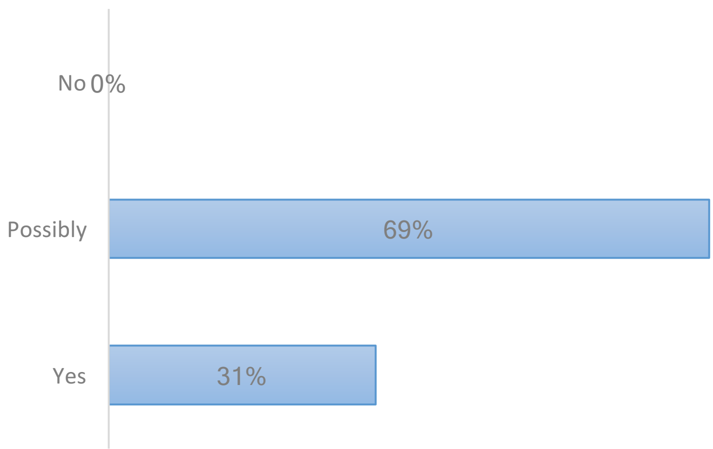

Figure 22 Assessment of blockchain capacity to disrupt wholesale trading of energy

5. *Will blockchain replace the current intermediaries in the energy trading business?*

In this occasion there is no clear answer with all respondents accepting that the new technology will impact somehow the existing intermediaries in the energy trading business such as brokers, clearing houses and power exchanges. This result could be explained in two ways. The first and more clear reason could be that there is no infrastructure in production where the new paradigm is tested so the expected benefits can only be justified as the theoretical framework proposed by Blockchain. The second interpretation could be that although the technology has the potential to replace some intermediaries many of them will still be needed, such as the role of a clearing house. This answer is quite correlated with the previous one where uncertainty regarding the level of change was stated.

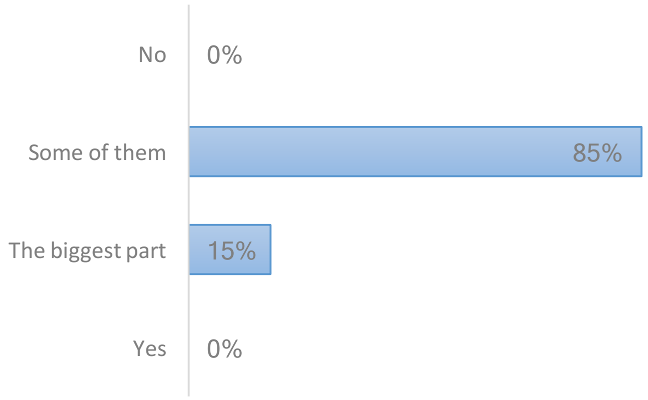

Figure 23 Blockchain technology capability to replace intermediaries in the energy trading business

6. *<u>Please rank the following intermediaries on a scale from 1 to 4, with 4 being the most impacted intermediary by the use of blockchain on wholesale energy markets.</u>*

The results are an average score given by the respondents. According to the participants the most impacted intermediary would be the OTC platforms followed closely by the brokers. This result is quite coherence with the development of this thesis where new technology can replace consolidated technology such as the centralized OTC electronic platforms. Additionally, brokers are candidates to have a less significant leadership in the bilateral trading of the future. Power Exchanges are with a considerable distance to the two previous intermediaries the next in the list. This intermediary is more difficult to replace because they are considered to be efficient by the industry and a good place to develop the price mechanism by the industry and the regulators. Clearing houses would be the least affective intermediaries given that some kind of clearing houses will be needed in the new infrastructure, for instance, to allocate resources for collateral.

