Possibilities for blockchain in the energy transition

Creating a classification for existing blockchain initiatives and a search for new opportunities for value added appliance of blockchain in the energy transition

David Lamers

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DAVID LAMERS

SUPERVISORS:

J.M. MOONEN *(FACULTY OF BMS, UNIVERSITY OF TWENTE)*

N. SIKKEL *(FACULTY OF EWI, UNIVERSITY OF TWENTE)*

J. VAN DER GRAAFF (ENERGY EXCHANGE ENABLERS)

UNIVERSITY OF TWENTE.

ENERGY EXCHANGE ENABLERS

MANAGEMENT SUMMARY

Purpose

The energy transition is a constantly moving and developing endeavour impacting every person worldwide. Developed countries are transitioning from a central supply where energy is generated from (mostly) fossil fuels to a decentralized supply by renewable energy sources, like solar panels and wind turbines. The challenge to keep a grid in balance, so as to match demand and supply, is becoming more difficult every day. Since renewable energy sources do not offer flexibility in supply – as traditional production does – top-down regulations are the safety net of first world's energy grids. A reliable and affordable energy grid is nowadays maintained through balance responsible parties and government subsidiaries. It makes customers unaware of the most important aspects of the energy transition while energy prices rise. The decentralization creates grid loads on parts of the grid it was not made for and so, can cause grid congestion. Increasing peaks in uncontrollable supply and demand requires flexibility in both, and (near) real-time settlement in order to maintain an affordable and sustainable energy grid. Also, locality becomes more important to reduce grid congestion. Decentralization, flexibility, locality and time being the most important aspects of the energy transition, this report investigates the possibilities for blockchain as supporting technology in the energy transition. Its real-time peer to peer transactions could support in the decentralization, flexibility, locality and time.

Blockchain technology empowers a fully decentralized platform for payments and data exchange and was created in 2008. In 2009 it was first applied in Bitcoin and nowadays it has evolved to a smart contract platform being able to execute scripts on decentralized machines. Despite its limitations in scalability, security and its significant energy consumption, it is a promising technology already being applied in multiple fields including the energy sector. Solutions for existing problems are being developed and another, new generation of blockchains, the directed acyclic graphs, are also providing new opportunities like feeless transactions. Start-ups as well as established companies are working on innovative and novel solutions within the energy transition. This report takes a perspective at all levels within the electricity markets and elaborates on two detailed solutions for Energy eXchange Enablers (EXE), a start-up focusing on technology solutions in energy transition.

Research design

This study first sketches a theoretical framework, based on the characteristics of blockchain technology, the energy markets and the energy transition. With those aspects in mind, current blockchain initiatives within the energy sector are analysed and classified and state-of-the-art initiatives are emphasised. Also some new opportunities fitting the energy transition and blockchain, not yet described in literature, are analysed. Existing as well as new opportunities form the classification of blockchain in the energy transition. The EXE product portfolio, focused on the energy transition, is analysed and is mapped onto the classification made. For possibilities with the highest potential, fitting the products strategy and blockchain adding high value, a blockchain proposition is designed and validated among nine energy market professionals and blockchain experts.

Findings

The classification of existing initiatives and new opportunities has led to nine opportunities for blockchain within the energy transition as shown in the table on the next page.

Energy trading	Energy trading on the blockchain, either peer to peer, with bid curves or directly on the energy markets
Local markets	Creating geographically close clusters being (almost) self-sufficient, trading energy on the blockchain
Rewarding cryptocurrency	The rewarding of people for their supply of renewable energy to the grid with cryptocurrency
Paying or receiving with cryptocurrency	Letting people share their energy connection and receive and pay for every kWh
Grid balancing	Decentral balancing of the grid by using device agents, possibly with cryptocurrency reward
Demand response communication	Demand response over the blockchain with other goals than grid balancing, for instance responding on the current energy price
Real-time guarantee of origin	Guarantee of origin on real-time basis instead of aggregated yearly by instant creating deals between supply and demand
Sharing meter data	Share (live) meter data on the blockchain to replace central parties like EDSN
Multiple suppliers at one connection	Variable suppliers at one certain grid connection with changing supplier, and so settlement, every PTU

Within the EXE product portfolio and each product strategy, significant opportunities are there to focus on energy trading, local markets and multiple suppliers with their product named Entrnce. For energy trading as well as multiple suppliers, a proposition was created and a demo was built using the Ethereum blockchain. Since time plays an important role in the energy transition, the design for the multiple supplier proposition also includes a real-time guarantee of origin solution. Regulations, however, make it difficult for any blockchain proposition within the energy sector to fully release its potential. In the current environment, a lot of administrative parties with complex processes not made for renewable energy are present. In an unregulated environment these would not be required anymore. Some parties involved in the energy grid and markets also do not entirely facilitate the energy transition.

Recommendations

For EXE, the main recommendation is to actively participate in possibilities where potential was found within the current product portfolio. The designed propositions were created starting off from EXE's software architecture and are therefore relatively easily adaptable. Since energiecoöperaties take a lot of effort in the energy transition by focusing on local and renewable energy, it would be useful to facilitate an energy trading system affordable for suppliers with below 10.000 customers. This request from the market is because common systems are too expensive. At higher level, it would furthermore be useful to reduce the regulations applying for energy suppliers so energiecoöperaties can operate in a more flexible environment. EXE cannot facilitate such a system directly to the market due to regulations. Therefore it is advised to work together with an organization specialized in blockchain or energy. Since other initiatives facilitating energy trading on the blockchain will also arise, EXE should take an active role to cooperate so they can fulfil the BRP role for their portfolios so the other party does not become a competitor.

In general, to fully enable an environment for blockchain appliances accelerating the energy transition creating a real smart energy grid, the following steps are required; (1) real-time data access is required at grid connection level and at low and medium voltage grids, (2) regulations for energy suppliers should be loosed, (3) bottom-up experiments outside current regulations should be allowed more at government level, (4) electric vehicle charge stations should play an important role in controlling the smart grid, (5) demand response systems with an open infrastructure should be available and (6) parties should not be limited to certain roles.

Most current limitations of the blockchain technology are widely known and are solved presumably in a few years. Currently, private blockchains are most useful in a development and test environment and consortium blockchains can already successfully be used in lower-scale production environments. In any development environment it is advised to revise the state-of-the-art blockchains regularly since they quickly improve.

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GLOSSARY

ACM Authority for Consumers & Markets

APX Energy exchange spot market

B2B2C Business to business to consumer

BRP Balance Responsible Party

C-AR Centraal Aansluitingen Register (central connection register)

Consortium blockchain Permissioned blockchain to cooperating parties

CPO Charge Point Operator

DAG Directed Acyclic Graph

DSO Distributed System Operator

EAN European Article Number (used to indicate a meter)

EDSN Energy Data Services Netherlands

Energiecoöperatie cooperation promoting renewable energy, most of the times at smaller geographical areas

eMSP e-Mobility Service Provider

E-program Electricity-program

ERC-20 Token standard for the Ethereum blockchain

EV Electric Vehicle

EVM Ethereum Virtual Machine

GoO Guarantee of Origin

Grassroot Community-led solution for sustainability

IRMA I Reveal My Attributes

kWh Kilowatt hour

KYC Know Your Customer

M2M Machine to Machine

ODE Opslag Duurzame Energie (renewable energy storage)

ODA Onafhankelijke Diensten Aanbieder (independent services provider)

P1 Port on a smart meter providing real-time data

P2P Peer to Peer

P4 Port on a smart meter transmitting data over GPRS

Private blockchain Permissioned blockchain

PTU Program Time Unit

Public blockchain Blockchain accessible for everyone

RGO Regional Grid Operator

Salderingsregeling settlement of the supplied energy with demanded energy at yearly level

Token A cryptocurrency on a blockchain

TSO Transmission System Operator

V2G Vehicle to Grid

1 INTRODUCTION

In this chapter the research is described by first summarizing the energy markets and blockchain technology. In the second section the most important problems in the energy transition are outlined. The research questions, method and design are outlined in the consecutive sections.

1.1 BACKGROUND INFORMATION

The energy markets as well as the blockchain technology are both complex concepts. Customers in the first world are luxuriated with energy on demand. In the past, centralized supply and parties have maintained the electricity grid delivering energy created from nonrenewable energy sources like fossil fuels. Since supply has to meet demand to keep the grid in balance, a lot of parties are involved in the delivery process of electricity. Suppliers have balance responsible parties predicting usage and selling and buying energy from up to four years upfront. Transmission system operators take care of the high voltage grid and make sure through reserve and regulating capacity, and in emergencies emergency power, that the grid is in balance. Distributed system operators maintain the medium and low voltage grids, create connections for customers and should provide enough capacity by taking a proactive congestion management role. With the current endeavor in the energy transition, a decentralization is occurring and customers should take an active role in the supply and demand of energy. This offers opportunities for the blockchain technology.

Blockchains are distributed ledgers with technologies that allow to reach consensus and immutable states without a central or third party. It solves the Byzantine Generals' problem and double spending problem often faced in digital currencies without third party. Besides the transfer of value through a cryptocurrency or token, it also allows to run a piece of code on the virtual machine created by all nodes in the blockchain network. This code, a smart contract, can for instance automate the transfer of value under certain conditions. Since a blockchain is immutable, it can also be used to save important data. In cases of privacy sensitive data it offers the possibility to save hashes of for instance certificates so when one receives a certificate off blockchain, one can validate the authenticity by comparing hashes.

The research was executed at the company Energy eXchange Enablers (EXE) which focuses on the energy transition. With their three software products, they want to support local energy, demand response and direct energy trading between demand and supply and to the energy markets. Possible opportunities for blockchain within the energy transactions are found and also for the EXE product portfolio.

1.2 PROBLEM STATEMENT

The energy transition has become an important part of most government's focus. In most countries the transition is behind schedule, mainly due to the high financial costs involved and the established companies not always focusing on the transition. It requires a lot of effort to create a grid with 100% renewable energy which is also affordable and reliable. Most important renewable energy sources require a large investment and are uncontrollable in their supply while one expects energy when demanded. To maintain this reliable grid, storage capacity is required and a flexible or shift in demand. Electric vehicles can play an important role in the energy transition due to their ability to store and supply energy from and to the grid and flexible charging opportunities since most of the times they are not used. These factors, together with the world-wide increase in electricity demand (due to for instance EV and houses without gas connection), also require active grid management by DSO's. Grids are having more peak moments due to the high supply by renewable energy sources and more extreme peaks due to the higher demand. Congestion management could be enabled by flexible and decentralized demand response systems and a higher focus on local energy.

Most of the actions within the energy transition are decentralized and require an active role from the customers. Energy prices are rapidly increasing with higher energy tax and special taxes for renewable energy. Customers are encouraged to install solar panels and get for instance subsidiary with the salderingsregeling, requiring a lot of money from the state's treasury. Time plays an important role in the energy transition and is for instance in the salderingsregeling not taken into account. It is questioned if these regulations are sustainable since they will require an increasingly amount of money and do not fit with the characteristics of the transition. Also a nationwide, or nowadays even continent focus is taken while local energy is very important. Blockchain can add value by for instance creating local self-sufficient areas, real-time settlement of supply and demand and real-time guarantee of origin. Its decentralized character, value transfer and contracts are important aspects fitting the energy transition.

1.3 RESEARCH QUESTIONS

The goal of this research is to find, analyze and design possibilities for blockchain in the energy transition. This goal is achieved by answering the following main- and sub-questions. The main research question is:

How can the blockchain technology support and accelerate today's energy transition?

The main research question is answered by first answering the following subquestions:

1. **What are the characteristics of the blockchain technology?**

   A literature research answers the most important aspects of the blockchain technology, its most important advantages and disadvantages and current limitations. An exploratory study is done to look at the characteristics of current blockchain implementations. This question is answered in chapter 2.

2. **What is the current architecture of the electricity market and how are reliable electricity connections provided by all parties?**

   This question was answered with a literature study and combined with knowledge from energy market professionals. The electricity markets and all involved parties are outlined together with their responsibilities in chapter 3.

3. **What are the challenges of today's energy transition?**

   The main drivers, reasons, efforts and complications of the energy transition are outlined in chapter 4. This was achieved by a literature study which besides scientific literature, also focuses also on research reports of consultancy companies. A prospect is also given on the future energy grid.

4. **What are the lessons learned from the blockchain initiatives focusing on the energy transition and how can we classify them?**

   This exploratory research question was answered by looking into thirty existing initiatives using blockchain in the energy sector. The state-of-the-art initiatives were analysed and the total set was classified into five categories. Furthermore, four new opportunities not found in current initiatives are outlined. This important deliverable of this thesis can be found in chapter 5.

5. **What is the potential for blockchain for the EXE product portfolio?**

   Energy eXchange Enablers provides three software products supporting and accelerating the energy transition. These are analyzed and mapped onto the nine potential opportunities for blockchain. The opportunities having the highest potential for EXE are explained in more detail. This research question is answered in chapter 6.

6. **How to develop a blockchain proposition for EXE that fits their product portfolio best?**

   For two opportunities found for EXE having significant potential, a design is made for the concept, its architecture and the architectural fit within the EXE product. The concepts, designs and validation are given in chapter 7.

7. **Which next steps can be taken by research and by EXE to extend blockchain support in the energy transition?**

   Opportunities for successive research in the fields of the blockchain technology, regulatory frameworks and EXE are given in chapter 8.

1.4 RESEARCH METHODOLOGY

The research was executed according to the design science research methodology as published by Peffers et al. (2007). An objective-centered solution is taken since the research was mainly triggered by the industry since there was an opportunity. However, even more opportunities are researched to accelerate the energy transition. The answers to the first three research questions form the theoretical framework for this research and include the blockchain technology, energy markets and energy transition. An exploratory research was executed to research existing initiatives. Possible blockchain solution were identified, each solving a different aspect of the energy transition with different objectives and unique designs.

Two designs are proposed in chapter 7 for the blockchain concepts with the highest potential for EXE. These designs were validated with energy and blockchain experts.

1.5 RESEARCH DESIGN

The research design is visualized in figure 1. The blue rectangles indicate the corresponding chapters of this thesis. The chapters in this thesis follow the order of the research questions.

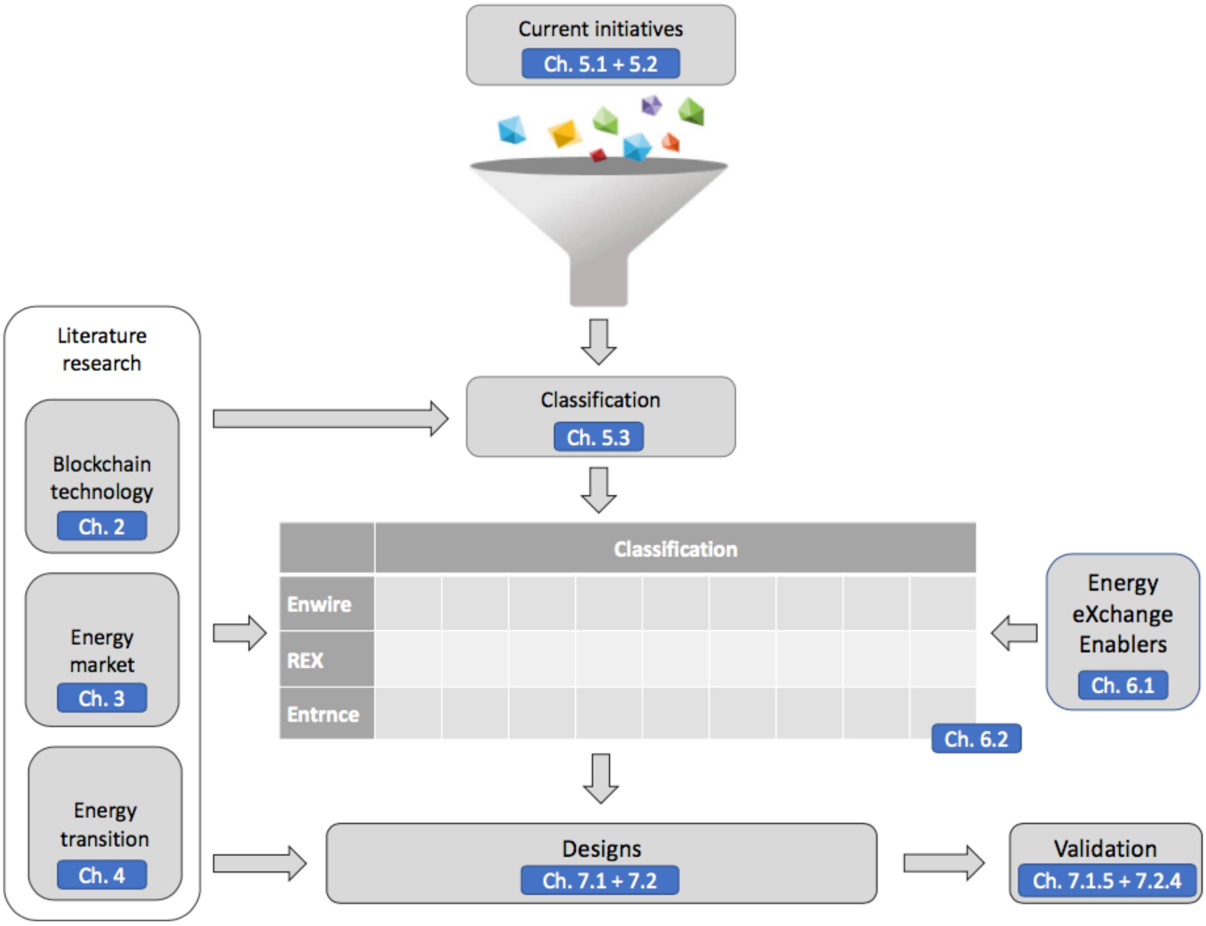

FIGURE 1: RESEARCH DESIGN

2 BLOCKCHAIN

In this section the blockchain technology will be outlined and (dis)advantages are discussed. Different consensus algorithms are compared and explained is how transactions are saved in the first subsection. In section 2.2, different types of existing blockchain implementations are analyzed. This section gives answer to the subquestion:

1. What are the characteristics of the blockchain technology?

2.1 BLOCKCHAIN TECHNOLOGY

The blockchain technology is first mentioned by Nakamoto (2008) who applied the technology in the digital currency bitcoin. A blockchain is a distributed ledger which saves all transactions in blocks. In the next subsections the most important aspects of the blockchain will be outlined: the chain, generating new blocks and the transactions. To reach consensus of the truth multiple algorithms are developed, these are explained in section 2.1.4. Section 2.1.5 discusses the advantages and disadvantages of the blockchain technology.

2.1.1 THE CHAIN

In the blockchain each block contains a list of valid transactions that are hashed and encoded into a Merkle tree (Nakamoto, 2008). A hash is a one-way function that has an input which is fed to the algorithm that calculates an output of fixed size. A hash function always generates the same unique output for each input. When the input differs a little the output is totally different. Since it is a one-way function, it is not by calculation possible to derive the original input when the output is known. The Merkle tree in blockchain is a tree of hashes in which the leaves are the hashes of a transaction. The nodes further up in the tree are the hashes of their children and the Merkle trees are binary, so there are only two child nodes under each node. At the top of the hash tree there is the top hash or root hash. This hash is saved in the block header and also the root hash of the previous block is saved in the block header. Thus, with the root hash one can verify that the transactions in the block are not manipulated since a block with a manipulated transaction will give a different root hash. And since a block contains the root hash of the previous block, a chain is created persistent to modification of the data. The structure of the blockchain with the root hash generated from the transactions through a Merkle tree is shown in figure 2. Table 1 contains the structure of a block of which one field is the block header which is shown in detail in table 2.