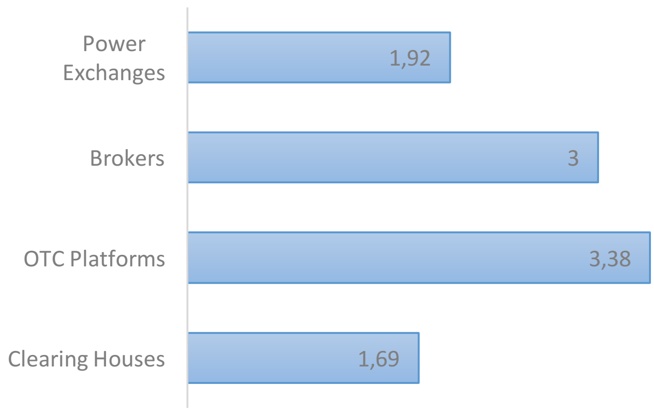

Figure 24 Ranking of the most impacted intermediaries in the wholesale energy trading because of Blockchain

7. *<u>Please rank the following barriers to execute energy trades in a blockchain on a scale from 1 to 4, with 4 being the most important barrier.</u>*

This question has the most divided answer with not a clear winner at sight. Regulation is slightly the most voted barrier that a Blockchain platform would face. This is coherent with the next chapter focused on the regulatory impact that could slow the adoption of this technology. It is also consistent with the results of [INOU18] where changes in the regulatory framework and uncertainty about applicable jurisdiction are the second most voted limitations to be confronted. This determines that regulatory uncertainty should be solved by the early involvement of National Regulatory Authorities contributing to the design of compliant Blockchain.
Next most voted barrier and very close to the first barrier is governance, also in line with [INOU18] where it was voted the most important limitation. New means for coordinating the structure must be found in order to properly govern the community and assuring a fair share in the decision making process.
State of the technology is assessed to be also a major drawback for the implementation of the technology. The current state of technology could be considered inappropriate for some use cases as the need to trade energy with a high frequency rate. Nowadays transactions rate in a Blockchain are limited by the design of the technology, for instance in average the transaction speed of Bitcoin is 3 to 4 transactions per second, Ethereum 20 transactions per second, Tendermint 10,000 transactions per second. This means that future improvements could balance this initial weakness.
Finally, illiquidity is a risk that a project of this nature could face to have success. A critical mass must be reached in order to accomplish the status of standard of the industry. A similar question was raised by [INOU18] questionnaire where shifting liquidity from existing markets to the new solution was considered the most important challenge. This could be solved by showing the benefits of the new technology and adapting the rest of processes to it, so participants would gradually shift to the Blockchain.

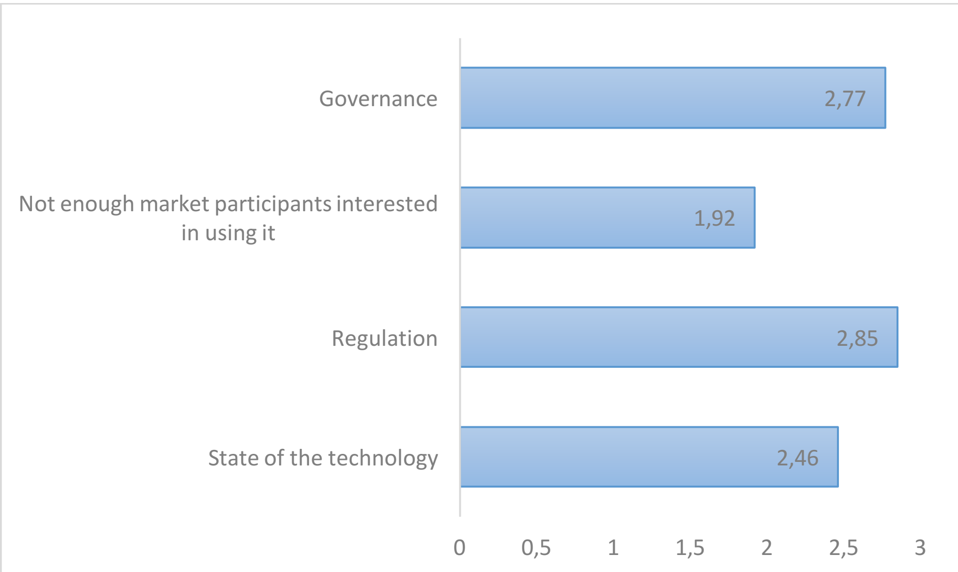

Figure 25 Ranking of barriers to trade energy in a Blockchain

8. *Please rank the following benefits of using blockchain in energy trading on a scale from 1 to 5, with 5 being the most important benefit.*

Cost reduction is the most voted benefit of using Blockchain in energy trading. This is totally coherent with the basic of Blockchain where the role of intermediaries disappears because everything is distributed among participants. This answer is totally in line with [INOY18] and note that in this survey also reach a comfortable result compared to the second classified (4,69 to 3,46).
Transparency is considered to be the second most important benefit but with not a clear lead with the following classified benefit: security. Security and transparency are also of capital importance on any Blockchain and have a secondary effect in the reduction of costs, for instance, transparency makes redundant the use of index agencies and security would shrink the need of some resources in the IT department.

Other benefits not listed receives a relevant qualification. It is interesting to highlight that the result no benefit has obtained the lowest score what means that all participants think that the blockchain application on energy trading has at least some benefits.

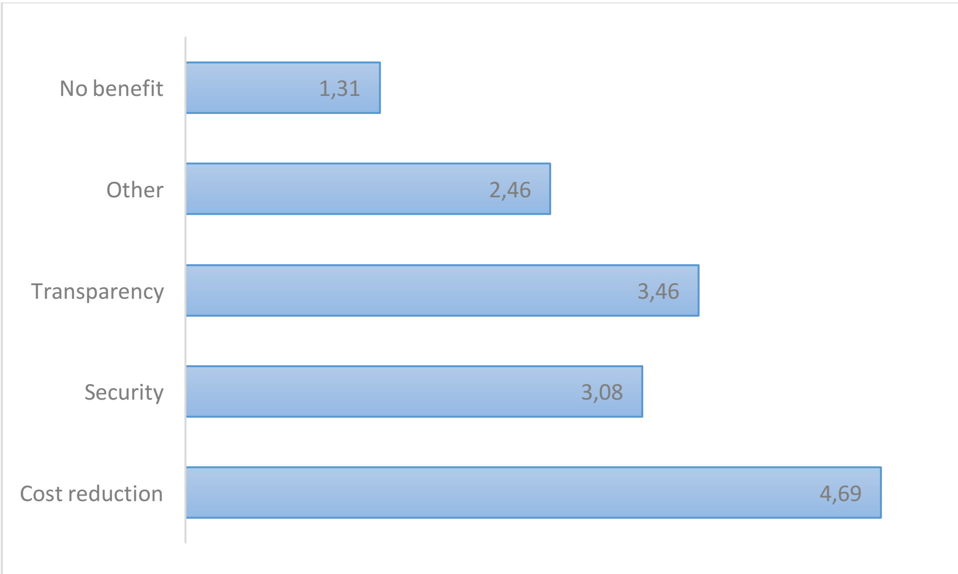

Figure 26 Ranking of benefits of using Blockchain

9. *Please rank the following processes of an energy management department according to its potential improvement thanks to blockchain on a scale from 1 to 5, with 5 having the most potential.*

The processes which could most be improved by the use of the new technology are the execution of trades in the wholesale energy and deal reconciliation with the first winning the poll. This result is comparable and follows the logics of [INOU18] where a P2P trading platform is seen to be the first commercial application of blockchain in this business. Settlement and standardization follows as key improvements. Finally, nomination is seen to have the least potential for improvement. This answer reveals that nomination is quite out of scope right now because all the bodies that have to be embarked, mainly TSO's, and all the processes that have to be adapted are apparently too complex for the expected benefits.