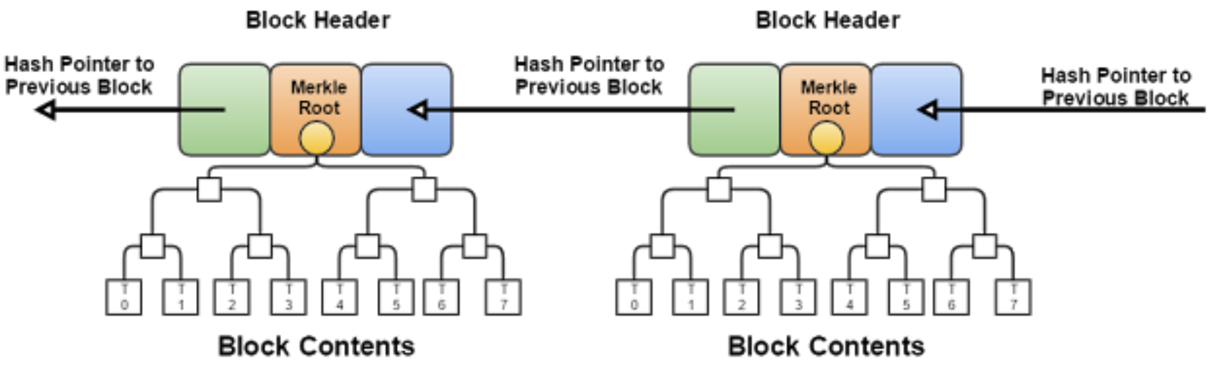

FIGURE 2: STRUCTURE OF THE CHAIN

TABLE 1: BLOCK STRUCTURE

Field	Description	Size
Magic number	Value, always 0xD9B4BEF9	4 bytes
Blocksize	Number of bytes following up to end of block	4 bytes
Block header	See table 2	80 bytes
Transaction counter	Integer	1 – 9 bytes
Transactions	List of transactions	variable

TABLE 2: BLOCK HEADER CONTENT

Field	Description	Size
Version	Block version number	4 bytes
hashPrevBlock	hashMerkleRoot of previous block header	32 bytes
hashMerkleRoot	Root hash of current block	32 bytes
Time	Timestamp	4 bytes
Bits	Target	4 bytes
Nonce	Number increasing with every hash indicating difficulty	4 bytes

2.1.2 GENERATION OF BLOCKS

A block in the chain is generated every time when the mathematical solution to the previous block was found. Most blockchains have a goal in solving an average number of blocks per hour, Bitcoin targets at six blocks per hour for instance (Donet, Pérez-Sola, & Herrera-Joancomart, 2014). To create a block one has to solve a mathematical puzzle with computational power. Since computational power is increasing or decreasing in the whole network, block generation is going faster or slower. To keep close to the target of ten minutes, the difficulty of the mathematical puzzle is changed every two weeks so it becomes more difficult or easier to find the solution. It is important to note that there is nothing as being close to the solution since you do not make progress towards solving it; one just has to be lucky. It is like throwing hundred dices and all dices roll a six, each time you try the chance is the same.

When starting with a new block, a miner collects unconfirmed transactions in the network and when the mathematical solution is found by a miner, the block is broadcasted to the network and added to the blockchain. To every transaction a transaction fee is included and the sum of all transaction fees in the block is rewarded to the miner. So the miners have the incentive to include transactions in the blocks they are trying to solve. It is possible that two or more miners find the solution at the same time which results in a split in the chain. The nodes in a network have a different truth since their truth of the chain is based on the first solution they receive. These splits will be resolved in short time after new blocks are generated since the network will accept only the most complex chain as valid.

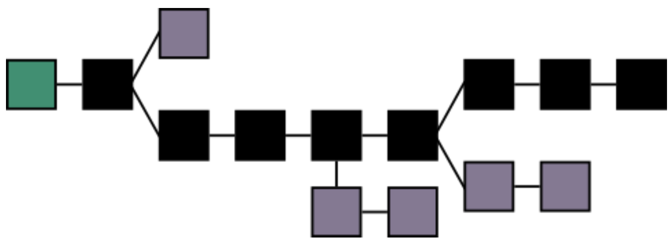

FIGURE 3: THE MAIN CHAIN WITH REJECTED SIDE CHAINS

2.1.3 TRANSACTIONS

A transaction in the blockchain is a transfer of value between one or multiple inputs and one or multiple outputs. The input of a transaction is a reference to the output from a previous transaction. The blockchain does not keep a record of account balances. So when making a transaction, the total value of the previous outputs is added up and the total is used by all outputs. To ensure an account has enough balance to execute the transaction, the fund has to be verified through the link of previous transactions.

A transaction is made between two bitcoin addresses. A new address can be generated by any user by creating a private key which should be a random 32 bytes long number generated from the SHA-256 algorithm. The private key is the most important one since this is the key required to send money. The public key is created through the elliptic curve multiplication which is then hashed through two algorithms and small other manipulations which gives the bitcoin address (Antonopoulos, 2014). All steps are irreversible and shown in figure 4.

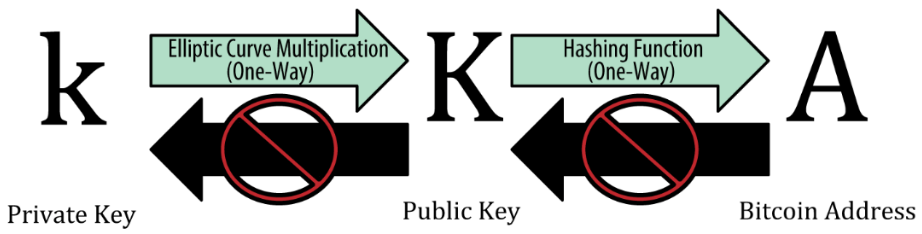

FIGURE 4: GENERATION OF THE PRIVATE KEY, PUBLIC KEY AND ADDRESS

Besides generating public keys, the private key is used to sign transactions when money is withdrawn from the address. With the public key, one can verify that one is indeed the account holder of the address without revealing the private key. Now the user will be able to sign the transaction and spend money from the corresponding address. The transactions are much more complex with for instance scripts that are send in the transactions and executed during the transactions for verification. For now, the current description of a transaction is sufficient.

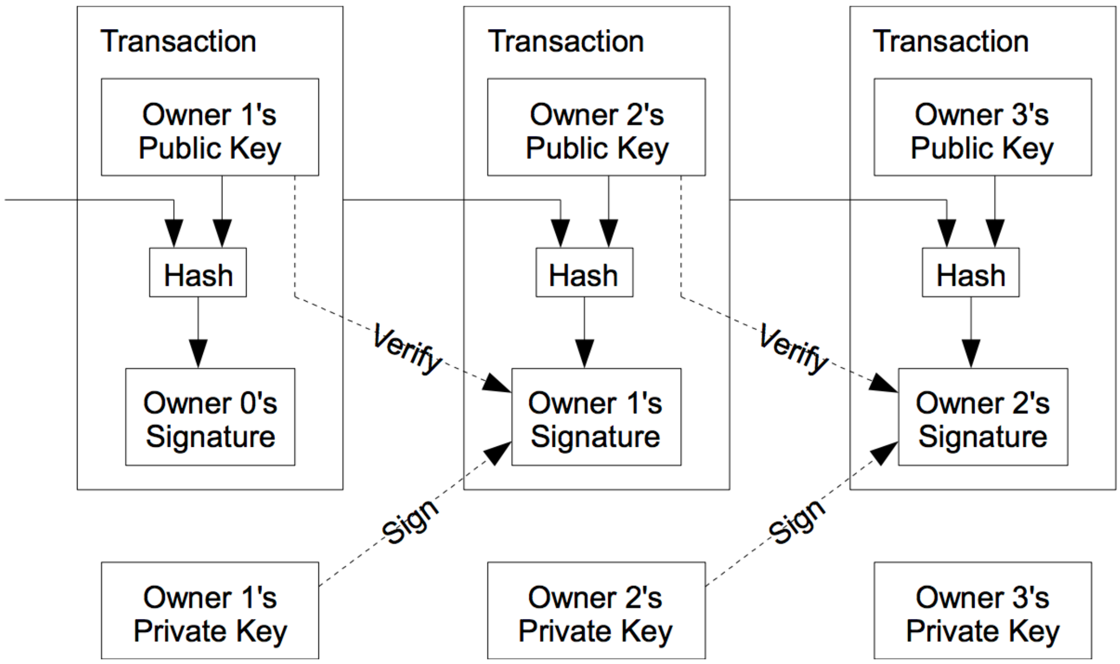

FIGURE 5: SIGNING TRANSACTIONS

2.1.4 REACHING CONSENSUS ON THE BLOCKCHAIN

At the moment there are two popular protocols existing to reach consensus on the blockchain. An implementation of a chain has to choose a protocol for how users of the chain reach consensus of the valid transactions in the chain. Proof of Work, which is also described before, requires users to solve mathematical problems and thus requires resources. The other protocol, Proof of Stake, requires from miners to put up a stake and let them create the new block. The following two sections explain both protocols.

2.1.4.1 PROOF OF WORK

The concept of the proof of work (PoW) system was presented by Dwork (1992) and the term PoW was formalized by Jakobsson & Juels (1999). This system was designed to deter denial of service attacks and service abuses by requiring some work from the service requester. This work is often processing time from a computer and in most appliances, does not result in a useful result. So the use of these resource, the computer and the electricity usage, is wasted.

When a blockchain network is using the Proof of Work (PoW) algorithm to reach consensus on the new state of the network, the work exists in most of the networks of solving a mathematical problem. These calculations happen through miners who all have a copy of the blockchain. Unverified transactions on the network are bundled together into a block. These miners verify that the transactions within a block are legitimate. To verify, they have to find the inverse of a hash and the one who finds the solution announces this to the whole network. Since this is not possible by calculation, one just has to guess a value and put this into a hash function. The miner gets a reward and the verified transactions are stored in the public blockchain. This Proof of Work mechanism was the most important idea by Nakamoto (2008) behind the bitcoin since it allows trustless and distributed consensus.

The difficulty of the calculation is in most implementations of a blockchain increasing over time. For bitcoin, the goal is to release a new block every ten minutes but computing power in the network is added by users every time so block generation goes faster. Therefore, every fourteen days a new estimation is made for the difficulty. Difficulty is set in a number (nonce) and how higher the number, how smaller the chance of finding the solution and so, increasing the average number of calculations needed to create a new block. This increases the cost of block creation so miners need an efficient system.

2.1.4.2 PROOF OF STAKE

The proof of stake (PoS) algorithm is another algorithm which is well known and becoming more popular. To create a new block in a blockchain using the proof of stake algorithm, one has to own an amount of coins (BitFury, 2015). The creator of a new block is chosen in a deterministic way and is depending on its wealth. No mathematical problems have to be solved so instead of mining, the blocks are 'forged'. For instance, when one owns 2% of all coins, this account is able to forge 2% of the transactions. Specific implementations of this algorithm slightly differ; for instance, some chains added a randomization to predict the following forger while others implemented a coin age advantage: when coins are held for longer time in the same account one has a greater probability of signing the next block (King & Nadal, 2012). In a PoS blockchain there are also no block rewards so forgers take only transaction fees. This means that no new coins are generated, so they are all created in the beginning.

A distinguishment can be made between chain-based proof of stake and BFT-style proof of stake. The difference between those two lies in when the truth of the chain is determined; in chain-based proof of stake this is decided after multiple blocks while in BFT-style this is decided within one block. The chain-based algorithm blocks point to some previous block, normally the block at the end of the longest chain. The longest chain here is the truth. In BFT-style, the forger proposes a block but the network still has to agree by voting if the block is part of the chain or not.

A security aspect of PoS is the nothing at stake problem. When there is a consensus failure or there is a malicious attempt and a new fork is created, the optimal strategy for a forger is to forge on every chain. You can try to forge on every fork since it does not cost anything. In this process an attacker can for instance create double spending. In PoW there is costs resources to mine so this cannot happen. Multiple solutions are created to solve the nothing at stake problem, for instance by punishing the attacker (Poelstra, 2015).

2.1.4.3 STRENGTHS AND WEAKNESSES

The PoW algorithm is applied in the Bitcoin blockchain and is the most popular algorithm at the moment. There are still some issues with PoS about security and incentives which should be solved by future tweaks. At the same time, more and more people are turning against PoW, mainly because of the high consumption of electricity. In popular chains like Bitcoin people are spending thousands of dollars for special hardware which require lots of energy to solve the mathematical problems in the PoW algorithm.

How much energy is used exactly is not known, but the most extensive calculation was published in Bitcoin Magazine (2017). Expected is that Bitcoin, so only one cryptocurrency of the existing hundreds, is using about 4,4 TWh annually which is the same as hundreds of thousands of U.S. households. Also the hardware cost of machines able to mine is significant. In PoS this hardware and so electricity usage is minimal so it can run on the simplest single-board computers like a Raspberry Pi.

An important issue in the blockchain is security and possible methods for attackers to somehow insert invalid blocks. In the PoW algorithm this can only happen when one miner or a mining pool (a group of miners sharing the block reward) control 51% of the computational power (Goodman, 2014). This gives full control of the network so the chain can be manipulated by for instance allowing double spending. It is almost impossible to gain 51% of the computational power since this requires a huge amount of money. In PoS, one has to own 51% of the currency to perform an attack. Besides that, this also requires a huge amount of investment in the cryptocurrency and the attack will destabilize the cryptocurrency which diminishes the value of their stake (Houy, 2014).

Another aspect of PoW is that when the price of the cryptocurrency drops, people have less incentive to mine which reduces the security of the system. This incentive drop can also happen after 21 million bitcoins have been mined since no more new bitcoins will be generated afterwards.

At the moment Bitcoin, Litecoin and Ethereum are the most popular cryptocurrencies using the PoW algorithm. Ethereum is using PoW but on the roadmap is a change to PoS. Peercoin and NXT for instance use PoS although a lot of cryptocurrencies are implementing a hybrid form of PoS and PoW (e.g. Bentov, Lee, Mizrahi, & Rosenfeld (2014) applying Proof of Activity) which should prevent security issues in the PoS algorithms and at the same time solve the electricity usage in the PoW algorithm.

2.1.5 (DIS)ADVANTAGES OF USING A BLOCKCHAIN

The blockchain offers two important general solutions; the Byzantine Generals' Problem and the double spending problem. The Byzantine Generals' Problem is the problem that you do not know which transactions are valid in a distributed network (Miller & Jr, 2014). By using the PoW or PoS algorithm one ensures that only valid transactions are added to the blockchain. In digital currencies the double-spending problem is the occurrence of spending the digital money twice. The solution in centralized systems is that a trusted third party verifies if the money has already been spent. Blockchain resolves this problem by verifying each transaction added to the blockchain by checking if the input for the transaction is not already spent.

The main disadvantage of blockchain is still cyber security concerns. The PoW algorithm is already applied on large scale but people are still worried about for instance the 51% computational power scenario. PoS is not proven at a large scale as PoW but might for the future, when solutions for current problems are created, solve the large energy consumption of PoW. Bitcoin is also creating blocks every ten minutes which still have to be confirmed, so for some implementations a blockchain like Bitcoin will be too slow. Furthermore, applying blockchain at large scale still requires cultural adoption, large initial costs and a clear regulatory status.

Besides this, a blockchain offers in general the following benefits (Iansiti & Lakhani (2017) and EY (2016a)):

- Transparency for all transactions
- Immutability; transactions cannot be changed or deleted
- Reducing risk since third party are eliminated
- High quality data which is complete, consistent and widely available
- No central point of failure so can withstand DDoS attacks
- One single ledger instead of multiple ledgers
- Faster transactions worldwide since the blockchain is processing 24/7
- Lower transaction costs since third parties are eliminated

2.1.6 DIRECTED ACYCLIC GRAPHS

In the second half of 2017 blockchains using a directed acyclic graph (DAG) emerged. The amount of these is still very low so to explain their concepts the IOTA DAG is used in this section as example. This DAG is the most mature one at the moment and is called the tangle (Popov, 2017). Unique concepts of IOTA are that there are no transaction fees and zero value transactions are possible on the tangle in order to only send data. Transaction fees are eliminated by not using miners but let the user that does the transaction perform a little proof of work. A user doing a new transaction has to validate two other transactions. These are selected according to an algorithm and are called tips. An example of the tangle is shown in figure 6 where each square is a transaction and the grey squares are tips which still have to be validated by upcoming transactions. Unlike with blockchain, there are no blocks or transactions fees. It is possible to send data with every transaction and extension interfaces allow for instance for quantum proof data to be send over the tangle without the transaction having value. Flash channels allow for payment streams without any data for micropayments. IOTA's main focus is on machine to machine interaction.

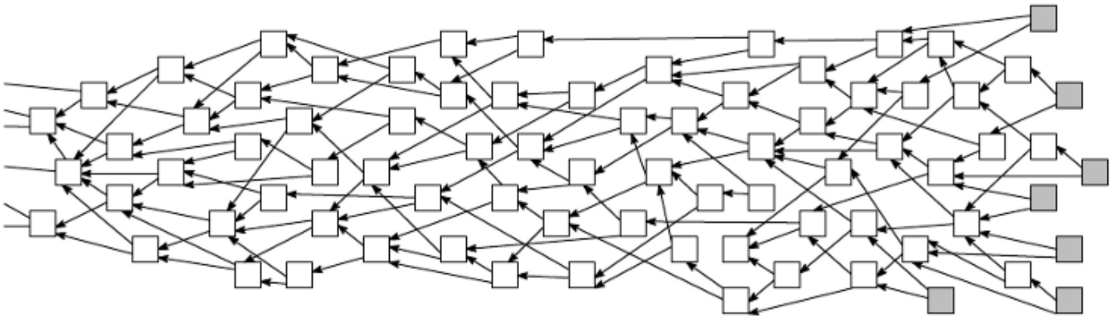

FIGURE 6: VISUALIZATION OF THE IOTA TANGLE (POPOV, 2017)

2.2 APPLYING BLOCKCHAIN

In this chapter the appliance of blockchain will be analysed at different levels. First of all, the three most popular cryptocurrencies by market capitalization will be outlined. At the level of appliance in industries, the financial, energy, and public service industries will be explained. Some big software vendors like IBM and Microsoft are offering blockchain in their platforms as well, this will be shortly explained in the last section.

2.2.1 CRYPTOCURRENCIES

A cryptocurrency is an applied blockchain with certain implemented algorithms and is running over a large amount of nodes. The market capitalization of a cryptocurrency is the total worth of all coins and might significantly increase compared to traditional share markets since the circulating supply in cryptocurrencies is in most cases constantly increasing by the block reward. Table 3 shows the information about the three cryptocurrencies with the highest market capitalization. In the next subsections their unique propositions are explained.

TABLE 3: MARKET CAPITALIZATION OF THE TOP THREE CRYPTOCURRENCIES, AUGUST 2017

#	Name	Market Cap 11-06-2017	Price	Circulating Supply
1	Bitcoin	$48,351,627,929	$2950.87	16,385,550 BTC
2	Ethereum	$32,154,060,971	$347.99	92,400,710 ETH
3	Ripple	$10,321,601,091	$0.269308	38,326,381,283 XRP

2.2.1.1 BITCOIN

Bitcoin (Nakamoto, 2008) was invented by Satoshi Nakamoto and was the first blockchain database which solved the double spending problem for digital money. Nakamoto published in 2008 'Bitcoin: *A*

Peer-to-Peer Electronic Cash System' and released the first bitcoin software a few months later. Remarkable is that it is unknown who Nakamoto is or who they are even though he or they were active in the development of the bitcoin till 2010. He claims to be a man living in Japan but a lot of speculations are going on and its real identity is still unknown.

Bitcoin is a digital payment system based on the blockchain and works according to the PoW algorithm. New bitcoins are released to the miner who finds the solution to the mathematical problem and thus when a new block is released. Every 210.000 blocks, which is approximately four years, the reward is 50% lower. Therefore, the total amount of Bitcoins is expected not to exceed 21 million. Since Bitcoin was the first, and is still used as base cryptocurrency at exchanges, it is still the most popular cryptocurrency. (Web)shops around the world support bitcoin as payment method. Because of the huge popularity it is facing significant verification speed with recent research showing 43% of the transactions are not included in the blockchain after 1 hour after first appearance and only 93% of transactions value being included after 3 hours (Pappalardo, Di Matteo, Caldarelli, & Aste, 2017).

2.2.1.2 ETHEREUM

Ethereum (Wood (2014) and Buterin (2016)) has a different goal than Bitcoin, it is often described as crypto-equity since it is more than just money. The Ethereum blockchain provides the Ethereum Virtual Machine (EVM) which can execute scripts using a network of public nodes. These scripts, called smart contracts, can be written in Solidity which is a Turing complete programming language. These smart contracts facilitate online contractual agreements and can be executed by users. Besides the smart contracts it also offers a cryptocurrency like bitcoin called ether which can be transferred between accounts.

Currently Ethereum runs the PoW algorithm but a unique transition is on the roadmap to PoS. Since Ethereum is switching of algorithm mid-flight there is a lot of criticism of concerned users. The discussion has led to the decision of developing an implementation of the PoS protocol named 'Casper'. This protocol has a solution for the nothing at stake problem and punishes participants which are not following several rules. Forgers can vote for the right block and the block which has the most votes is added to the blockchain. If you vote for multiple blocks you will lose ether. The first version of the Casper protocol is now (end 2017) tested on the test network and will be released in 2018.

The smart contracts Ethereum is offering, contain functions to interact with other contracts, make decisions, store data and send ether. Smart contracts can be added to the network by users but are executed on the network (the Ethereum Virtual Machine) and exist as long as the network exists. To execute a contract 'gas' is needed. Each function in the code will be measured by a cost measured in gas since it requires resources. For instance, a SHA3 operation requires 20 gas and a transaction 500. The gas price differs and can also be expressed in ethers, so when one account executes a smart contract it has to pay ether. The gas is rewarded to the nodes since the execution takes their resources. The idea behind gas is that it stops denial of service attacks from infinite loops or inefficient code which makes an attacker pay for performing an attack.

Dapps are decentralised applications that can be built on top of the Ethereum network since they rely on self-executing smart contracts. A Dapp is open source, since the content of a smart contract is visible, and operates autonomous. Data is saved in the decentralised chain. Examples of Dapps are Augur, which attempts to forecast the outcome of real world events by letting people bet and gambling games where people can bet ethers or other tokens in worldwide known gambling games.

A very interesting project that was running on the Ethereum blockchain was the DAO, a decentralized autonomous organization. Through crowdfunding hundred million dollars were raised to create the organization that relied on a set of contracts. Investors got DAO token that gave them voting rights for projects in the organizations. However, the complexity of the code base together with the rapid deployment brought a lot of security issues. Most of them were solved quickly but on 17 June 2016 a combination of exploits was used in an attack and 3.6 million Ether was stolen. The Ethereum blockchain was hard forked and now two Ethereum chains exist; Ethereum and Ethereum Classic.

Smart contracts also allow for the creation of tokens on the Ethereum blockchain. One can create a own token with its own value. These smart contracts have been standardized in a so called ERC-20 token interface contract (code snippet 1) and allows crowdfunding and payments for a business concept on the Ethereum blockchain.

2.2.1.3 RIPPLE

The goal of the Ripple is to facilitate a peer to peer payment network like Bitcoin. The difference with Bitcoin is that you do not have to wait till transaction validations by the network; the transactions are executed immediately. This should also allow to connect a Ripple account directly to a real bank account. Especially in international bank transactions this would provide fast and feeless transactions. It provides a flexible platform which offers also bridges to other currencies. One pays with USD and underwater the USD is changed to XRP and then to EUR to provide quick bank transactions.

The generation of new Ripple coins is regulated and so, no Ripples are rewarded for mining. The Ripple does not use PoW or PoS but has its own algorithm; Ripple Protocol Consensus Algorithm (RPCA). Most cryptocurrencies are created, developed and maintained by the community, but the Ripple network is developed by the company Ripple Labs. The Ripple chain itself is as third cryptocurrency worldwide very popular but the protocol is also increasingly adopted by banks and payment networks to investigate in the blockchain as new financial platform. So when banks use the Ripple network this does not mean the Ripple cryptocurrency is used for international currencies. Therefore, the value of the Ripple coin does not necessary increase in value and is not connected to these banks, but it definitely proves the trust and safety in the Ripple blockchain implementation.

2.2.2 INDUSTRIES

Started as technology behind the Bitcoin cryptocurrency, it is predicted that blockchain will disrupt almost every industry in the world (PwC (2016), EY (2016b) and Iansiti & Lakhani (2017)). Where the blockchain implementation in bitcoin is rather slow and only allows digital financial transactions there are now hundreds of cryptocurrencies with most of them having another unique proposition. Different algorithms, extensions and connections to the real world are in place which distinguishes the cryptocurrencies from each other. Blockchains can also have limited access so only allowed users can use it and large software vendors are offering platforms where one can easily set up an (private) blockchain. In the next sections the opportunities for each sector will be shortly outlined. Another option is to create a consortium blockchain where only access is granted to companies involved in the blockchain project.

The financial service industry is showing the most interest in blockchain through public as well as private blockchains (Deloitte, 2015a). The distributed ledger which is offered by the blockchain can take over the function of banks, stock exchanges and payment processors (Trautman, 2016).

Blockchain can reduce the infrastructure cost of banks and their reliance on central systems. Nowadays, banks rely on a central infrastructure which is a target for hackers and the same holds for systems like SWIFT, which facilitates all international transactions. Transactions are immediately processed worldwide at low cost (Jaag & Bach, 2017) and international transactions do not have a higher cost than national transactions. Ripple Labs is the biggest independent developer of a blockchain technology facilitating software in the financial services. Also, cryptocurrencies are worldwide increasingly accepted as payment method in physical shops as well as webshops. The disadvantage of accepting a cryptocurrency like Bitcoin as payment method is that the exchange rate to a fiat currency is very volatile.

PricewaterhouseCoopers performed a very extensive research on the opportunities of blockchain for energy producers and consumers (PwC, 2016). They conclude that in the financial services the development of blockchain is more mature, but that there are a wide range of energy use cases (PwC, 2016, p. 3). The blockchain can support the energy transition where energy is generated decentralised in a way that energy can be directly bought and sold with a high degree of autonomy. Important here that they note limitations in the current legal and regulatory framework in the energy sector. This framework should be adjusted to fully support the requirements of the decentralised transaction models.

The most notable pilot was executed in New York where in a neighbourhood, decentral generated energy was directly sold to neighbours over the blockchain. The project has as final goal to establish a fully decentralised energy system without involving a third-party intermediary. Besides direct energy transactions, blockchain can be the basis for metering, billing and clearing processes, guarantees of origin, emission allowances and renewable energy certificates. Prospect by PwC is that blockchain first changes individual sectors and ultimately the entire energy market.

In almost every sector the blockchain can provide new opportunities in some way. More interesting possible appliances beyond financial services and the energy sector providing distinguishing features are:

- Blockchain can provide a work's provenance or attributors so it can secure intellectual property and digital creative works. For example, Spotify acquired a blockchain start-up in order to research possibilities to create a distributed database where contributions to music are captured so Spotify known to who it should pay royalties (McIntyre, 2017).
- Internet of Things (IoT) devices can be connected to the blockchain for transaction processing. Devices can interact after transactions or when functions in smart contracts are executed. This can also be applied at large scale where for instance a leased car is only able to start when a person is on his or her lease payments.
- The blockchain can also be applied for record-keeping in the public sector. For example, the start-up Fantom doing a pilot with the Honduras government to record land-ownership which should prevent corruption and fraud by offering a distributed, transparent ledger (Prins, 2016). Other record-keeping implementations are tamper-proof voting records, vehicle registries and digital identities (Deloitte, 2015a).

2.2.3 VENDORS

Multiple large software vendors or open source communities offer blockchain implementations in an easy to use platform or even as a service (Blockchain as a Service, BaaS).

Both IBM and Microsoft are offering BaaS. Microsoft offers BaaS as module to its Azure cloud platform and their BaaS is based on open-source code and supporting different blockchain protocols with a preference to Ethereum (Microsoft, 2017). So Microsoft relies on an external platform where changes can be made without influence from Microsoft. IBM on the other side offers Bluemix, a so-called ‘managed service’ for Hyperledger Fabric (IBM, 2017). Hyperledger is a project governed by a steering committee where IBM is taking a very important place so they rely less on external parties. A certain danger lies in these small blockchains since there might be not enough mining power for a secure infrastructure (Gencer, van Renesse, & Sirer, 2017). Gencer (2017) describes a solution where a private blockchain can be created where only allowed users gain access in order to prevent 51% attacks. This is also the case in Hyperledger Fabric; it is a permissioned blockchain using the PBFT algorithm to reach consensus. It also provides smart contracts but in a different way than Ethereum since it does not use the Solidity programming language.

3 THE ENERGY MARKET

This section outlines the current state of the energy markets and all parties involved and so, gives answer to the subquestion:

2. What is the current architecture of the electricity market and how are reliable electricity connections provided by all parties?

3.1 THE ENERGY GRID

A lot of different parties are active in the Dutch energy market with as main purpose to successfully generate, transmission, distribute and retail energy. This complex market is set by the Electricity act (1998) and was at that time introduced to create a fair, liberalized and stable electricity grid by decoupling between utilities and electricity supply. However, the system operator (TSO) Tennet and utilities (in the Netherlands seven companies that each take care of the regional energy grid), have a monopoly position in the electricity market.

It is important to know that the electricity grid always has to be in balance. This means that the demand has to meet supply exactly. The supply is the sum of production and import minus export and demand the use of electricity in the grid. The Electricity act (1998) distinguishes clearly between small consumers and large consumers. Small consumers are households or small companies and large consumers are almost always companies with a meter connection higher than 3x80 ampere. In 2013, 79% of the electricity was used by large consumers (CBS, 2015)

CBS has performed a research on the current electricity supply, demand, prices and import and export. Since the research will take into account trends in the electricity market, the most important findings will be outlined first. Energy consumption grew between 1950 and 2013 with an average of 4,5% to 119 billion kWh. In 2016 the Netherlands was still producing electricity from fossil fuels for 81%, which is shown in figure 7 and 8. It was not possible to combine the data in these figures in one figure since usage till 2010 was not available in numbers for each year. Remarkable here is that energy production was growing till 2010 but because of the recession and new possibilities in international energy trading, the production was 15% lower in 2013.

The renewable energy comes mainly from wind and biomass and a smaller part from hydropower and solar as can be seen in figure 9. Since renewable energy sources can be created in smaller initiatives than the original fossil fuel electricity, this is more and more generated decentral (figure 10). Local communities or individuals invest in solar panels, biomass electricity generation and wind turbines in order to generate energy for themselves. Since they will not be able to use all the energy themselves at the moment it is available, they often also produce energy for the grid.

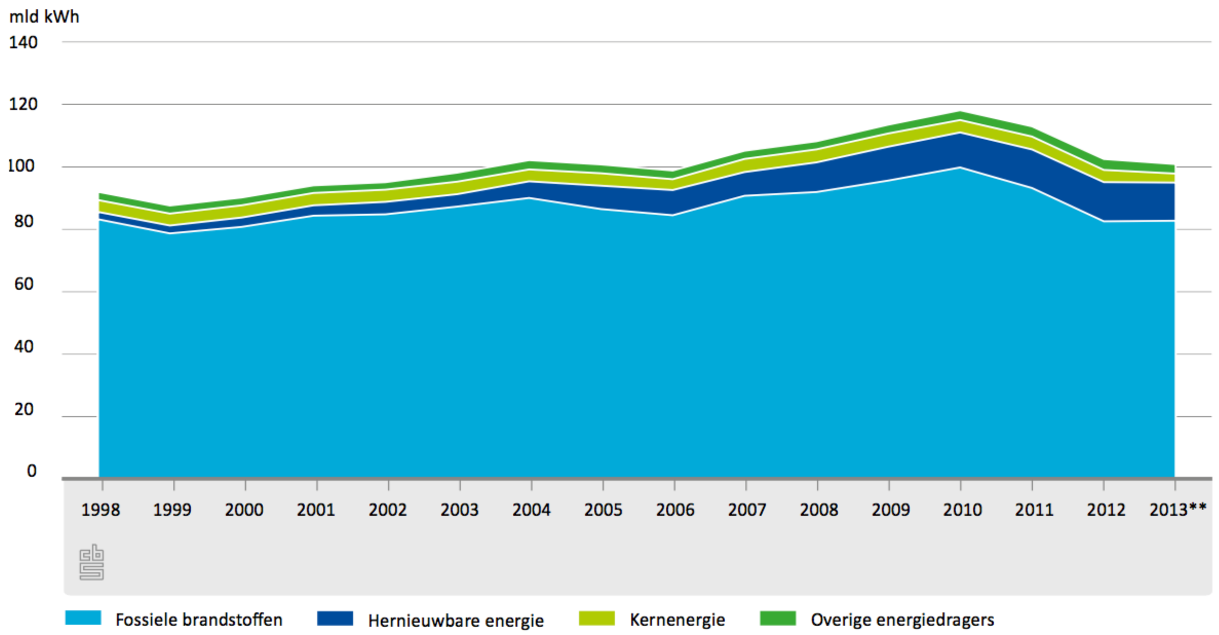

FIGURE 7: ELECTRICITY SOURCES 1998 – 2013 (CBS, 2015)

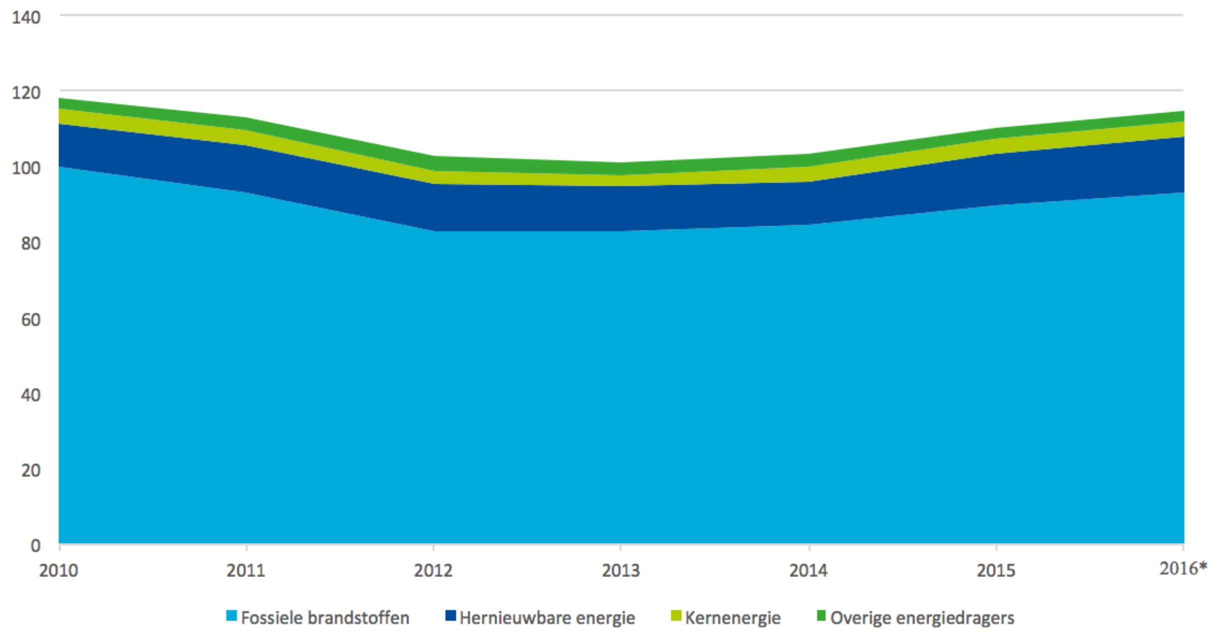

FIGURE 8: ELECTRICITY SOURCES 2010 – 2016 (CBS, 2017)

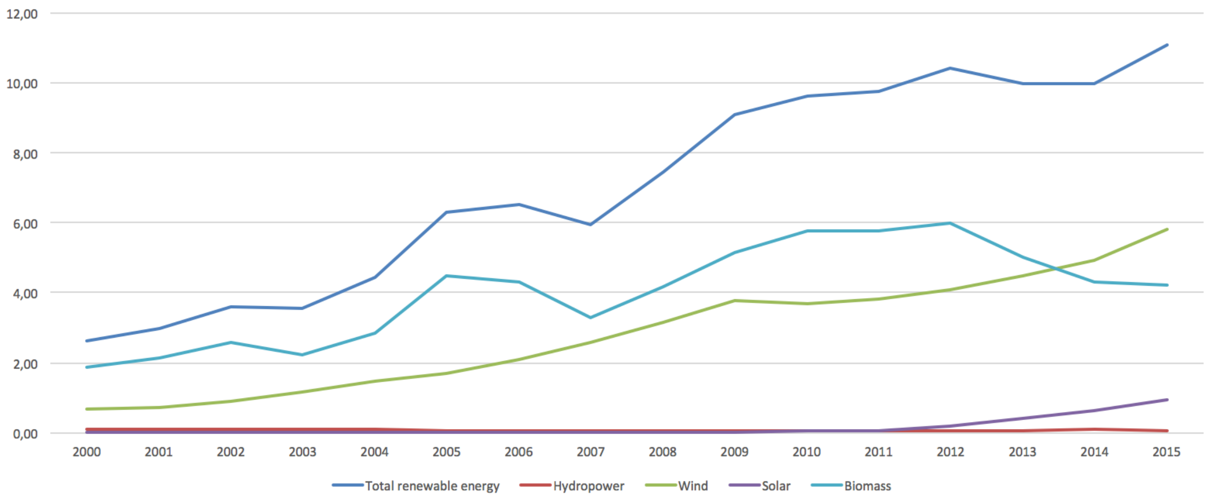

FIGURE 9: PERCENTAGE OF RENEWABLE ELECTRICITY 2000 – 2015 (CBS, 2015)

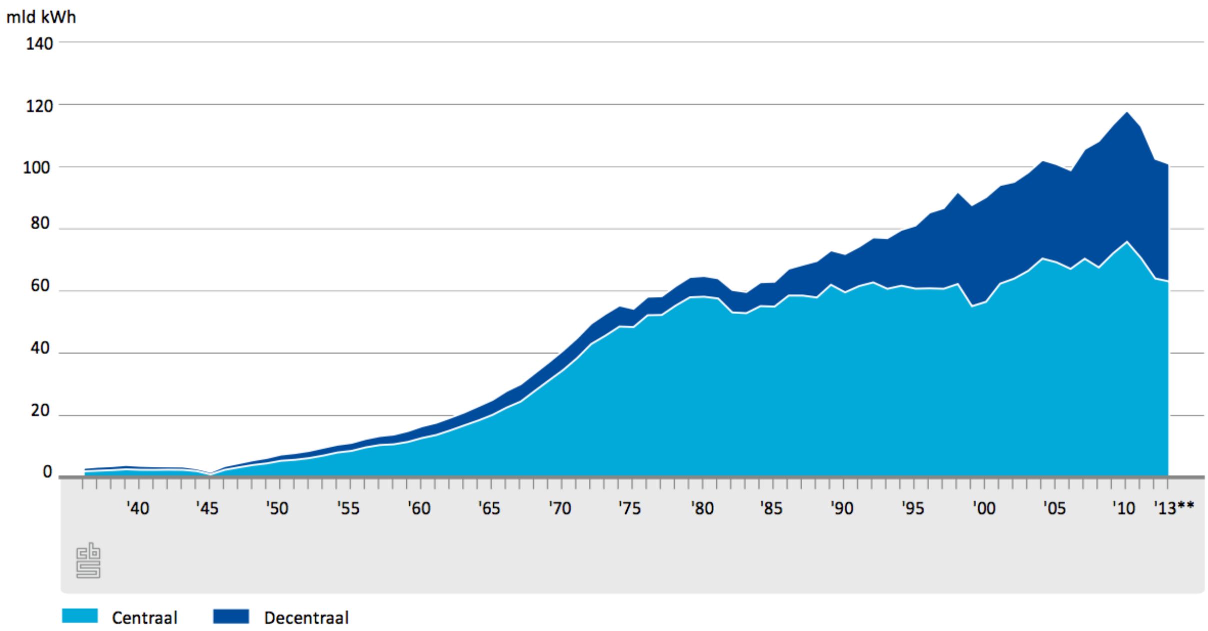

FIGURE 10: CENTRAL AND DECENTRAL PRODUCTION OF ELECTRICITY (CBS, 2015)

3.2 INVOLVED PARTIES

Figure 11 shows all roles involved in the electricity supply to a customer in the Dutch market. In practice, one company can take multiple roles such as being a supplier and balance responsible party. In this section we will shortly outline what all involved parties do (Cace & Zijlstra, 2003):