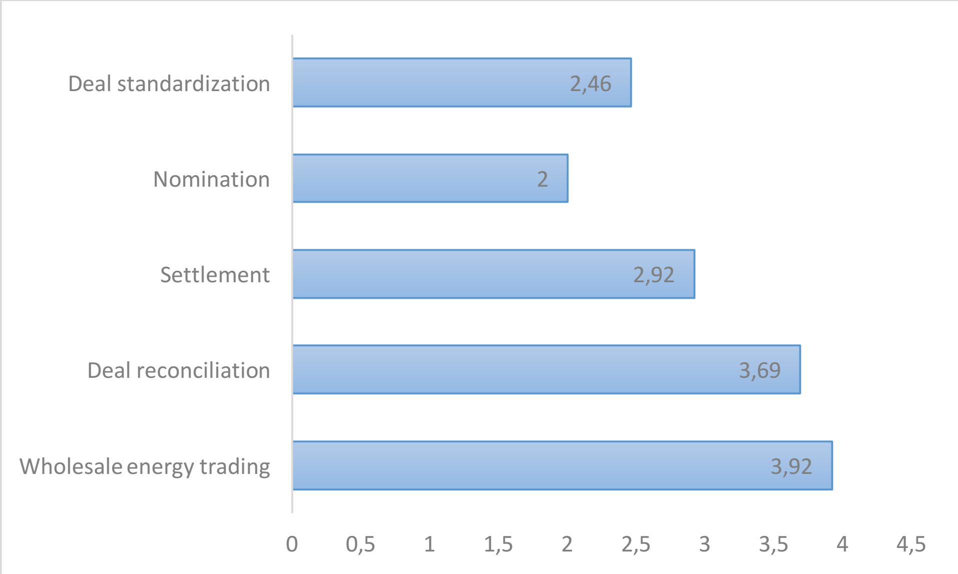

Figure 27 Ranking of the processes with most potential of improvement

10. When do you think that blockchain will be mainstream for energy trading?

Finally, the respondents evaluate when the blockchain will be mainstream in the industry. The most voted answer is the latest in time, beyond 2023, with 39% of the votes. However, the not so far in time period 2021-2023 is the second most voted choice with 31%. This can be explained as participants are cautious about the rise of Blockchain in the industry but do not discard a sooner adoption. There are only 15% of respondents that think that in three years the blockchain will be irreversible in the industry and the same amount of respondents think that it will never happen. This two late results suggest that the period of 2021-2025 would be the most plausible time for the rise of Blockchain in the wholesale energy trading.

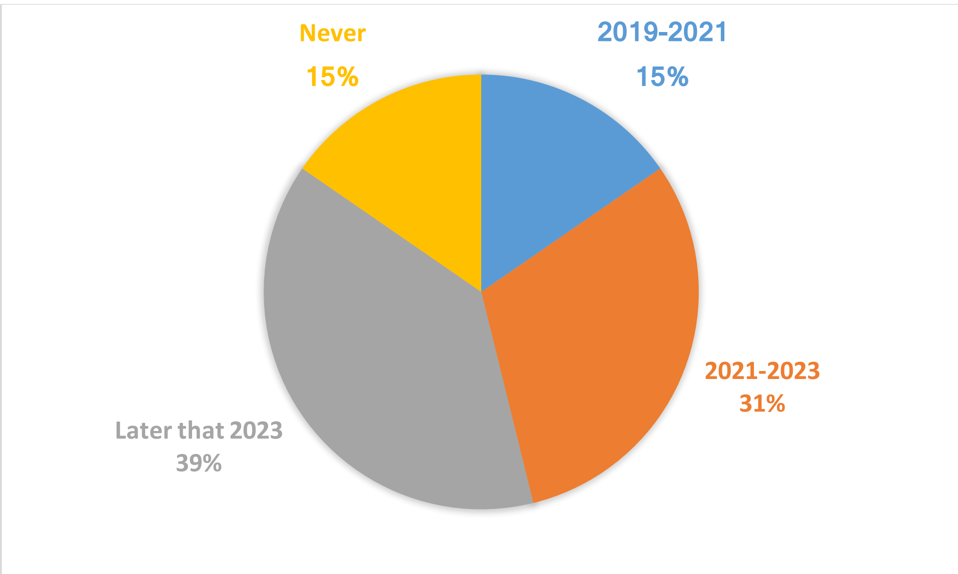

Figure 28 When will blockchain be mainstream in the industry

4.4. Conclusion

This market research has revealed some important insights from employees working in trading companies, mainly in electric utilities, with some level of knowledge on Blockchain technology. Its significance can be considered to be high given the small population under study and the number of respondents.

Everyone considers that Blockchain will affect somehow the business but its impact is not clear, leading to the partial or complete replacement of intermediaries in the long run. The most impacted intermediaries will be OTC electronic platforms and brokers, with Power Exchanges and Clearing Houses perhaps changing some part of their role but surviving to disruption. Regulation is seen as the most important barrier to overcome followed closely by governance. Governance practices will have to evolve due to the new setting where there is no central body. Other barriers to consider are the state of the art in technology and the liquidity, both barrier thought to be surpassed with the passing of the years and the improvement of technology and change of mind-set in participants.