- The **customer** has a contract with an **electricity supplier** to buy, or in some cases also sell energy. A customer has to have an electricity supplier and can chose the energy supplier itself. In the Netherlands there are a lot of suppliers like Nuon, Vandebron, Greenchoice and Essent. Most suppliers offer fixed prices per kWh or distinguish between night and day, only a few offer flexible per hour pricing. Decentral storage is becoming more popular which means people can store their own generated energy and use this later or sell it at a moment to their supplier.
- The **regional grid operator** (RGO) connects the customer to the electricity grid and in order to do so, they build, maintain and manage the grids. Furthermore, they are responsible for transportation of electricity over the grid and should be able to assign transported electricity to all parties in their area. In The Netherlands there are seven RNB's operating each in a different area.
- Each connected customer has the responsibility for measuring their meter in a correct way and on time. This should be done by a party who is recognised by the company Tennet. These parties are called **Meter Responsibility** (MR) parties. They also have the tasks to deliver, install and maintain the energy meter.
- The customer pays only the energy supplier who pays the regional grid operation and meter responsibility party. In the case of small consumers, the meter responsibility is done by the regional grid operator
- Each party that has one or multiple connections to the grid is balance responsible. Involved tasks can be executed by the electricity suppliers or can be executed by special **balance responsible parties (BRP)**. These BRPs have to create an electricity program (e-program) which is the expected supply (created by their **producers**) and demand of the grid (TenneT, 2014) per PTU (15 minutes). These e-programs are communicated daily to Tennet for the next day. After the day the BRPs are sending their real supply and demand to Tennet and these are compared to the e-programs. If there has been a difference, there was an imbalance on the grid caused by the BRP which might have financial consequences.
  Balance responsible parties can trade on the electricity **market** with other BRPs in order to match supply and demand in their portfolio. These energy exchanges allow to buy and sell energy from 4 years before till the day before and are explained in more detail in the next section.
- **Tennet** is the Transmission System Operator (TSO) which has three important tasks (Electricity act, 1998):
  - Build and maintain the high-voltage grid in the Netherlands
  - Facilitate efficient and stabile electricity markets in the Netherlands
  - Balance demand and supply 24/7 with the correct systems using SRR and SE parties
- **SRR/SE parties** are used to protect the grid against difference in e-programmes. TenneT let these parties use or generate energy in the 15-minute time slots.
  - SRR: supplier regulating and reserve capacity
    Every large producers and users above 60 MW are obliged to offer flexible power to TenneT, have it available when needed and to offer a price (University of Amsterdam, 2014). How this flexible power is used is explained in the next section.
  - SE: supplier emergency power
    In case of a larger power outrage TenneT can fall back on at least 20 MW emergency power (TenneT, 2017)

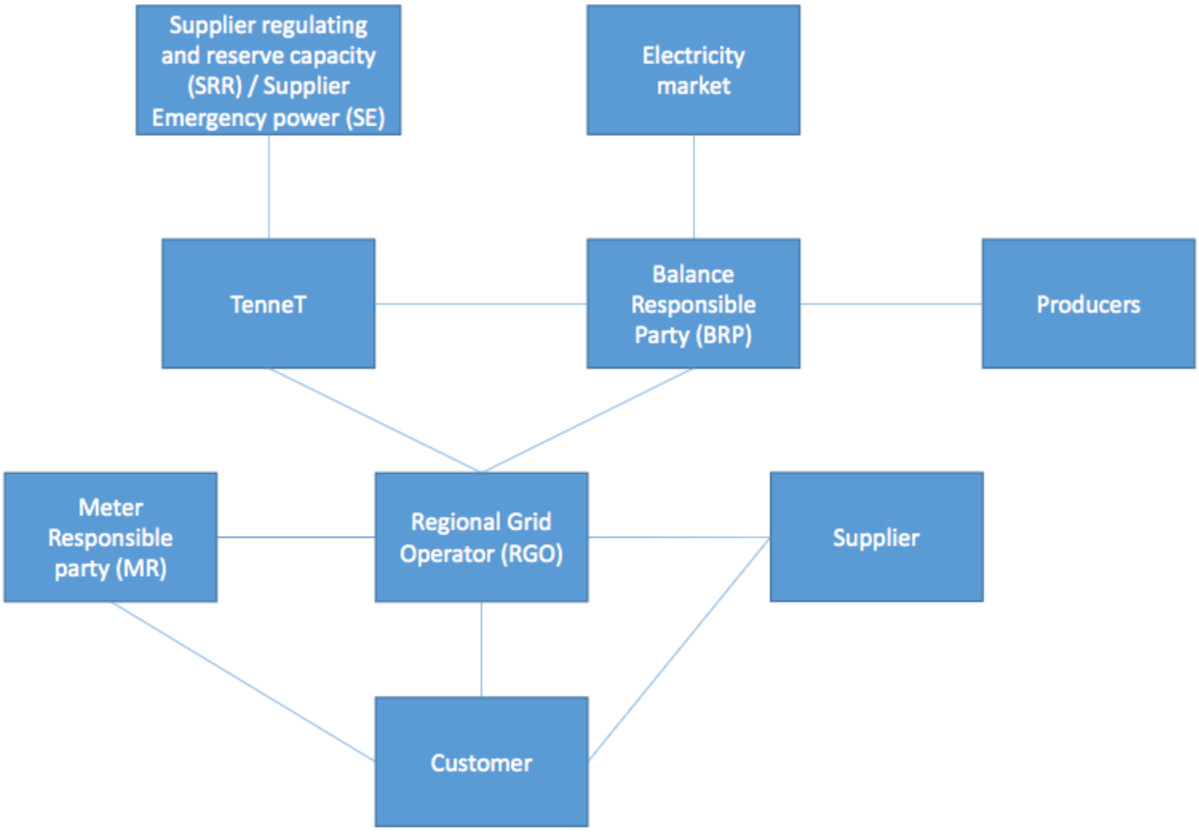

FIGURE 11: PARTIES INVOLVED IN THE DUTCH ENERGY MARKET

3.3 ELECTRICITY MARKETS

A balance responsible partner is responsible to keep balance between supply and demand. In order to do so, a BRP walks through the steps shown in figure 12 for every market day. In the reminder of this report, a market day will be given as 'D'.

FIGURE 12: BRP PHASES FOR EVERY MARKET DAY

Prepare

Preparing for day D can start 4 years before day D. In the preparation phase the BRP estimates the required electricity and where the electricity has to come from. They can buy and sell electricity in four different ways (KEMA, 2011) during the preparation step:

- The Netherlands has an electricity exchange where trusted parties can trade in energy. The following markets are available:
  - ENDEX: future market where one buys long term contracts (for a week, month, quarter or year). There is traded from four years till 1 day before D. The ENDEX has three different products:
    - Base load: constant supply for the whole day
    - 16-hour peak load: constant supply from 7:00 till 23:00
    - 12-hour peak load: constant supply from 8:00 till 20:00
  - APX Day-Ahead: Day-Ahead is the market where electricity is traded one day before supply and this happens in blocks of 1 hour. One can bid from 8:00 till 12:00 and at 12:40 the APX publishes the prices for each hour. The APX sums all bids for supply and demand for each hour which create two offer curves. The market price for the hour is determined by the intersection of the two curves
- Over The Counter (OTC) market: traders can trade energy with each other without having the electricity been on the market. This can happen from 4 years before till D+1 10:00.
- Power station: some suppliers also own a power station so they can produce and trade intern.
- Foreign countries: The Dutch electricity grid has a connection to Belgium, Germany, England and Norway (KEMA, 2011). Even though the cross-border capacity is limited so one has to pay fees, it might be cheaper to buy it in a foreign country since electricity prices highly differ

At D-1 14:00 all BRPs have to deliver their E-program to TenneT and these E-programs contain all electricity the BRP is going to supply and demand in their portfolio (Frontier, 2015). This has to be on the level of every program time unit (PTU, which is a length of 15 minutes). After these have been validated by TenneT they are used for delivery for the next day, the execution day.

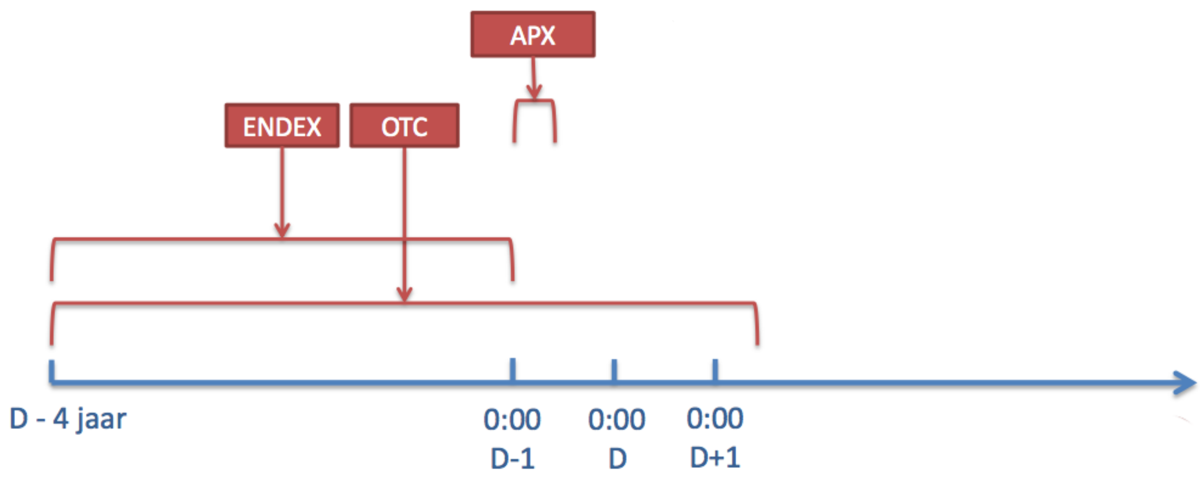

FIGURE 13: POSSIBLE ELECTRICITY MARKET TRADING DURING THE PREPARATION PHASE

Execute

At the execution day, day D, the energy is delivered and used. The E-programs that TenneT received from all BRP are estimates. In order to maintain the balance on the grid the electricity is constantly measured real-time in MW. When there is an imbalance, the grid is brought into balance by parties supplying regulating and reserve (SRR) capacity. These parties have the ability to use or supply electricity when required by Tennet within 15 minutes. A party can place bids in a bid curve which can be accepted by TenneT.

In the case that the SRR capacity is not sufficient, TenneT also has the ability to enable the suppliers of emergency power. TenneT contracts parties that are able to increase or decrease their usage for at least 20 MW in 15 minutes. When a power station fails or there is a problem in the grid this is used to maintain the balance.

Furthermore, a BRP has the ability to use the Intraday exchange market to trade in electricity when they expect differences between their E-program and the real electricity demand and supply. This market is also connected to the Belgium, French and Scandinavian market and there is also an exchange market with Germany.

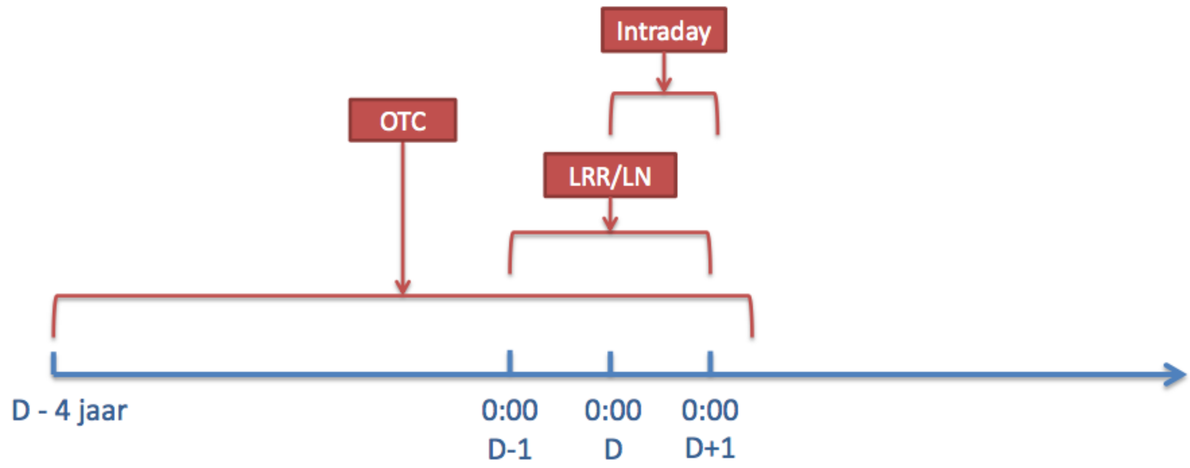

FIGURE 14: POSSIBLE ELECTRICITY TRADING DURING DAY D

Finish

The Meter Responsible parties send their measurement data at D+1 10:00 to the RGOs which then assigns usage to the BRPs who sends it to BRPs and TenneT at 16:00. This process is called the allocation process. TenneT can now compare the E-program with the real electricity usage and sends the BRPs a temporarily invoice. The BRP has the possibility to ask for a correction of the allocation by the RGO. At D+5 a temporarily allocation in sent at D+10 the final allocation is sent to the RGO.

The Meter Responsible parties determine the total used electricity at D by 3 factors: telemetric usage, profiled usage and net loss. Large consumers have a meter with data available per hour. Small consumer usage is calculated by created profiles which is a model that predicts the electricity use.

When transmitting energy over the grid a percentage is lost which is paid by the RGO and have to be taken into account in the allocation process.

The RGO measures also the supply by the high-power grid. This has to be in balance with the total usage. Therefore, the profiled usage is often corrected by a measurement correction factor.

Settle

At D+10 the allocation from the finish phase has reached its final state. The BRP receives an invoice for the created imbalance and the reconciliation process starts. The reconciliation process settles the difference between the calculated consumption of profiled customers and the actual consumption when this is known (Van der Veen, 2007). The price per kWh difference is set by a reconciliation price which is the weighted market price.

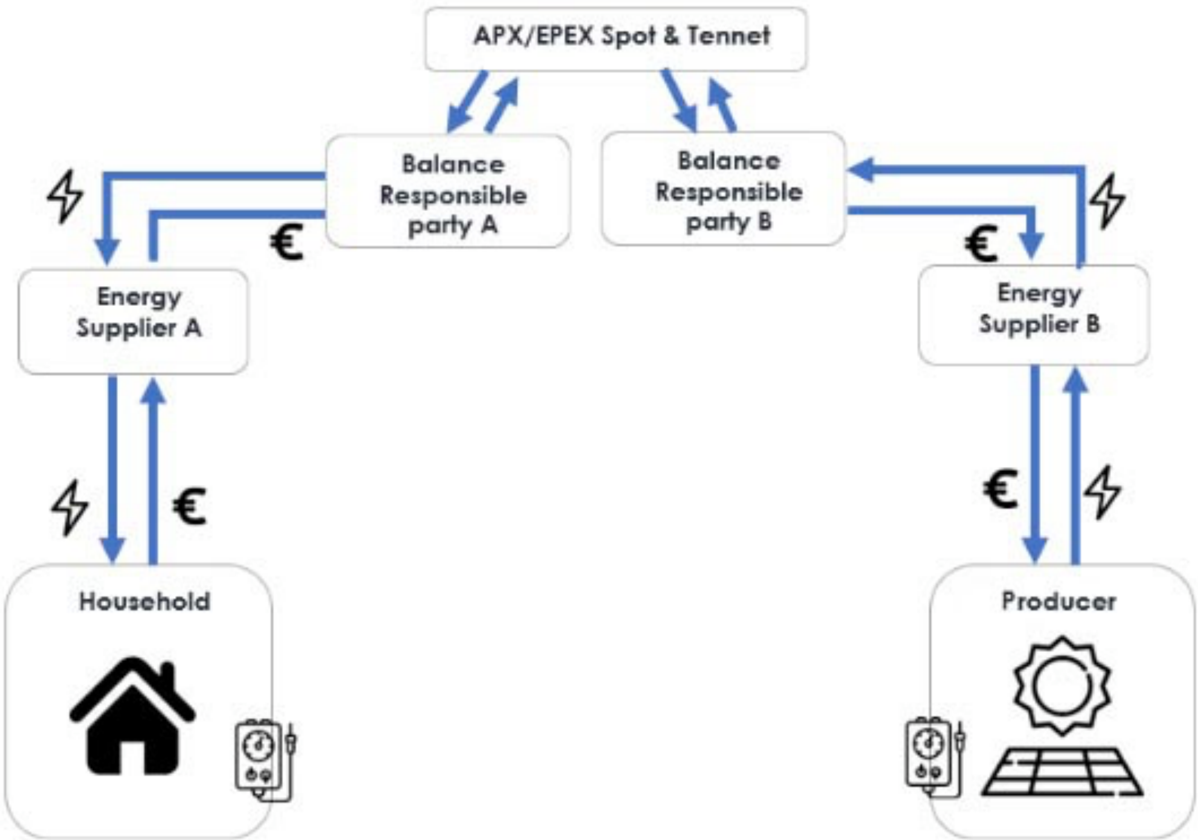

FIGURE 15: THE FLOW OF KWH AND EURO IN THE CURRENT MARKET

4 THE ENERGY TRANSITION

In this section the transformation made in the energy transition is analyzed, together with problems caused by the transition and possible solutions. This section gives answer to the subquestion:

3. What are the challenges of today's energy transition?

4.1 ARISING PROBLEMS

The energy sector is facing serious problems in their fossil fuels dependency, reliability and environmental problems. Therefore, the energy transition is taking place with a shift to the supply of renewable energy. As shown in figure 7 and 8, more renewable energy is produced every year. Wind and solar energy supplied more than half of the renewable energy in 2015, but depend highly on the weather circumstances as shown in figure 16. This section will outline the reasons for the energy transition, problems created by the transition and discuss IT solutions that can help the energy transition. What do we do with our surplus of energy on windy sunny days or at 9:00 when everyone arrives at the office to charge their car, take the elevator up and heat or cool their office. Or how, in this scenario, do we use as less as grey electricity as possible.

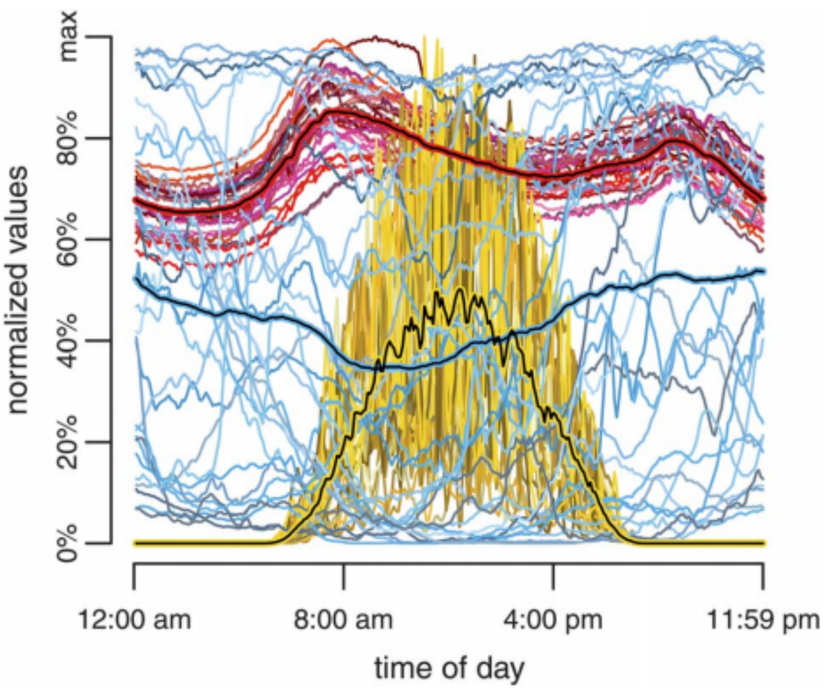

FIGURE 16: THIRTY DAY TIME SERIES DATA FOR GENERATION AND DEMAND (BARNHART, 2013)

BLUE = WIND POWER GENATION, GOLD = SOLAR POWER GENERATION, RED = POWER DEMAND

4.2 THE ENERGY TRANSITION

For years the idea that the world was running out of fossil fuels was giving urgency to the energy transition. But for now this is not the most critical factor. Production of fossil fuels is relatively getting dirtier since it is becoming more difficult to find them and the sources found are relatively small. This is increasing the price (TNO, 2011). Therefore, the world is focusing more on the harmful effects on the use of fossil fuels that threat human health (Armaroli & Balzani, 2007) such as pollution and greenhouse gases associated with global warming. With the energy use rising per capita and the total increasing population, the total energy consumption worldwide grows 2% per year from which 80% originates in fossil fuels (Johansson et al, 2012).