As expected and main topic of this study cost reduction is the main benefit sought in Blockchain. Then transparency and security are thought to be the second most important advantages of applying the technology in wholesale energy trading. When asked about the quick wins of applying Blockchain to the business, executing deals are considered to be the best candidate followed closely by deal reconciliation. Settlement, payment and invoicing are thought along deal standardization to have lesser important gains with the new technology. However, nomination is seen less impacted.

According to the poll respondents Blockchain will be mainstream in the business starting from the period 2023 or later which is coherent with the current state of platforms intended to go commercial.

5. *Potential Regulatory Impact*

Chapter 5. Index

5.1. INTRODUCTION

The regulatory activity in the European wholesale energy and finance markets have been prolific in the past years. One of the main drivers has been the European integration but 2008 financial crisis could be seen as the trigger of the comprehensible re-architecture of the new regulatory framework.

The arrival of new technologies such as distributed energy resources to the market are forcing the regulator to rethink some rules to adapt to the new reality. The adoption of new digital technologies as blockchain could bring the regulator to change or adapt a portion of the regulatory legislation.

The European Parliament has already showed interest on being part of the blockchain adoption and is willing to foster innovation on the matter: "There is a strong entrepreneurial interest in blockchain. European Parliament, as regulator, needs to make sure that all this effort will be embraced by the necessary institutional and legal certainty" [EURO18]. This setting could contribute to the adoption of the technology also in the energy trading sector, but it is well-defined, that the new infrastructure will have to comply with the rules in force. However, because of the decentralized nature of the blockchain, it may be necessary to change some parts of the law without violating its essence.

In this chapter, the relevant regulation in place, that is, EMIR, REMIT and MiFID II will be examined in the light on how the use of blockchain on this field could comply with them and what advantages could bring the technology observing the existing regulation.

5.2. EUROPEAN MARKET INFRASTRUCTURE REGULATION

In 2012 the EU adopted the European market infrastructure regulation (EMIR). The aims were to increase transparency in the OTC derivatives markets (also energy derivatives), mitigate credit risk and reduce operational risk. These goals were sparked by the 2008 financial crisis when significant weaknesses in the OTC derivatives markets became evident [EC__18].

Increasing transparency is achieved in EMIR thanks to the new reporting requirements on derivatives markets. This regulation requests market participants, themselves or through third parties, to report detailed information on each derivative contract to central trade repositories (TR), cleared and bilateral OTC contracts, so supervisory authorities can access the information on any occasion. These deals must be identified with a Unique Trade Identifier (UTI). TRs have to publish aggregate positions by class of derivatives, for both OTC and listed derivatives so risk can be better measured. The European Securities and Markets Authority (ESMA) has to monitor these TRs and is responsible of granting access to these repositories. Moreover, there are different roles depending on which regulatory authority has to access the TR.

The reduction of counterparty credit risk in derivatives contracts is accomplished in EMIR with a new set of rules: all standard OTC derivatives contracts must be centrally cleared through Central Clearing Counterparties (CCP). However, if a contract is not cleared by a CCP, risk mitigation techniques must be applied. Additionally, CCPs compliance standards are more restrictive.

The regulation also requires market participants to monitor and mitigate the operational risks associated with trade in derivatives such as fraud and human error, for instance by using electronic means to immediately confirm the terms of OTC derivatives contracts.

5.3. Regulation on Wholesale Energy Market Integrity and Transparency

The Regulation on Wholesale Energy Market Integrity and Transparency (REMIT) is an EU regulation designed to increase transparency and stability in the European energy markets, power and gas, while preventing inside trading and market manipulation. REMIT became operational in the European Union in 2011. Some obligations around registration and transaction reporting only came into effect after the REMIT Implementing Acts were approved. The EU Agency for the Cooperation of Energy Regulators (ACER) is responsible for the supervision and regulation of energy markets in accordance with REMIT.

As it is mentioned in the REMIT, the most important goal is to have fair and competitive prices on wholesale energy markets in Europe. Another ambitious goal that REMIT sets is to increase the integrity and the transparency of the wholesale energy markets and that prices that are set on wholesale energy markets reflect a fair and competitive relationship between supply and demand, and that no profits can be drawn from market abuse [EURO11].

The need for reporting has brought the creation of the the largest database in the European energy market, the ARIS system, which collects daily more than 1.5 million records [ACER17].

Starting from October 2015 Organized Market Places (OMP) and the European Network of Transmission System Operators for Gas and Electricity (ENTSOs) have the obligation to report to the ARIS system the following: OMPs have to report data from the records of transactions in wholesale energy contracts, including orders to trade, admitted to trading and the ENTSOs have to report fundamental data from their central information transparency platforms.

Starting from April 2016, market participants, TSOs, LNG System Operators (LSO) and Storage System Operators (SSO), have the obligation to report to the ARIS, data resulting from OTC, standard and non-standard supply contracts and transportation contracts from market participants, as well as reportable fundamental data from all aforementioned operators.

Finally, starting from January 2017 market participants need to comply with the obligation to disclose inside information on their website and to enable the web feeds so ACER can collect the data efficiently.

Under Article 15 of the REMIT persons professionally arranging transactions (PPATs) have two main obligations: to notify the national regulatory authority (NRA) without further delay, when it reasonably suspects that a transaction might breach the prohibition of insider trading or the prohibition of market manipulation of REMIT and to establish and maintain effective arrangements and procedures to identify breaches of Article 3 or 5 of REMIT [EURO11]

5.4. MARKETS IN FINANCIAL INSTRUMENTS DIRECTIVE II

Since its implementation in November 2007, MiFID has been the basis of capital markets regulation in Europe. Though, not all benefits have been experienced by the investor as initially predicted. MiFID II is aiming to address the deficiencies of the original MiFID release and respond to lessons learned during the financial crisis.

As the commodity and energy trading market grew in complexity since MiFID I came into force and the participants dealing in commodities increased, transparency has become even more important for regulators. The main novelties in respect of the previous MiFID are that the reporting scope is wider, exemptions are very restricted and position limits have been introduced.

The reporting scope is broader because new instruments have been added, such as, physically settled commodity derivatives traded on Organized Trading Facility (OTF), emission allowances, C6 commodities derivatives and C6 energy derivatives which includes physically settled oil and coal derivatives traded on an OTF (options, futures, swaps, and any other derivative contracts mentioned in Section C.6 of Annex I relating to coal or oil) [SNOW14]

There are no more exemptions for commodity dealers and for proprietary trading for commodities for firms trading on a Regulated Market (RM) or Market Trading Facility (MTF). Furthermore, quantitative tests have been included to the ancillary activity exemption.

A set of test and position limits have been introduced. The Market Share Threshold test is used to determine if the firm is a large participant in a particular Commodity asset class while the Main Business Threshold Test compares the company's trading activities. Positions limits are applied by the NRA on the firm's net positions and aggregated positions at a group level for all commodity asset classes traded on an EU venue and the economically equivalent OTC contracts.

It must be noted that that bilateral OTC participants trade mostly forward contracts and these have to be physically delivered what means that most of the OTC market is excluded from MiFID II

5.5. POTENTIAL IMPACT OF USING BLOCKCHAIN FROM A REGULATORY PERSPECTIVE

In this paragraph, the main issues but also benefits of using the new technology will be discussed presenting if necessary possible modifications to the regulation.

The very nature of blockchain where registers are immutable could be incompatible with the common goal of regulation to have the most updated information in the relevant repositories. For instance, in case a record has been erroneously introduced, a mechanism must exist to correct the data. However, a new transaction in the blockchain could be used to update the wrong record for instance by adding a time stamping rule where only the most recent record must be taken into account. An editable blockchain could also be the answer but it would be a big deviation from the original spirit of the technology.

As stated in [ESMA17] regulatory reporting under MiFID and EMIR could be done through a blockchain, what could be assessed as an advantage because the centralized trading repository, an intermediary, would not be needed any more. However, some changes to the existing regulatory requirements may be needed, as for instance the regulatory authority in charge of the monitoring should be an active participant in the blockchain by operating a node with privileges to disclose the relevant information under scrutiny depending on the regulation it is responsible for. This brings the point that different roles must be created and a set of rules which defines which level of access should have each regulatory body must be defined.