At worldwide, regional and country level agreements and goals are set to reduce greenhouse gas emissions and increase the share of renewable energy. The Paris agreement was signed by 195 parties in June 2017 who all have to commit to mitigate global warming and report their contribution. However, this agreement leaves all countries free to set their own goals at certain dates and there is no forcing mechanism. At lower levels like continent or country level specific goals are set. The European Union has as goal to generate energy for 20% from renewable energy by 2020 and in 2030 27% (Energy, 2010). The Netherlands has a goal of 14% for renewable energy by 2020 and so is lagging behind compared to most EU countries (Deloitte, 2015b).

Figure 17 shows the ambitions in the energy transition which are also challenges since one does not contribute to the other, or they are even counteracting in the current energy system. As TNO (2015) describes; sustainable energy is less reliable since we depend on sun or wind and to make it reliable it might not be affordable anymore since solutions like batteries are still very expensive.

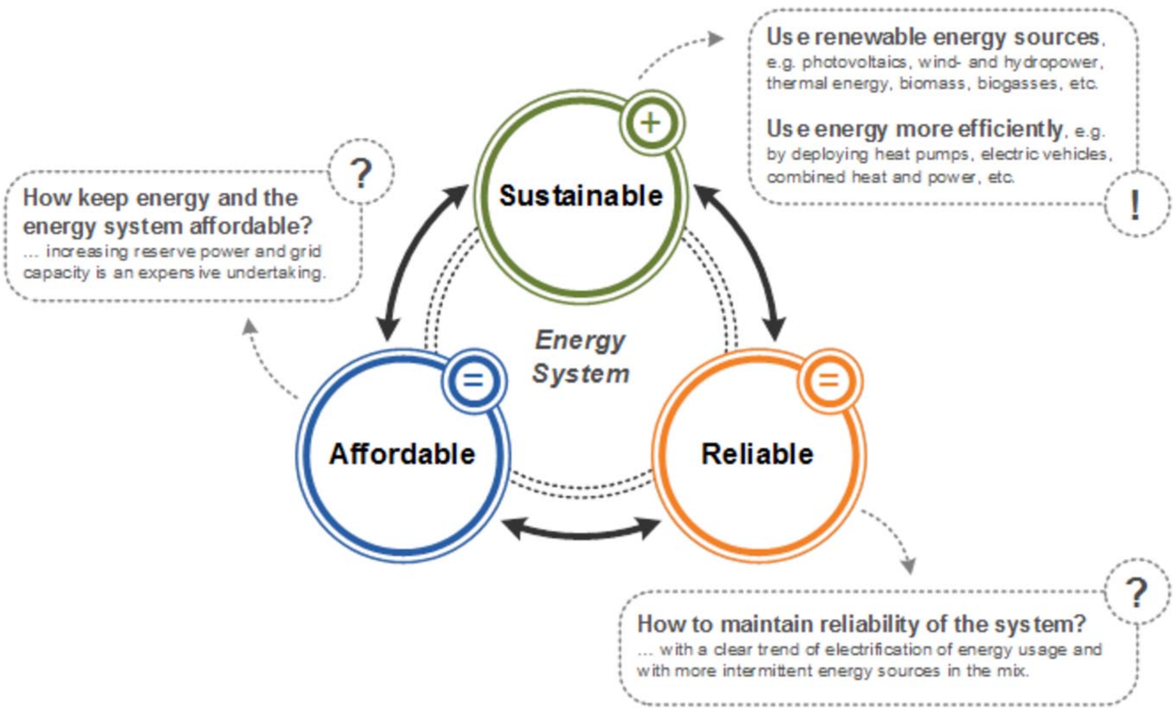

FIGURE 17: AMBITIONS IN THE ENERGY TRANSITION OF EUROPE AND THE NETHERLANDS (DONKER ET AL, 2015)

4.3 LOCAL COMMUNITIES

The energy transition will not be done by large companies. It requires from the consumer to become a prosumer and to become energy aware. The prosumer in the energy world is nowadays mainly described as the one investigating in energy generation through for instance solar panels or for large consumers by biomass or by wind energy. However, this kind of prosumers are not achieving the required renewable energy speed. Local communities are a huge driver (Walker, 2008) for energy initiatives. Van Der Schoor et al (2017) performed an extensive research of passive consumers or simple prosumers moving towards active creators of new energy systems. Most of these initiatives are grassroot innovations which means they are community-led solutions for sustainability (Hargreaves et al, 2013). These bottom-up initiatives take control over the production and distribution of energy. Table 4 shows these grassroot innovations at the level of prosumer and communities besides the top-down possibilities. The grow of local and regional initiatives is supported by a research from TNO (2015) who performed research towards a future-proof energy system. They recall a trend towards an energetic society with wealthy, cooperating and autonomous citizens and innovative companies. Local communities can contribute to the three ambitions and challenges as shown in figure 17 since the energy they generate is sustainable, they create a more reliable grid by having a local grid and thus reduce transfer of energy over the large grid thus also reducing the price since less transportation is required.

TABLE 4: TYPES OF TRANSFORMATION AT DIFFERENT LEVELS (VAN DER SCHOOR ET AL, 2016)

	Prosumers	Communities	Regional networks	National networks
Incremental reform within existing energy policies	Reduce energy for heating and appliances	Local cooperatives for supplying green energy	Regional networks for support of local cooperatives	Projects for support of local cooperatives
	Produce own electricity, grid connected	Local PV-groups	Cooperative provider set up by regional networks	Organisation with local cooperatives as members
	Buy green energy	New social enterprises for supply and production of energy		
Radical reform of energy governance	Energy neutral, passive houses	Autarchy, low carbon, or energy neutral communities	Extend cooperative servicesto all households in the area	
	Produce own, off grid	Local grids	Experiments with cooperative network management	

4.4 FLEXIBILITY

Since sustainable energy is not always present when required flexibility should be offered, one can reach flexibility through three main methods; flexibility through production, usage and storage. When using flexibility in production, the energy supplier can match the demand by increasing production. The disadvantage of some resources is that they have a significant ramp up or down time which means the time that is required to use their full potential. Table 5 shows the different ramp up/down times for the different resources available together with the average electricity they can produce.

TABLE 5: FLEXIBILITY OF ENERGY RESOURCES (TNO, 2015)

Power generation	Ramp up/down time	Rated power
Nuclear plant	> 8 hr	100 – 1000 MW
Waste-Incineration plant	2 – 8 hr	10 – 100 MW
Coal-fired plant	> 30 min	100 – 1000 MW
Gas-fired turbine (combined cycle)	< 30 min	100 – 1000 MW
Gas-fired turbine (single cycle)	< 15 min	100 – 1000 MW
Combined heat and power plant	< 15 min	1 – 10 MW
Fuel cell	Instantaneous	< 1 MW
Hydro power plant	Instantaneous	1 – 10 MW
Wind turbine	n.a.	1 – 10 MW
Solar panel	n.a.	< 1 MW

In the world we live in today, energy is produced when required. A more and more embraced idea is to start using energy when it is the right moment. This means that energy should be used when widely available and not at peak moments when the generation of energy is not showing the same peak. There are multiple important aspects involved here:

- One or two-way communication: one can choose to send a message to the user to adjust usage or one can have a 'conversation' in which the possibilities at different prices are exchanged and the user choses an opportunity
- Certainty of response: does a user always have to respond when adjusted usage is asked or can it also just do the opposite
- Direct or indirect: the signals are direct and no decision is possible or is for instance a formula given for the price and the system choses how much to use

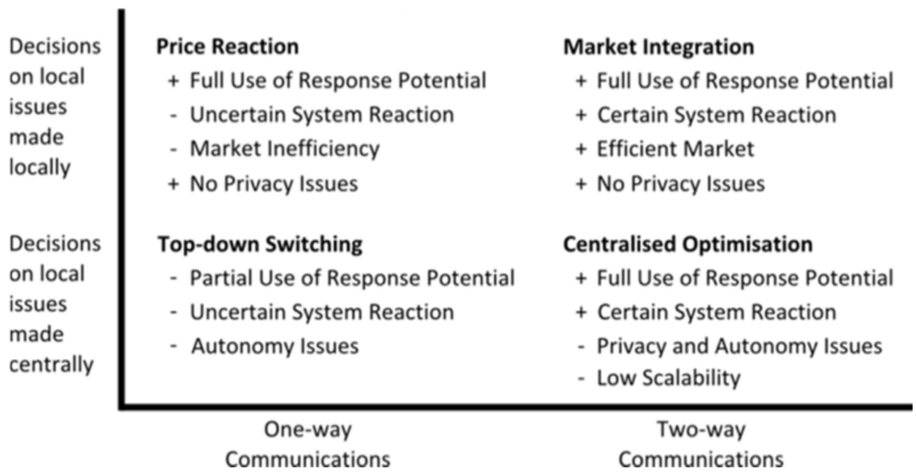

FIGURE 18: OPPORTUNITIES FOR FLEXIBLE DEMAND (TNO, 2015)

Other opportunities for flexibility are storage of energy in for instance batteries, hydrogen fuel cells, pumped hydro storage, or compressed air energy storage. Or interconnection to foreign grids or system integration (power to gas, power to heat) is possible in combination with storage.

An extensive research on flexibility options in The Netherlands has been performed by (Triple, 2014) for TNO. The flexibility in the Netherlands seems to be relatively high and diverse comparing to neighbouring countries. A high share of combined cycle gas turbine and combined heat and power plants and the interconnection to other countries provide a lot of flexibility. However, with the increasing part of renewable energy they foresee an increased request for power-to-heat and demand response systems soon.

4.4.1 DEMAND RESPONSE

The idea of end-users reducing or increasing their use of electricity in response to power grid needs, demand response is expected to increase by an average of 1 to 1.25% per year until 2030 (Triple, 2014). Especially reducing peak demands is of common interest. With the increasing use of electric cars (42.000 in use in 2014 and an expected use of 1 million by 2020 by the Dutch government) the 'vehicle-to-grid' (V2G) idea is offering lots of possibilities for flexibility. Their batteries offer flexibility in consuming and feeding the grid. Demand response can also add value for DSOs in order to reduce grid congestion. Congestion is an overload of the grid which can lead to overheated cables and so damage them. DSOs should increase the capacity of the cables which is a very expensive and time-consuming process so preventing congestion with demand response is becoming more popular.

4.5 REGULATORY FRAMEWORK

Especially small consumers are subjected to a wide range of laws and regulations. With the increasing popularity of grassroots this is becoming a problem since they cannot fully utilize the opportunities or their investment (University of Amsterdam (2011), University of Amsterdam (2014), Van der Veen (2007)). The Electricity act (1998) in the Netherlands was created to ensure a reliable, sustainable and efficient electricity network with market forces enabling the customer to choose their own supplier. All parties shown in figure 11 are required to be in place in the electricity market and this collides with one of the most core function of blockchain: eliminating third parties.

Being limited in practice does not mean initiatives should be limited by law and regulations since law and regulations can and will change over time. Also, parties can start using the blockchain technology with all required roles still being fulfilled by the electricity act. PwC (2016) describes roles that are not required anymore when blockchain would be applied at large scale in the energy sector. When direct relationships are established between energy producers and energy consumers, the consumers have to become balance responsible parties. This means they have to make forecasts about their usage themselves for the next day or longer term. Furthermore, the parties producing the energy have to become an electricity supplier. The role that is performed now by meter responsible parties can be automated partly since meter data can be published directly to the blockchain but their function for providing the meters will still be required. The TSO furthermore does not need any clearing processes since transactions can be finished real-time.

PwC (2016) foresees that small or local businesses will have reduced barriers for market entry in the energy sector due to the regulations creating a barrier. This would match the grassroot trend explained in 7.2 where local communities are the ones start energy initiatives from bottom down. Another obstacle is uncertainty regarding legal recognition of blockchain as a technology and payment method. At the moment today's legal systems are based on clear allocation of organisations (PwC, 2016) while blockchain does not rely on central organisations.

Some papers are also calling the current infrastructure and regulations a regime (DENA (2016), Van der Veen (2007)), and DENA (2016) sees the implementation of blockchain, and in specific P2P trading, for the medium to short term. So it will take some time before being applied at large scale at all parties (TSO, RGO and local).

4.6 PROSPECT

At individual, company, regional, national or international level, the goal to achieve 100% renewable energy is increasingly set. At the individual and company level this goal is already achieved and even regions are achieving this goal for multiple weeks in a year. To achieve such goals a high flexibility in production, usage and storage is required. This section will shortly outline important goals that have to be achieved for 100% renewable energy.

Flexibility in production is achieved by using resources with a low ramp up/down time as shown in table 5. A 100% renewable energy environment is coming from biomass, solar panels, wind, hydropower and fuel cells. Hydropower and fuel cells have low ramp up/down times and thus are very flexible. Biomass can fulfil the base load power since dispatch time is slow and production through solar panels and wind turbines is uncontrollable. This means that fuel cells and hydropower are very important in creating a sustainable reliable grid since they can both produce as well as use energy from the grid with low ramp up/down times (hydropower only when it is pumped storage).

An interesting development here is the increasing use of electrical cars. With only a rough 42.000 cars driving around in the Netherlands at the moment, the goal is to have 1 million cars in 2025 (RVO, 2015). With all of them having fuel cells that can fulfil in flexible production as well as usage they play an important role in a reliable sustainable energy grid. When there is a peak in production they can start charging and when there is a demand peak they can feed the grid by discharging – as long as they know when they have to be available for driving. More flexibility in usage can be achieved by controlling for instance cool houses or heath pumps.

To create more flexibility in storage, decentral storage in special fuel cells is becoming more popular although they are not used at large scale yet due to high costs. An interesting development here is for instance the Tesla Powerwall (Tesla, 2017) which offers fuel cells for homes. This allows individuals to (almost) become 100% powered by renewable energy.

Besides the storage cost of energy being high, there is another important barrier limiting the adoption speed of renewable energy. The current market, established parties and regulatory framework only allows consumers with solar panels to produce energy for the supplier the customer has a contract with. When one produces more than is used in a year the prosumer can sell their energy to the supplier but not to its family or neighbours without solar panels. So they pay the full amount for their energy while the prosumer gets a smaller amount. Also most energy suppliers only offer fixed pricing so companies or consumers use energy whenever they want. When pricing would be flexible they are more encouraged to use energy when supply is high.

5 BLOCKCHAIN ENERGY SOLUTIONS

In the last years several projects are applying blockchain in their project contributing to the energy transition. This section analyses all initiatives found and classifies them in five categories. Furthermore, four more new possibilities for blockchain in the energy sector are outlined. This section gives answer to the subquestion:

4. What are the lessons learned from the blockchain initiatives focusing on the energy transition and how can we classify them?

5.1 CURRENT INITIATIVES

The changing energy market described in the previous section can utilize the blockchain technology at full power. At the moment a lot of parties are involved who all have their own databases even though they communicate on daily basis. Blockchain can create a decentralised platform at different scales eliminating third parties, creating a faster network with if required direct (financial) transactions and high-quality data. In this chapter 30 companies enriching their energy initiatives with blockchain are outlined in table 6. These companies have been found by searching on the internet for initiatives and companies working on blockchain in the energy sector and have a specific product. The list is not complete but gives a general overview on how and why blockchain is applied.

In the table the term P2P is used. P2P stands for peer to peer and means the transfer or sale of energy from one consumer to the other and is a deal that is not provided by a large party.

TABLE 6: BLOCKCHAIN ENERGY INITIATIVES

Company	What, how and current state	Why blockchain
AdptEVE (Freeelio)	**What** Enabling rooftop enabled houses to optimize electricity usage by creating a self-learning system in Germany. Selling surplus in a local P2P marketplace **How** Supporting Ethereum and other chains like SolarCoin **Current state** Idea, company founded October 2016 **Country** Germany	Creating a decentral ledger system and support other initiatives like SolarCoins, Gunstromjetons and ECOins.
Bankymoon Usizo	**What** Crowdfunding utilities for needy schools in Africa **How** Enabling schools with blockchain aware meters so when a cryptocurrency is coming in, they get energy or water **Current state** Successful pilot in 2016, company founded in 2015. **Country** South-Africa, global focus	Enabling fast transactions worldwide and enabling a IoT device to immediately act on blockchain transactions
BCDC Ecochain	**What** Blockchain based investment hub connecting investors to renewable energy projects **How** Using BCDC tokens, smart contracts and bitcoin	Executing financial transactions under certain conditions

	Current state In development **Country** Worldwide	
Brooklynn Microgrid	**What** Creating a micro grid with a P2P marketplace. Together with LO3 Transactive grid and Consensys. Goal is to save transaction loss and create fairer prices. **How** Using Ethereum and self-executing smart-contracts **Current state** Pilot done in 2016-2017, waiting for right licenses now **Country** United States	Sharing production and consumption data and automatically pay. Later on, build demand response hardware.
ConsenSys	**What** Blockchain company developing variety of applications together with partners. Working together with LO3 on the Brooklyn project and with Innogy for the Co-tricity project **Current state** Multiple pilot projects **Country** Worldwide	-
Co-tricity	**What** Matchmaking of renewable energy between local producers and consumers. In the end creating blockchain stored profiles. Matching consumption curves **How** Sharing meter data to Dapps with smart contracts (mainly C2B). Project between Innogy & Consensys **Current state** Project ran in 2016, current state and plans unknown **Country** Germany	Sharing meter data Scalable Transparency Automated profiling
Dajie	**What** Peer to peer energy trading, redeem carbon credits **How** Let IoT devices create a network of nodes doing transactions on the blockchain **Current state** Idea **Country** Worldwide	Decentral energy trading Decentral carbon credits
Electron	**What** Record and manage energy consumption, P2P trading, balance the grid efficiently, real-time access, profiling **How** Ethereum **Current state** Under development, simulated data demo **Country** United Kingdom	Quick transactions Transparency Distributed ledger
ElectricChain	**What** Save data about solar panel production for research (climate change, weather, pollution) available for everyone. Also rewarding SolarCoins. **How** Own blockchain **Current state** Looking for partners and involved in thirteen different projects **Country** Worldwide	Distributed easy to access database Reward for solar panel production
Energy21	**What** Developed a new energy market model with a smart P2P market, matching production and consumption per PTU and let machines act on surplus or deficient energy.	No need for third party Transparent platform Privacy and secure communication

	How Unknown **Current state** Pilot **Country** The Netherlands	Very low cost-to-serve
Energy Web Foundation	**What** Non-profit organization focused on accelerating blockchain technology in the energy sector. Research and develop together with partners. **Current state** Starting collaborations and doing research, no product **Country** Worldwide	-
Grid Singularity	**What** Company with energy market and blockchain professionals developing a decentralised energy data management and exchange platform supporting all levels (balancing, trading, validation, real-time information recording). This should also facilitate energy data analysis and benchmarking, smart grid management, trade of green certificates, investment decisions and energy trade validation **How** Ethereum smart contracts **Current state** Under development **Country** Austria	Transparency Real-time transactions Removing third parties Reducing cost Reducing complexity
GrünStromJeton	**What** Energy consumption token issued to energy consumers. When a customer consumes at times with a high availability of green energy the consumer receives green tokens, otherwise grey tokens. **How** Smart contracts enabling tokens on Ethereum **Current state** Live **Country** Germany	Traceable tokens
Hanzenet	**What** Dutch company that developed a new Dutch energy model. Local energy grid in the neighbourhood that creates profiles and divides surplus from one house to the others. In the end also response demand technology. **How** Using the Disney Dragonchain for smart meter data storage and smart contracts **Current state** Prototype for saving smart meter data in the Disney Dragonchain **Country** The Netherlands	Transparency Transactions
Innogy	**What** Creating a sharing economy where everyone can buy, sell and own energy resources in a (local) P2P energy market. **How** Connecting smart meters to the blockchain and enable Ethereum smart contracts, taking into account weather forecasts, to pay/distribute energy **Current state** Pilot **Country** Germany	Simplified architecture and data visible for everyone. Should create insight for everyone. Suitable for IoT device. A coin can represent energy; 1 kWh = 1 coin
Ponton: Enerchain	**What** Trading flexibility, smart balancing products, P2P market **How** Bringing together 23 companies interested in the platform; their own Enerchain framework / chain **Current state** Prototype **Country** Germany, but global focus	No transaction fees