Other possible regulatory problem would be the jurisdiction regarding post-trade activities because by definition the blockchain have their records distributed among all the nodes and is not restricted to a defined location. This could also need and adaptation of the law.

Anonymity in trading must be assured in order to avoid market manipulation and disclosure of trading strategies. However, before the trade has been executed the counterparties must know if they can trade with each other. This is done for instance with a credit matrix which contains the tradable counterparty and its credit limit. This information is daily updated through the brokers. In a blockchain, with no broker as intermediary new ways must be found. To keep privacy among participants some solutions are being developed. For example, the use of private keys would allow that only the two parties to a given transaction have access to the full details of the transaction. Yet, this could be an issue for other market participants acting as validators. While the use of private keys and encryption could help address some of the issues, they might not suffice to guarantee the privacy that would be needed for instance in a situation where the identity of a market participant, although technically unknown, is inferred from its trading patterns recorded in the system [ESMA17].

Governance is the last issue to be reviewed. In a scenario of a distributed ledger where the centralized market operator is not needed any more the promoters of the blockchain could face conflict of interest in how they govern it. Strict rules that do not discriminate between promoters and plain participants must be incorporated.

The role of validator nodes must be analysed under REMIT because they may be categorized as PPAT. As mentioned before these entities are obliged among others to monitor the market and report suspicious behaviour to the competent authority. Because of the encrypted nature of blockchain this could not be done by those validators. This could be arranged with the participation of the authority itself by operating a node with access to all the relevant information to detect potential market abuse as in the proposed case of regulatory reporting.

5.6. Conclusion

Regulators should join blockchain projects in development from an early stage so they can understand and analyse the technology and guide the implementation of the wholesale trading, assuring it complies with the law. Besides, they should anticipate the relevant changes needed, keeping the purpose of the law but adapting it to the new technology, so blockchain projects are not delayed by regulators' inaction and because the platforms do not comply with the regulation because of minor technical details. The EU Commission has already requested to start to work in this direction but unfortunately progress is slow and probably the implementations under way will go faster than regulation.

6. *Conclusions and Future Work*

Chapter 6. Index

6.1. CONCLUSION

Energy trading business has to achieve efficiency by reducing overall costs per trade. An interesting solution could be the use of blockchain for trading given that this technology promises no transaction costs, transparency and enhanced security making central markets unnecessary.

A complete description of the blockchain technology linked to the energy sector has been performed with emphasis in energy trading. The fundamentals of traditional energy markets have been reviewed to contextualize the use of the new technology. In this new infrastructure the lifecycle of a OTC trade (pre-trade, execution and post-trade) would be optimized in different levels.

With the increment of renewable and linked to it the foreseeable increase of transactions in spot market, it has been proved that a new infrastructure with no variable but low fixed costs could replace those market venues. The large companies could be the most benefited in the first stage but a closer look reveals that the small companies, not only the existing ones but the future small players like small energy communities producing renewable energy and prosumers would be the most favoured. It could also be concluded that the end consumers in the retail market could also benefit given that the intermediary costs are reduced dramatically.

The study has been focused in the power spot market of Germany but it could be theoretically used in any power and gas wholesale market in any given European country, therefore, the savings would even be higher than the one reflected on this research. The recurrent annual cost reductions computed, only taking into account the German spot market, amount 99,91% for large companies, 98,32% for medium companies which participated in the development of the infrastructure, 91,58% for medium companies which did not participate and 96,65% for small companies which did not participate as well. The traditional market operator could not beat this business model because of their complex and costly structures even if they try to change their current business models.

The market research in the form of a survey, whose significance can be considered high, has revealed some important insights from employees working in trading companies, mainly in electric utilities. Everyone considers that blockchain will affect somehow the business but its impact is not clear yet, leading to the partial or complete replacement of intermediaries in the long run. The most impacted intermediaries will be OTC electronic platforms and brokers, with Power Exchanges and Clearing Houses perhaps changing some part of their role but surviving to disruption in the short term. Regulation is seen as the most important barrier to overcome followed closely by governance. Governance practices will have to evolve due to the new setting where there is no central body and conflict of interests could arise. Other barriers to consider are the state of the art in technology and the lack of liquidity that could be overcome with time. All participants agree that cost reduction is the main benefit found in blockchain and executing deals is a quick win application. Finally, the majority of respondents think that blockchain will be mainstream around 2023.

Finally, some regulatory issues have been detected when using a blockchain to trade energy but the technology could also make some regulatory processes more efficient: error correction in trade repositories could be solved by new mechanisms, regulatory reporting and market abuse monitoring could be done more economically if the regulator forms part of the blockchain, jurisdiction would remain an open question because of the distributed nature of the technology, full anonymity of counterparties must be assured but yet to be checked in this use case. Governance practices must be redesigned in order to avoid conflict of interests among energy trading peers.

6.2. FUTURE WORK

The current study is based in estimative costs for a new infrastructure based on blockchain to trade energy and it it would be interesting that other researches compute the costs of the infrastructure to compare them with this research. Given that new projects will be deployed and start-ups will appear in the coming years, it would be interesting to compare their commercial offer to the figures shown here and if their business models concur with the one proposed here.

Another attracting field of research is the market design with this technology at its core. One of the many subjects to deepen would be the interoperability of blockchains as proposed in the thesis, for example, the interconnection of a P2P platform for distributed energy generation with a P2P wholesale energy trading platform. There would be a rich set of use cases and research opportunities for the synergies and potential savings.

Finally, the adaptation of current regulation and adoption of the technology by regulators is key to predict the success of the technology in the energy business sector. Regulators should facilitate the introduction of this technology which brings relevant savings and allow small market members to participate in the wholesale energy market given that transaction costs are very low. However, still progress has to be made to integrate regulators in the blockchain infrastructure so they can exercise their monitoring task and define some legal issues as jurisdiction and governance.

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Annex A. Survey Data Sheet

- **Period**: 23.05.2018 to 23.06.2018
- **Respondents**: by invitation only through an email with a link to an URL.
- **Validator respondents:** before sending the survey it was tested with 2 pilot respondents. This test was excluded from final
- **Participants profile**: members of the European energy trading community with at least basic knowledge on blockchain.
- **Number of surveys:** 26 or 52% of contacted people.
- **Average completion rate:** 100%.
- **Typical time spent:** 3 minutes and 34 seconds.
- **Privacy**: anonymous.
- **Type of questions**: multiple choice and ranking choice.
- **Compulsory answers**: all.
- **Length**: 10 questions.
- **Progress indicator**: yes.
- **Costs**: time spent on learning survey techniques, survey design, data collection, interpretation and report.
- **Online survey service and type of account**: free account in https://www.surveymonkey.com/

Annex B. Online Questionnaire

* stands for compulsory answer.

*1. What type of company do you work for?

- Electric Utility
- Oil & Gas Company
- Trading House
- Energy Service Company
- Municipal Utility
- Other

*2. How many people are employed at your company?

- Less than 100
- From 100 to 1000
- More than 1000

*3. How deep are you involved in a Blockchain project?

- None
- A little
- Big part of my work

*4. Could Blockchain change the way for the wholesale trading of energy?

- Yes
- Possibly
- No

* 5. Will blockchain replace the current intermediaries in the energy trading business?

- Yes
- The biggest part
- Some of them
- No

*6. Please rank the following intermediaries on a scale from 1 to 4, with 4 being the most impacted intermediary by the use of blockchain on wholesale energy markets.

— Clearing houses
— OTC Platforms
— Brokers
— Power Exchanges

*7. Please rank the following barriers to trade energy in a blockchain on a scale from 1 to 4, with 4 being the most important barrier.

— State of the technology
— Regulation
— Not enough market participants interested in using it - illiquid market
— Governance

*8. Please rank the following benefits of using blockchain in energy trading on a scale from 1 to 5, with 5 being the most important benefit.

— Cost reduction
— Security
— Transparency
— Other
— No benefit

*9. Please rank the following processes of an energy management department according to its potential improvement thanks to blockchain on a scale from 1 to 5, with 5 having the most potential.

— Wholesale energy trading
— Deal reconciliation
— Settlement
— Nomination
— Deal standardization

*10. When do you think that blockchain will be mainstream for energy trading?

- 2019-2021
- 2021-2023
- Later that 2023
- Never