Power Ledger	**What** Allow renewable energy asset owners to sell their surplus at their own price. So P2P trading in Australia **How** Permissioned hybrid blockchain developed by Ledger Assets, PoS **Current state** Successful trial finished end 2016, currently under development **Country** Australia	Transparency of where energy is generated Easy transactions
Powermatcher	**What** Distributed energy auction for balancing supply and demand, no details known. **How** Dapp being developed using Ethereum smart contracts **Current state** Work in progress **Country** The Netherlands	Payments
Qiwi	**What** Enabling blockchain energy transactions in Russia. Payment for energy over the blockchain **How** Unknown, started may 2017 **Current state** Unknown **Country** Russia	Payments
Share & Charge	**What** Creating a sharing economy by making private charging stations for electric cars public. Partnership with Slock.it and Innogy. **How** Ethereum smart contracts with an own token (worth 1 euro). One can purchase and earn token by providing and use services. **Current state** Almost 12.000 charging points in Germany are enabled with this technology **Country** Germany	Transactions IoT devices Tokens
Smappee	**What** Company creating technology to make your home energy efficient (without blockchain) but now also supporting SolarCoin when users have solar panels **How** IoT device **Current state** In use **Country** Belgium, global focus	Cryptocurrency
Solarcoin	**What** Special cryptocurrency which is rewarded for every MWh generated by a solar panel. People have to send the electricity bill at the moment. **How** Their own chain and coin **Current state** In use, improving their wallets and integration with solar panels **Country** worldwide	Cryptocurrency
Solether	**What** Autonomous electrical energy entities. A single-board computer is checking an Ethereum address and when one pays, he or she gets power through an USB port produced by a direct connected solar panel. **How** Running a Ethereum node and checking one specific account balance **Current state** Working open source prototype **Country** Online project	Internet of Things integration Cryptocurrency

Stedin	**What** Dutch RGO working together with EWF to look how blockchain can be applied in the energy sector **How** All options are still open **Current state** Idea **Country** The Netherlands	Smart contracts Payments
StromDAO	**What** A DAO is a decentralized autonomous organization. This DAO should operate automatically by creating a local grid, fully automated transactions through smart contracts and balancing. When local grid is not efficient; use energy exchange markets. **How** Smart contracts in Ethereum **Current state** Open source implementation available for simulation, available and still under development for improvement **Country** Germany	Smart contracts Transactions DAO
Sun exchange	**What** Allow people to invest in solar panels and lease them to schools and companies in third world countries. Projects in these countries are crowdfunded and one can buy solar panels with fiat currency or cryptocurrency. One is rewarded in cryptocurrencies. **How** Pay and reward in Bitcoin **Current state** In use **Country** Founded in South-Africa, global focus	Transparency
TenneT	**What** TenneT working together with Vandebron in order to balance the grid over blockchain. By using blockchain they want to use capacity of electric cars and household batteries. **How** Hyperledger Fabric **Current state** Idea **Country** The Netherlands	Transparency Flexibility
Transactive Grid (LO3)	**What** The TransActiveGrid is a project from LO3 and offers an open energy platform for real-time metering of generation and usage. Enabling P2P energy transactions. Is applied in the Brooklyn project. **How** Their own TAG product **Current state** Demo and successful PoC **Country** United States	Transparency Auditable Non-repudiable
Vector	**What** P2P trading in New Zealand by applying and working together with Power Ledger **How** Applying the Power Ledger concept **Current state** Trial **Country** New Zealand	Transparency of where energy is generated Easy transactions
Volt markets	**What** Open trading platform for renewable energy. Everything saved in the blockchain enables to verify the resource. **How** Smart contracts in Ethereum **Current state** Concept **Country** United States	Transparency Tracking energy assets
Wien Energie	**What** Using the BTL Interbit platform Wien Energie uses blockchain mainly to streamline processes and to	Reducing transaction cost

	create a save distributed platform against cyber threats. **How** Unknown **Current state** Successful pilot, looking for more participants for development **Country** Australia	Distributed platform
ZF (Car eWallet)	**What** a blockchain-based payment system for cars. The car can automatically pay for its energy usage, parking and toll. Does not focus on energy solely but creates an open integrated system **How** Unknown **Current state** Idea **Country** Germany	Distributed ledger Transparency

5.2 LESSONS LEARNED

Large established energy companies as well as new initiatives and start-ups are trying to use the blockchain. The initiatives are at different levels and so are the blockchain implementations. Most of them are still in pilot phase and most of them are based on Ethereum since it is the most mature, accessible blockchain and enabling smart contracts.

We can conclude that there are a lot of ideas and pilots trying to apply blockchain. With the energy transition taking place blockchain can solve a lot of challenges and provide solutions in a lot of different ways. The initiatives are active in the following:

- Saving data (from e.g. smart meters) to the blockchain
- P2P trading of renewable energy
- Pay for electricity in real-time (billing process over blockchain)
- Creating a flexible energy grid
- Balance the grid
- Creating micro grids
- Rewards (a special cryptocurrency) for generation of renewable energy
- Guarantee of origin (green and/or local)

The reason for implementation of a blockchain are mainly:

- Immerse scalability (using off-chain transactions)
- Direct access to immutable data
- Direct access to accounts (holding money) through smart contracts
- Traceability of energy by creating transparent deals
- Reducing cost
- Eliminating third parties in theory (not always allowed yet)
- Creating a network with IoT devices

Remarkable is that blockchain can be applied in a lot of different ways. But still when for instance implementing blockchain for P2P trading one can apply a coin in different ways; a coin can represent 1 kWh or 1 euro or it might fluctuate in value and there is an exchange to trade euros for a coin. Almost all types of implementations of blockchain can also be done together and work together. When all data is saved in the blockchain and P2P trading happens over the blockchain, one can also balance the grid with data from the blockchain and in order to do so by creating a flexible grid over the blockchain by making devices blockchain enabled.

Advantages achieved by implementing blockchain might also be achieved with other technologies like an API and centralized database. However, multiple of the blockchain advantages are in the past not achieved by any other technology. At the moment there is not a 100% successful – fully operational – blockchain initiative in the energy sector. This is mainly due to the fact that the blockchain technology is developing quickly and still has to reach maturity and the fact that the energy market is complex with a lot of barriers. There are a lot of implementations possible and due to restrictions the ones applicable at small scale, for instance a neighbourhood or city, are the ones most successful in the short term.

Where transparency is often given as advantage, in the energy sector this might be a disadvantage. Since small as well as large consumers might not appreciate their usage is visible for everyone because one can determine when a small customer is on holiday or for a company how environmentally aware they really are. However, this can be solved by specific blockchain algorithms already implemented in two popular cryptocurrencies (Monero and Zcash). The transaction speed problem is solved by Ripple, scalability in the amount of transaction by off-chain transactions and scalability in total chain size by sharding (splitting the database over different nodes). However, cyber security concerns still exist and attackers owning 51% computational power or stake are still able to generate fraudulent transactions in most blockchain networks. So small, private blockchain implementations are weak and an easy target for hackers.

5.3 CLASSIFICATION

From all initiatives and the conclusions derived from them as outlined in section 5.2, a classification has been made to group the initiatives since there is a large overlap in their goals. These categories are not mutually exclusive, so an initiative can have multiple of these goals. In the next section these initiatives are mapped onto the classification made. In the sections 5.3.2 till 5.3.6 each category is explained in more detail and interesting, if possible state-of-the-art, initiatives are highlighted. In section 5.4 this thesis provides even four more possibilities for applying blockchain within the energy section. The five types of common goals in the initiatives that have been found are defined as follows:

Energy trading: creating a decentralized market platform which allows for peer to peer trading between prosumers

Local markets: having a focus on creating small energy markets at neighborhood or municipality level

Rewarding crypto: unique cryptocurrency coins are rewarded for the supply of renewable energy

Pay/receive crypto: enabling the user to pay for his energy, outside his home, with cryptocurrency and on the receiver side sharing your energy supply and receive cryptocurrency

Grid balancing: balance the grid by matching supply and demand and use automated techniques in order to do so

5.3.1 MAPPING

Table 7 maps the initiatives that were found and explained in table 6 onto the classification.

TABLE 7: MAPPING INITIATIVES ONTO CLASSIFICATION

Company	Data source	Energy trading	Local markets	Rewarding crypto	Pay/receive crypto	Grid balancing
AdptEVE Freeeloio	Website & Slides	X	X			
Bankymoon Usizo	bankymoon.co.za				X	
BCDC EcoChain	bcdc.online				X	
Brooklynn Microgrid	lo3energy.com	X				
Co-tricity	Consensys slides	X				
Conjoule	conjoule.de	X	X			
Dajie	dajie.eu	X	X			
Electron	electron.org.uk	X				X
Greeneum	greeneum.net	X				
Grid Singularity	gridsingularity.com	X				X
Grid+	Whitepaper & Demo	X				X
GrunStromJeton	zoernert.github.io			X		
Hanzenet	Interview & Slides	X	X			
Hive	Whitepaper v1.0	X				
Innogy	innogy.com	X				
Lumenaza	lumenaza.de		X			
NRGCoin	Multiple papers	X				
OneUp	Interview	X				
Ponton EnerChain	enerchain.ponton.de	X				X
Power Ledger	Whitepaper v3.0	X				X
Qiwi	News	X				
Scanergy	scanergy-project.eu	X				
Share & Charge	shareandcharge.com				X	
Smappee	smappee.com			X		
Solarcoin	solarcoin.org			X		
Solether	solether.mkvd.net				X	
Stedin + Energy21	Whitepaper May '17	X	X			
StromDAO	stromdao.de & Slides	X				
Sun exchange	thesunexchange.com				X	
SunContract	Whitepaper April '17	X				

TenneT	tennet.eu					
Vector	vector.co.nz					
Volt markets	voltmarkets.com					
WePower.Network	Whitepaper v0.7					
Wien Energie	wienerstadtwerke.at					

5.3.2 ENERGY TRADING

Most initiatives are developing a distributed energy trading platform on the blockchain. Since the blockchain eliminates third parties and so enables peer to peer trading, this perfectly fits the energy transition. This is also a very interesting development in the energy transition since supply is more decentralized whereas it was first centralized through the generation of energy from nonrenewable sources. Prosumers now generate their own energy but want to sell surplus. In today's energy market and frameworks it is not possible to make deals between consumers. The only option is to sell it to your energy supplier which determines the price you get. In the Netherlands multiple regulations create a positive price for the consumers. But this regulation is only active till 2023 which means afterwards consumers will get a very low price for their surplus.

Movements in the energy transition therefore creates a perfect suitable environment for the appliance of blockchain. In the energy trading category there is still a significant difference between each initiatives' approach. Therefore the approaches and capabilities of five initiatives with significant differences will be explained in the next subsections. The initiatives are all capable of the following:

- Saving data from smart meters to the blockchain
- P2P trading of renewable energy
- Pay for electricity in real-time (billing process over blockchain)

5.3.2.1 POWER LEDGER

Power Ledger offers a platform that offers trustless, transparent and interoperable energy trading with a suite of applications (Power Ledger, 2017). In this platform they have their own coin, called the Power Ledger Token (POWR). This high-level tokens are used as software license pricing and can be traded for Sparkz which is the coin that is used to trade energy. After doing some pilots in Western Australia in 2016 they expanded their platform in 2017 and held an investment round in the end of 2017 to start the development of more of their applications. The application landscape exists at the moment of the following:

- P2P trading: allows to let consumers trade electricity with one another and pay and settle in real-time. It is also possible to select your energy source, trade with neighbors and receive money for surplus. In a regulated environment, there has to be an energy supplier or retailer that offers this services to customers.
- NEO-retailer: a retailer which supports the P2P trading platform through smart demand and supply management

- Microgrid/Embedded network operator: enables metering in the blockchain and manages the grid through big data analysis
- Wholesale market settlement: application that takes care of the reconciliation and settelement process of wholesale energy marketplaces
- Autonomous Asset management: allows for shared ownership of renewable energy assets and trading of the ownership. It is able to buy and sell electricity and distribute income over the owners.
- Distributed market management: a fully enabled blockchain market and network, including load balancing, frequency management, demand side response and demand side and load management
- Electric vehicles: settlement of EV charge points on the blockchain including user identification
- Power port: enable EVs to discharge when required to supply to the grid
- Carbon trading: trade carbon credits and certificates with smart contracts
- Transmission exchange: expand to the high-voltage level network and provide them with real-time meter data, transaction settlement and network load balancing

All applications have to be still developed or tested, except the P2P trading which is also the most interesting in this research. In most first world countries there has to be an application host that adopts this Power Ledger service to offer the P2P application to consumers since there is a regulatory framework. Within this framework the parties make sure the network is in balance and costs are split between the parties. In the Netherlands an energy supplier can take the role of application host. The application host has to provide the consumers with Sparkz tokens which can be bought with fiat currency. The application host is also responsible for buying electricity at the energy markets and having a balance responsible party.

Power Ledger uses a hybrid public and consortium blockchain which are both Ethereum blockchains. The public one is used for POWR tokens while the consortium blockchain (called EcoChain) is used to handle the high transaction volume in a fee-less way with a proof of stake algorithm.

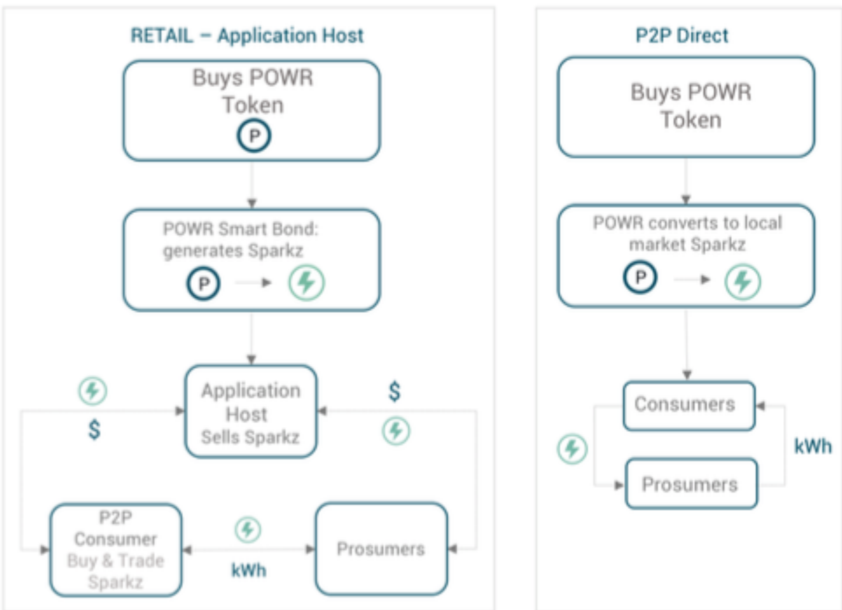

FIGURE 19: ARCHITECTURE WITH AND WITHOUT APPLICATION HOST (POWER LEDGER, 2017)

Their P2P product is offered as white label service which regulates the billing and invoice process and offers prepaid energy for consumers. In the application consumers can see their usage and energy inflows and outflows. However, in a meeting with one of the employees of Power Ledger it seemed they assumed all smart meters are Wi-Fi enabled but in this case in the Netherlands, a smart meter provided by a network operator is never Wi-Fi enabled. To connect a consumer to their platform a device has to be connected to the smart meter to publish meter values instantly to the Power Ledger platform.

5.3.2.2 GRID+

Grid+ is using a device agent that is connected to a smart meter and also has its own coins, the BOLT tokens (Consensys, 2017). The device agent is holding the tokens in a safe way where only the owner has the private key and uses them to pay for electricity at the energy markets. It can trade on its own at the day-ahead and real-time markets by creating and optimizing its own algorithm. It predicts usage for the next day and next hour depending on historical meter values and buys the amount of energy needed. In this way flexible prices are given to the user with prepaid energy.

Another feature is that they want to do demand response management by controlling devices in a house through the user agent. In this way it can activate or deactivate devices on behalf of the system operators or when market prices are low or high. In the future capabilities will be enhanced with tracking of people in the house.

Grid+ is using the public Ethereum blockchain with multiple instances of smart contracts. Device agents set up a payment channel with the central Grid+ smart contract (so called Karabraxos) to exchange BOLT tokens. It is unknown how this smart contract really buys energy according to the country's regulatory framework. In the Netherlands, it would also still need a balance responsible party which is creating e-programs for the next day. Grid+ is focusing on the United States and their whitepaper does not collaborate on this role. The whitepapers states that 50% of a retailers cost are not associated with the purchase of wholesale energy and so offers a cost reduction close to this.

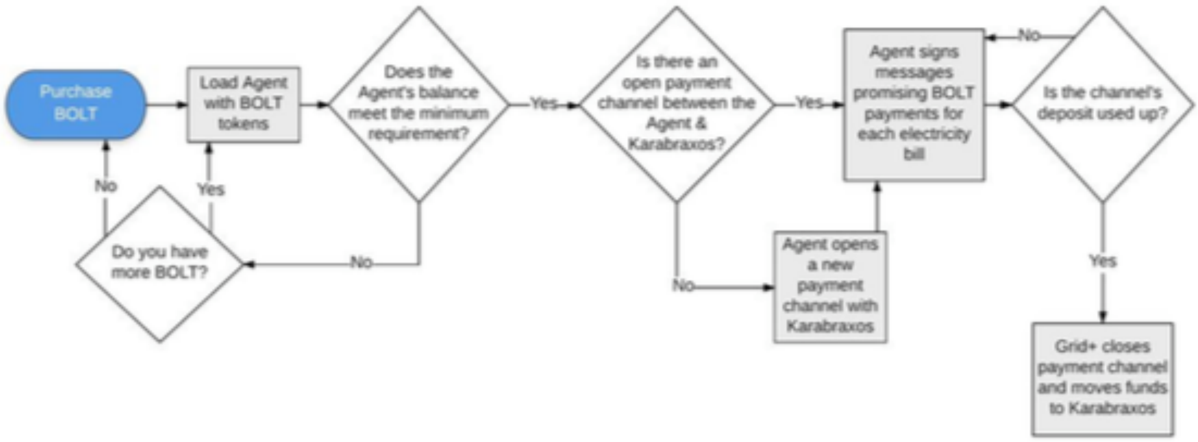

FIGURE 20: WORKFLOW GRID+ AGENT (CONSENSYS, 2017)

5.3.2.3 WEPOWER.NETWORK

The WePower solution focusses on energy trading as well as investments for renewable energy projects (WePower, 2017). Their main focus is the latter, since they found the energy transition was going too slow due to a lack of capital since financing is going down. Within their platform they want to support renewable energy developers by providing consumers direct access to future projects. Developers can sell energy from future projects upfront to consumers who can use it later on or sell it. According to the whitepaper the IRR is 17-20% for investors.

The energy from the future renewable energy project is tokenized, so for every supplied kWh one coin or token is produced on the platform. These tokens are distributed over the investors according to their share. Only a part of the predicted energy supply is sold upfront due to uncertainty. It also facilitates a connection with the energy markets to sell energy when there is not enough demand on its own platform or buy energy when there is not enough supply.

WePower is using the Ethereum blockchain with a set of smart contracts to make investment structures clear and verifiable. It is unknown how pricing structures will work and how investors should gain such a high IRR. Especially since time is a very important role in energy prices it would be important to know which prices will be used when buying energy upfront for such large time frames. With energy prices from large solar and wind parks sometimes becoming negative, the WePower platform will give one negative returns when one uses energy at these moments.

5.3.2.4 SUNCONTRACT

The primary objective of Suncontract is to create a peer to peer trading pool (SunContract, 2017) where one can buy and sell energy with Suncontract Tokens (SNC). People can trade fiat currency to SNC and register themselves in the pool with a mobile app. The same holds for producers which can supply the pools with energy and get SNC tokens per kWh. Producer and consumer can determine bid and asking prices and a trading algorithm in smart contracts will take care of the matching and settlement. Their first step is to implement this in Slovenia and afterwards expand to other countries and to also take care of load balancing and demand response services.

The Suncontracts whitepaper does not state anything about how it will get information from the meters. Their whitepaper suggests consumers and products only have to download an app but it is unknown how they will retrieve meter values and if they take the role of an energy supplier or balance responsible party in the energy markets. The pool is using a set of smart contracts on the Ethereum blockchain for settlement.

5.3.2.5 GREENEUM

Greeneum wants to offer a decentralized sustainable energy market with real-time energy transactions (Greeneum, 2017). Their marketplace leverages smart contracts and uses artificial intelligence (AI) and machine learning to generate real-time predictions for supply and demand. With their GREEN ERC-20 tokens people can trade peer to peer without fees. Furthermore, green certificates and carbon credits are provided to guarantee people use renewable energy. Greeneum is using the Ethereum blockchain and did not release a whitepaper yet.

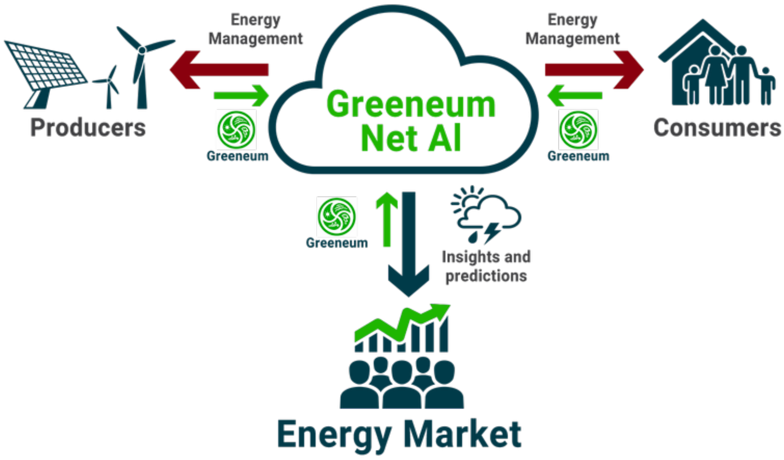

FIGURE 21: GREENEUM LANDSCAPE (GREENEUM, 2017)

5.3.2.6 NRGCOIN

NRGCoin distinguishes itself from other platforms since it was created in a scientific environment (Mihaylov, Radulescu, Razo-Zapata, & Nowe, 2017) and not a commercial one which gives a realistic view of the feasibility of such concepts and research papers which also name the disadvantages or difficulties when using blockchain enabled energy trading. In the NRGcoin concept one pays 1 NRGcoin for 1 kWh of green energy to a smart contract. The smart contract pays the grid fees and taxes to the DSO. Prosumers can also receive NRGcoins for every kWh injected into the platform. The fiat value of a NRGcoin should be around the retail price of one kWh. The research papers nor website do not state anything about the role NRGcoin should take in the energy markets and who should take care about balancing the grid.

Experienced disadvantages are mainly the blockchain technology since it is rapidly developing itself. Also, regulation of the blockchain technology and cryptocurrencies is still unclear so adaption is slow. The NRGcoin itself still has to be worked out properly too, like the economic model, security, data privacy and tamper prevention.

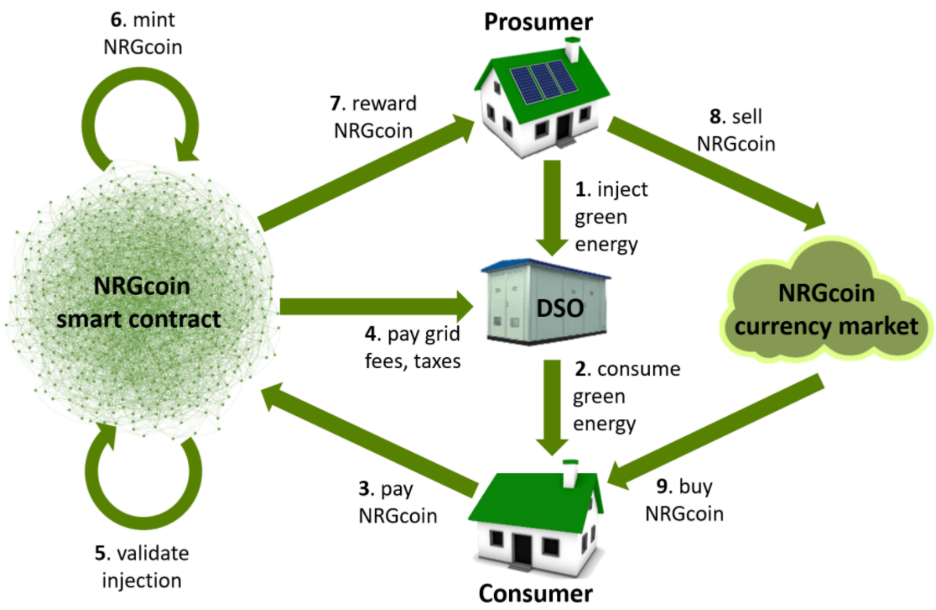

FIGURE 22: PARTIES IN THE NRGCOIN NETWORK (MIHAYLOV ET AL, 2017)

5.3.3 LOCAL MARKETS

All initiatives creating local markets are also applying energy trading but on smaller scales. This is from pools of 10 households till municipality level (ten thousand of households). This stimulates the usage of local energy usage and so creates a more decentralized energy grid. In the next subsections, the most important characteristics of the most extended initiatives will be highlighted.

5.3.3.1 STEDIN & ENERGY21

Stedin, a Dutch regional grid operator and Energy21, a company with energy expertise, developed a model for a new energy market which should solve the negative effects of the energy transition (Stedin & Energy21, 2017). In their market model blockchain, was a way to solve the problem and they did not start from the point of view that they wanted to do something with blockchain, a point of view you often see within companies. It distinguishes themselves from other initiatives since they want to create an open market instead of peer to peer deals. Their main goal is to lower network congestion and to reduce prices for customers.

This should be achieved by creating local markets in geographic areas. In these local markets the energy should be cheaper than the wholesale market for the whole country. This should be achieved by changing the law and create tax reductions, the same as happened with the 'postcoderoos' projects. The postcoderoos also gives tax reductions for local energy, but you have to invest in the energy source to get this reduction. If there is no tax reduction it will be difficult to make the smaller local markets more attractive than the wholesale market. The local markets should be connected to the wholesale market in case there is a surplus or shortcoming of energy in the local market. A gateway will be between the local and wholesale markets to add the tax fee and make sure this is collected. In the local markets energy will be sold with auctions and these also happen in the blockchain.

A demo was built to demonstrate the model by using a consortium blockchain. At the moment (September 2017) they are discussing the market model with all parties involved in the energy market to get feedback and to find out if it would be useful to implement such a model.

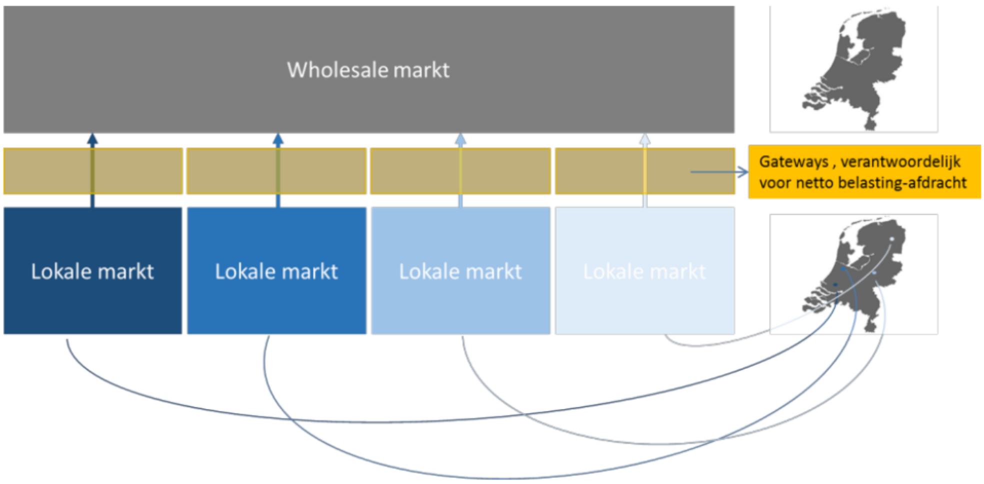

FIGURE 23: ARCHITECTURE OF THE LOCAL AND WHOLESALE MARKETS (STEDIN & ENERGY21, 2017)

5.3.3.2 JOULIETTE

The Jouliette (Jouliette, 2017) is more than just an energy trading concept since it should also be used as unit for trading of off-blockchain work or items. But in the first step the goal is to use it to settle the energy of a private grid behind the public grid. This is done in the Ceuvel (Amsterdam, Netherlands) and is shown in figure 24. The Jouliette coin is used as unit which is gain by prosumers for every kWh produced. Consumers pay with the Jouliette coin for their energy. Since this is a private grid the Ceuvel could build their own energy meters which are already blockchain enabled. With a private blockchain, based on multichain, they experiment with this solution.

The launch was in September 2017 and they want to create a community where the Jouliette coin can also be traded for goods or service. For now the total energy bill to the public grid is split according to the amount of Jouliette that is hold by each houseboat and then the balances are reset each year. It is the first announced already happening blockchain energy trading in the Netherlands.

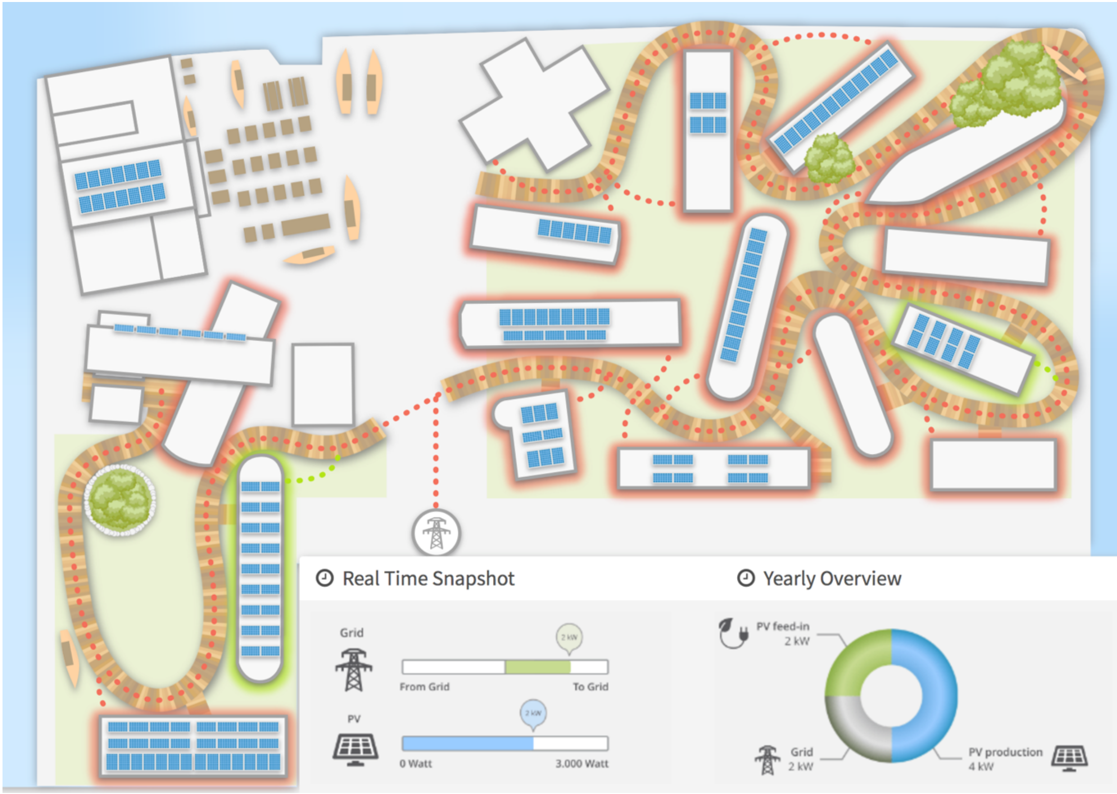

FIGURE 24: MAP OF THE CEUVEL

5.3.3.3 HANZENET

Hanzenet (Hanzenet, 2017) wants to introduce the Hanze, an own regional coin just like Jouliette. This initiative is in its begin phase in Deventer, the Netherlands. The difference with Jouliette is that all houses are connected to the public grid so regulations differ. Hanzenet is using a fork of the Dragonchain which is developed by Disney but is extended a lot by Hanzenet so it now also supports smart contracts. At the current moment, August 2017, they are saving the meter values from ten houses in their blockchain. This happens indirectly with the P4 data retrieved from EDSN so they are always one day behind. Their future vision is to create at every smart meter a blockchain node which reads the meter values and publish them in the blockchain.

They want to create small clusters of ten houses geographically close to each other, who trade with each other. All clusters should be close to self-efficient. In the first phases all houses should be still connected to a regular energy supplier but in the future they want to buy shortcomings or sell surplus from and to the APX. It is unknown how they want to do this within the regulatory framework since small consumers are required to have an energy supplier. Their main goal is to create a guarantee of origin and to create self-sufficient local clusters. The Hanze as coin should be the administration for the energy usage and so consumers need to buy these. The future vision is to balance the grid at micro level and create also a demand response system on this level.

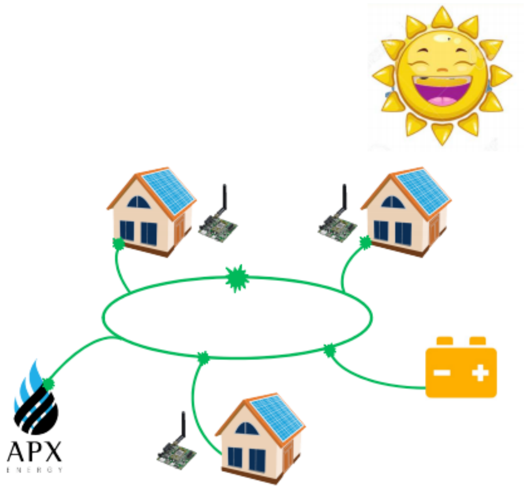

FIGURE 25: HANZENET FUTURE VISION (HANZENET, 2017)

5.3.4 REWARDING CRYPTO

The rewarding crypto category was described as ‘unique cryptocurrency coins are rewarded for the supply of renewable energy’. This process is pretty straightforward since initiatives in this category have their own blockchain and if you can prove you have generated renewable energy you get a certain amount of the cryptocurrency used on the initiatives’ blockchain. Two such initiatives will be shortly analyzed.

Solarcoin is the biggest in this category and is widely used, they are granting solarcoins in 44 countries. They started with an offchain process where prosumers could send their energy bill from their energy supplier to Solarcoin and so receive Solarcoin according to their supply. Solarcoin is now focusing on integration with solar installers, so small IoT devices implemented in the solar panels should submit their supply and retrieve the Solarcoins for the prosumer. It is already possible to connect with smart meter APIs and it is also integrated in Smappee, a company developing smart energy devices for your home.

GrünStromJeton is rewarding ‘Grünstrom Tokens’ and ‘Graustrom tokens’ for the kind of energy you used. They have no business model and focus more on the proof of your green energy usage. Since they state that it should be possible to trade these tokens it can be seen as substitute from green certificates.

A main issue in this category is that it is difficult to create value for not popular cryptocurrencies. They are gain as by-product from producing energy and so more or less free. However, they are a proof of the generation or use of renewable energy and so, can be seen as substitute from green certificates which have decent value. However, in the current energy markets one will get the traditional green certificates and a Solarcoin or Grünstrom Tokens. An average house with a solar panel installation of 3 kWp will supply about 2550 kWh. At the moment, one gets 1 Solarcoin per 1MWh and a Solarcoin is worth $0.28 so the gain is $0.71 yearly. None of the initiatives stated they want to substitute green certificates.

5.3.5 PAY/RECEIVE CRYPTO

Initiatives in this sector use cryptocurrency as payment method to enable the flow of energy through an energy connection. This can be used at public places, as consumer to share your energy or to pay someone else's electricity bill.

Share&Charge is the largest initiative in this category facilitating more than 1200 EV charging stations with cryptocurrency as payment method. It creates the possibility to make private charging stations at peoples' home public for everyone and to get paid for the delivered electricity. Users do not notice that it is using the Ethereum blockchain since all balances are shown in a fiat currency. The project is now expanding to Europe and might be very important when EV sales highly increase. Fewer public charge stations will be required.

Sun Exchange is a company where one can invest in solar panels on the sunniest places on earth and pay their investment in cryptocurrency and also get their return paid in cryptocurrency. The solar panels will generate income for 20 years and these panels will be placed in developing countries. Bankymoon's Usizo is another crowdfunding project but is focusing on crowdfunding the electricity bill for schools. Meters in these schools are blockchain aware and can respond to payments received. In this way, you are sure your payments are really used to facilitate schools.

5.3.6 GRID BALANCING

As explained in section 3.1 the grid always has to be in balance. Supply has to be the same as demand and this is measured by the frequency in the grid which should be around 50 hertz and in practice is allowed to be between 49.9 and 50.1 Hz. Therefore each connection to the grid has a balance responsible party that sends predictions for the next day to TenneT through an e-program. TenneT will balance the net during the day and parties deviating from their e-program will get financial sanctions. TenneT is using regulated reserve capacity and if required emergency power throughout the day to balance the grid.

Large consumers with a direct grid connection and parties supplying more than 60 MW are required to provide reserve capacity. For the emergency power TenneT contracts parties who get paid yearly, even if they have not acted. Due to the higher share of renewable energy TenneT is looking for new solutions since fluctuations in demand and supply are higher (TenneT, 2016). They cooperate with Vandebron, an energy supplier, to create flexible charging for electric vehicles. In a pilot, they promise consumers 200 till 300 euros discount a year for joining (Vandebron, 2017). Your EV will be used to use and supply energy to and from the grid when demanded by TenneT. IBM is also cooperating, probably by providing their hyperledger blockchain solution. In this case blockchain can provide a transparent decentral solution for all parties involved in this project and can reward consumers.

In Power Ledger's whitepaper, they also describe how electric vehicles' charge stations will also be fully blockchain enabled. The platforms application power port should be used to also let EVs discharge to supply energy back to the grid. The Grid+ whitepaper also states their device agent should be used in a demand response environment where it can control thermostat or Tesla chargers to balance the grid and by doing so, create revenue for the consumer.

A publication by the TU Deflt (Hijgenaar, 2017), in collaboration with CGI, describes also how blockchain can be used together with electric vehicles to balance the grid. Simulations with real life situations using an algorithm for peak shaving and shifting to let EVs (dis)charge shows that cost for the charge session is below market tariffs. The Tendermint blockchain platform is used to securely store trade data and should give transparency for consumers and grid operators for trade data and billing.

In the future, when batteries are cheaper and devices can be easily controlled from distance, it will be possible to use these as well for grid balancing instead of only electric vehicles. Blockchain can offer, besides a decentralized communication protocol, rewards for users directly with cryptocurrency when they offer flexibility.

5.4 MORE OPPORTUNITIES

Remarkable from most initiatives is that they miss a clear vision on how they want to implement their solutions in an environment where, in most countries, a strict regulatory framework is in place. This is done since the grid should be in balance but there should also be a deregulated market to ensure fair prices for consumers. The classification made in section 5.3 does not mean there are no more possibilities with blockchain in the smart grid and energy markets. In this section four more propositions are discussed where blockchain could add value in the energy sector and markets.

5.4.1 DEMAND RESPONSE COMMUNICATION

Demand response communication happens to keep the grid in balance or with other goals. So, an external trigger increases or decreases the energy demand from specific devices. This category is close to ‘grid balancing’ but we can distinguish between grid balancing and demand response since grid balancing might be one party responsible to balance the grid whereas demand response might happen by multiple parties on the same grid with a different goal then grid balancing. For instance, for grid congestion management or in order to let devices respond to the market prices of energy. The IOTA tangle is focusing on machine to machine interaction and allows for zero value transactions and so, could be most suitable in this case.

5.4.2 REAL-TIME GOO

Currently GoO’s are rewarded on yearly based and third parties are created like CertiQ in order to distribute the certificates. So this happens on yearly aggregation and grey energy can be made green by buying certificates. The buyer is responsible for crossing out kWh on certificates when they have sold energy with a green label. The society is missing a transparent, decentralized and honest system. By publishing meter data from renewable energy sources in the blockchain, one could generate real-time GoO aggregated on PTU level instead of yearly. This fits reality best and is most fair to use for everyone. Energy suppliers selling green energy have to make more effort in delivering green energy 24 hours a day but can give an honest guarantee, instead of aggregating all data and using a nontransparent system. When introducing such a system, one should look into how to make the conversion from the current certificate system to a real-time GoO system on the blockchain. If certificates are still rewarded, these should probably not be used.

5.4.3 SHARING METER DATA

As shown in figure 11, there are 9 parties involved in the energy markets. But even more parties are involved when you include administrative processes. For instance, a party like EDSN (Energy Data Services Netherlands) is retrieving all P4 port data over GPRS and saves this in a database. Independent services providers (ODA's) can get access to this data when a customer has signed a contract. This process is complex, non-transparent and delivering old data. The customer also has no control of their privacy since it cannot verify if for example an ODA has stopped reading his data on their request. A new platform based on the blockchain technology could provide a transparent and safe system for all parties involved in the energy markets, preferably based on real-time P1 data.

5.4.4 MULTIPLE SUPPLIERS

Having multiple energy suppliers at one energy connection is becoming a popular concept in the energy transition. The ACM has created a system where this is possible in 2018 in the Netherlands, however it requires the installation of a second meter. Besides the practical implications, time it takes to enroll such a system and costs, it does not offer a flexible system. Energy suppliers are still assigned for the longer term in the C-AR. Blockchain has the ability to provide a settlement system which can settle easily every minute or every PTU and take responsibility for the distribution of income. This could for instance be implemented at charging stations for electric vehicles to create a separated charging infrastructure. Normally a third party would be required to setup the administrative system, for example in the Enexis pilot creating a separated charging infrastructure, Elaad had to build and maintain the system.

6 OPPORTUNITIES FOR EXE

EXE is a startup focusing on the energy transition and is delivering three software products. Currently these products are not using blockchain and it is unknown if they can support any existing blockchain initiative. This section gives answer to the subquestion:

5. What is the potential for blockchain for the EXE product portfolio?

6.1 EXE PRODUCT PORTFOLIO

Energy eXchange Enablers (EXE) is a spin off from Dutch regional grid operator Alliander. The vision of EXE is to give the user control of their energy through three different IT solutions. They experienced the energy transition was going too slow and foresaw a problem for grid operators to balance the grid with the increasing power generation by renewable energy sources. Problems that will arise are outlined in section 4 and are mainly the inflexible production and high congestion levels. As explained in section 3 a lot of parties and complex processes are involved in the energy sector. In total 9 parties are involved in the delivery and metering process of energy and this energy can be bought and sold between parties before delivery in 5 different ways depending on the time left before delivery. EXE's solutions offer easy access to the control of your own energy through enabling grassroots, peer to peer trading, flexibility and direct access to energy markets. In the following subsections, these IT solutions are explained in more detail.

6.1.1 ENWIRE

Enwire is a market place for sustainable energy to enable the usage of local energy. The product is offered to energy suppliers and local initiatives like energiecoöperaties. One can create a customized marketplace where consumers can choose their own energy source as fixed energy supplier for their home. This are most of the times the cooperatie's solar parks in the same municipality as the consumer or farmers with bio energy. There are two possibilities: you fund a solar panel or multiple solar panels and consume the energy as soon as they are installed or you select a source that is already installed and only consume energy. For the first option, consumers can get a reduction of their energy tax of 9 eurocents in the Netherlands (known as the 'postcoderoos' or 'regeling verlaagd tarief'). For the second option, a prediction is made of the energy generated by a source and 90% of the predicted supply is sold to customers. If it is generating more than the energy sold to customers, this is sold at the energy markets.

The deals are made between the energy suppliers and the consumer where Enwire is only the facilitating platform. It does not take any of the roles in the energy market.

6.1.2 R.E.X.

Realtime Energy eXchange (R.E.X.) connects the energy demand and supply of flexible devices to the energy market. Flexible devices are devices that can provide some flexibility in their time of energy usage, e.g. shift it one hour forward or backward. In this way, a device can react to energy prices and so, use energy when the prices are low and supply the network with energy when prices are high. This is done by equipping devices that allow flexibility, like heat pumps and cold stores, with a device agent. These devices agents send their flexibility margins to R.E.X. which aggregates all the data. Flexibility margins can be for instance that a cooling house should stay between -20 °C and - 25 °C and should not switch more than 20 times a day on and off. This provides flexibility for when the cold storage should be cooled down to -25 °C.

R.E.X. uses the open source software Powermatcher which is developed by the Netherlands Organization for Applied Scientific Research (TNO). Powermatcher provides coordination for a smart grid by letting devices communicate which each other so they can balance supply and demand. It helps with lowering network congestion and lowering energy prices. It does so by creating a hierarchy of three levels; device agents, concentrators and an auctioneer agent. This is shown in figure 26. Device agents send bid curves to the concentrator which concentrates or aggregates all bids and publishes a single bid curve upward in the hierarchy which makes a network more scalable. The auctioneer agent is at the top of the hierarchy and determines the market price when all bids are received and the market price is communicated down to all devices.

In this case, R.E.X. creates a link with the energy market prices to create financial advantage to the users. It does not sell or buy energy, it only let the devices react to the current market price.

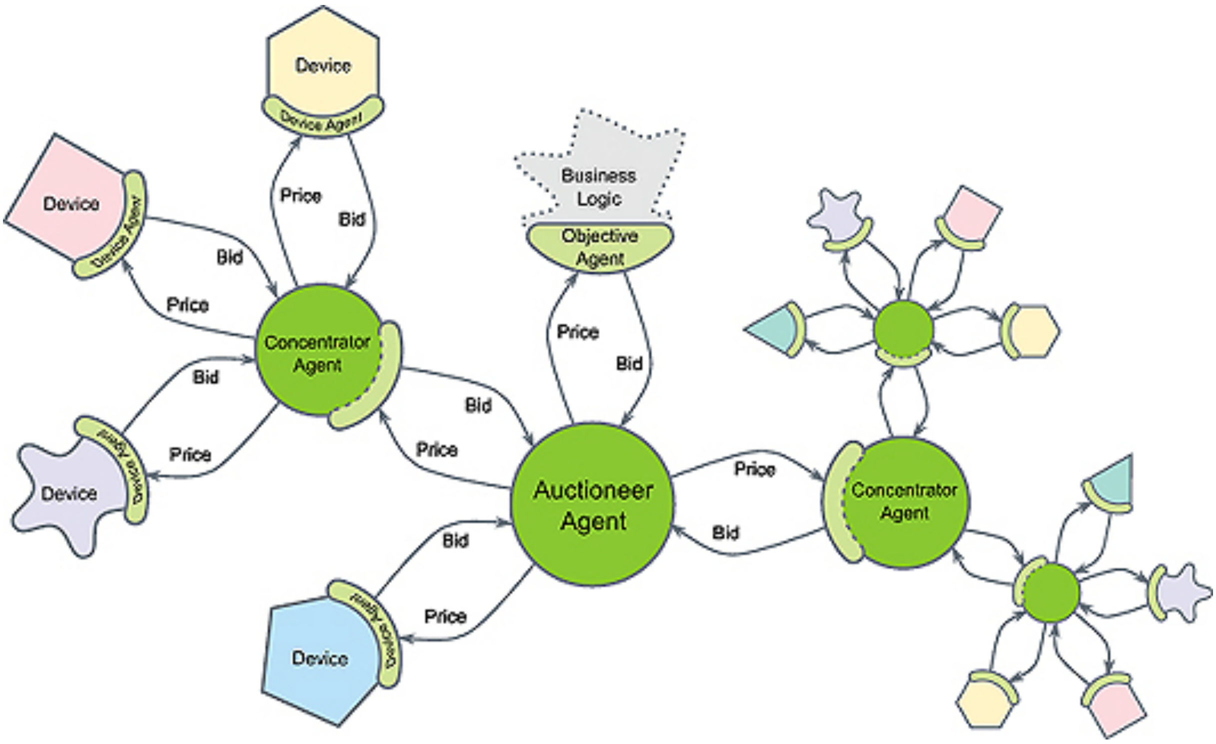

FIGURE 26: POWERMATCHER ARCHITECTURE

6.1.3 ENTRNCE

Entrnce makes direct transactions possible from EAN to EAN and gives the user direct access to energy markets. An EAN is a smart meter connection in the grid, so it facilitates peer to peer trading. It takes the role of the balance responsible party as explained in section 3.2. This means that customers of Entrnce send their expected energy supply or consumption to the Entrnce platform. If a customer has only supply or only consumption the energy will be sold or bought at the energy markets. If a customer has production facilities as well as consumption at different places, EAN to EAN transactions are executed. All transactions happen per PTU (15 minutes). Entrnce aggregates the expected energy flows from all customers and creates a single e-program which is sent to TenneT.

Any differences between the customers expected and real usage as well as the cost or income from buying or selling energy at the markets is settled on the Entrnce platform. The main focus of Entrnce are large producers and consumers, since for small consumers it is legally required to have an energy supplier and for large consumers it is not. This does not mean that Entrnce cannot support in the energy supply for customers but in order to do so, it becomes a B2B2C product where it is used by an energy supplier.

6.2 OPPORTUNITIES

In this section fits between the classification made in section 5.3 and 5.4 and the EXE product portfolio will be analyzed. For each product and its strategy, possibilities for blockchain will be analyzed together with their potential. In section 6.3 a conclusion will be derived.

6.2.1 ENWIRE

The white label marketplace Enwire which is an B2B2C product is a platform to connect consumers to a specific energy source. After the consumer has selected his future energy source on the Enwire platform, all administration in the future is done by the energy supplier and EXE is not involved anymore. Therefore, there is not a real proposition where blockchain can add value in the current Enwire product. However, it is a facilitator of local energy and a direct supply is chosen by the consumer. Time is not taken into account in supply and demand, both are aggregated for one year. So one can be sure when selecting a solar source the energy in the evening and night is not generated by the selected source.

When Enwire would like to create more transparency, there would be the following options:

(1) Publish meter values from the energy source and consumers into the blockchain yearly. This creates value for the consumers since they can validate the energy source has indeed supplied enough energy for all consumers connected to the source. If not, the source is oversold and some consumers should be dropped.

(2) Match supply and demand per PTU by publishing meter values per PTU to the blockchain and create matches per PTU. This makes consumers more renewable energy source aware and shows them timing is important. A dashboard can show them at which times they have really used energy from their selected energy source (when supply was available) and when not. This option fits with the real-time GoO as explained in section 5.4.2.

In the case of (1), consumers can validate the energy source is not oversold and so, to validate the Enwire platform and the energy cooperation is honest. But in most cases these parties will already be experienced as trusted by consumers. (2) is giving the user a more honest view of their energy source. In reality timing plays a very important role but supply and demand are now aggregated to yearly level. It would be of interest to know for their consumer at which times they used energy when their source was supplying it. This makes them more source aware and creates the most transparent solution.

At the moment Enwire is only a facilitating platform to connect consumer and supply and does not make any energy deals. Solution (1) and (2) focus more on the process after the contract has been signed and therefore, are slightly off the strategy of the Enwire platform.

6.2.2 R.E.X.

As explained in section 6.1.2, R.E.X. is utilizing the Powermatcher software to create a demand response environment where devices act depending on the actual energy market prizes. Figure 26 shows how devices communicate to each other in a layered structure to create a scalable infrastructure. A familiar characteristic with blockchain is its decentralized structure. However, R.E.X. is using managed databases for each cluster of devices which is hosted in the cloud. With the structure and value R.E.X. want to create, one could enable the usage of blockchain in the following ways.

(1) Publishing bids and prices into a smart contract or in the IOTA tangle. As shown in figure 27, each device has an API to receive bids and prices which are aggregated or forwarded. A blockchain or DAG solution creates a secure decentralized system which is scalable. Concentrators might be required in a lesser degree or not at all. A smart contract can be the central place to send bids and where the Equilibrium price is set and can be read by device agents. This eliminates establishing connections and setting up sessions. It also fits the blockchain philosophy of being an event driven system and not a scheduled one (no timed events are possible in a blockchain). In the case of using IOTA, one can use its MAM protocol to send messages. Channels can be used to send bids and concentrators and/or aggregators can listen to these channels to determine the equilibrium price and publish this in the same channel. If concentrators will still be required is unknown since it is unknown to how many channels one can listen simultaneously.
The main advantage for EXE will be the decentralization and hosted infrastructure. When using smart contracts, transaction cost might be a disadvantage. Therefore IOTA, with its focus on machine to machine communication might be the perfect fit. It also supports MQTT, a ISO standardized publish-subscribe-based messaging protocol, used in R.E.X.

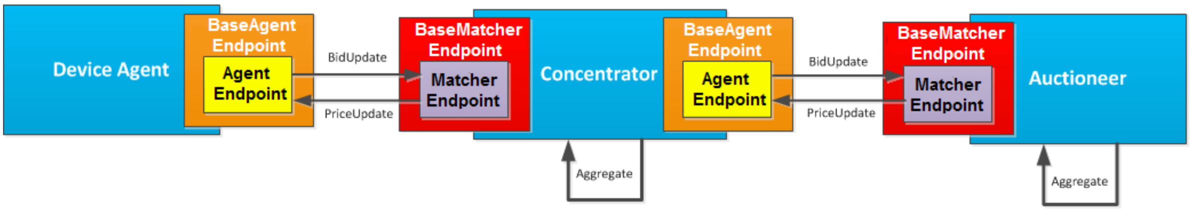

FIGURE 27: COMMUNICATION POWERMATCHER INSTANCES

If a system like R.E.X. would be used to balance the grid or it would include financial rewards for increasing or decreasing the supply or demand from the grid, blockchain could add value with the following propositions. For now, this is outside the scope of R.E.X. but it could be valuable in demand response systems.

(2) Publishing meter values from a device, or a connection to the grid, into the blockchain to validate a device's response to the demand response system. A solution like powermatcher let devices communicate their bids and a price is determined to balance the cluster. However, it is not guaranteed that devices indeed act according to their bid when the equilibrium price is received. When the usage of a device would be transparent in the demand response system one could validate its adjusted demand. Also, when the smart meter would publish its meter values into the blockchain one can validate adjusted demand, even though energy usage is aggregated from all devices, by recognizing patterns. Likely, this will be used together with (3).

(3) Awarding users with cryptocurrency on a demand response request. Since a demand response system like powermatcher does not guarantee the device agent does what it said it will do, it is likely this solution will be used together with (2). A TSO has parties supplying regulating and reserve capacity and suppliers for emergency power to balance the grid. Regulating and reserve capacity parties sent their bids one day before to TenneT with their available capacity per PTU. When used by TenneT, one gets the price asked for their supply of regulating and reserve capacity. Emergency power parties are getting a phone call when their capacity is required and should adjust according to TenneT requirements within 15 minutes. These systems require now human actions but could also easily be solved when all logic would be implemented in smart contracts.

6.2.3 ENTRNCE

The Entrnce platform facilitates direct transactions between demand and supply or to the energy market. They fulfil multiple value propositions which cannot all be named here due to confidentiality. However, one of the top three most important value propositions is facilitate energy service providers. They want to support new propositions created by startups by providing easy access to the energy markets. By taking the role of balance responsible party, they can facilitate people making peer to peer deals in the current markets. Since EXE is part of the DSO Alliander, it is not allowed to buy or sell energy itself. Therefore, parties using the Entrnce party platform have to make predictions of their energy usage the next day. Afterwards, any differences will be settled with the prepaid balances users have within the Entrnce platform.

Taking into account the capabilities as platform and what it provides to its users, the following blockchain propositions are possible.

(1) Entrnce as enabler of any blockchain initiative using energy trading, locally or not. In section 5.3.2 the most mature energy trading blockchain initiatives were analyzed. A common shortcoming is that they are created without taking the current energy markets into account. In order to implement this on the public grid it has to take the role of a balance responsible party when only having large customers and/or the role of energy supplier when having small customers. In both cases, Entrnce can take the role of BRP so these initiatives do not have to take into account the complex energy markets. Entrnce can buy the energy for the portfolio of connections for an initiative. It does not matter if the initiative focusses locally or nationwide.

(2) Entrnce as BRP for grid connections with multiple energy suppliers using blockchain as administrative platform. Having multiple energy suppliers at one connection is becoming more popular, especially for EV charging stations. It occurs that tenders are held for charging stations and that these charging stations are connected to a specific energy supplier. EXE wants to create an open charging infrastructure with a free choice of energy supplier for the user. Blockchain could add value by creating a transparent settlement system for all parties involved where Entrnce could buy the energy for the charging station portfolio.

However, it can also be seen as competitor when parties are taking the BRP role themselves. The peer to peer trading is a shared philosophy of Entrnce and most initiatives. It is not easy to get a BRP license, at the moment (November 2017) there are 48 registered BRP parties in the Netherlands. Therefore, it seems unlikely that worldwide blockchain energy trading initiatives will choose to gain their own license and build their own systems to fulfill the BRP role when Entrnce facilitates easy access. Possibilities for Entrnce to create a blockchain based solution in their own infrastructure can be as follows.

(3) Use a smart contract or a set of smart contracts to settle deals. Everyday the differences between predicted and real meter values are settled in fiat balances on the platform and users have a prepaid account. The whole account and financial part could also be resolved by using a blockchain and using an own token. When meter values would be saved real-time on the blockchain any imbalance can be settled every PTU. Since the Entrnce system is already build, the benefits of implementing blockchain are minimal.

6.3 CONCLUSION

The conclusion derived from the previous section, and so taking into account the EXE product portfolio and the abilities of blockchain and initiatives, has led to the mapping shown in table 8. The first column is the EXE product portfolio and the 9 consecutive columns the different possible types of blockchain appliance in the energy sector. Of these 9, the first 5 are derived from current blockchain initiatives and the consecutive 4 are additional opportunities as outlined in section 5.4. The pluses and minuses represent the potential in the mapping of products and blockchain opportunities.

TABLE 8: BLOCKCHAIN POTENTIAL EXE PRODUCT PORTFOLIO

	Energy trading	Local markets	Reward crypto	Pay/receive crypto	Grid balancing	Demand response communication	Real-time GoO	Sharing meter data	Multiple suppliers
Enwire	--	--	--	--	--	--	+-	+-	--
R.E.X.	--	--	+-	--	--	+	--	+-	--
Entrnce	++	++	--	+-	--	--	+-	+-	++

The potential is concluded from analyzing the product strategy EXE has for each product. In most cases this includes for instance proposition wheels and the market entry plan. When the option would include building an own blockchain based solution, there was looked into in which factor blockchain would add benefits or that the goal could also be realized with a central party and database. The biggest potential for EXE is to enable blockchain energy trading by offering the BRP role to these initiatives. The same holds for initiatives creating local markets. Furthermore, there is potential in enabling multiple energy suppliers at one connection where Entrnce can take the BRP role and blockchain enables a transparent platform and financial transactions between all parties involved.

The next section explains at more technical level how to support and implement the most potential options.

7 SOLUTION DESIGN

In the previous section, multiple potential opportunities for EXE and blockchain are indicated. This section analyses the opportunities with the highest potential and creates a possible design for each solution. This section gives answer to the subquestion:

6. How to develop a blockchain proposition for EXE that fits their product portfolio best?

7.1 ENERGY TRADING: BLOCKENERGY

This section explains how a proposition where energy is traded on the blockchain, between suppliers or prosumers and consumers, can be applied in the public grid within the current regulatory framework and using the Entrnce software. To do so, the hypothetical energy supplier BlockEnergy is designed.

7.1.1 DESIGN

All initiatives trading energy on the blockchain are using more or less the same concept, except Grid+. Grid+ creates a direct connection to the energy market where the others create deals between the users. Both cases fit the Entrnce philosophy: EAN 2 EAN deals and a direct connection to the APX. None of the parties take into account the energy markets and roles like a BRP. Therefore, Entrnce can be the enabler of these initiatives.

The concepts as shown in table 7 and of which some are further explained in section 5.3.2, are generalized and visualized in figure 28. This concept could be implemented by the hypothetical energy supplier BlockEnergy. A user can buy the internal token the system is using for fiat currency and this token is traded for energy in later stages. In case the user is a prosumer or supplier he or she gets tokens and these tokens can, if not used, be converted back to fiat currency. A smart contract is responsible for creating deals between the supplier and consumer. How this is done is up to the initiative. This can be for instance direct deals, sometimes even with a preference given by the user and fixed prices, or flexible deals with energy pools. Smart meters should always be enabled with a direct internet connection to publish meter data in the blockchain. Therefore a device has to be connected to the smart meter's P1 port. Trades are settled on a selected time span; in most cases between every 1 and 15 minutes.

The pricing of tokens and energy is different for each initiative. Some use 1:1, so 1 token gives 1 kWh of energy. However, in these cases timing is not taken into account since one can buy tokens when they are cheap or they even have a fixed price. This while time plays a very important role in the energy transition since supply is fluctuating more than before. Therefore, it is most acceptable to use fixed prices for tokens and a flexible rate for the exchange from tokens to kWh. The latter will be based on current APX prices provided by Entrnce. To make it user-friendly and clear it is advised to price a token 1 cent.

Most cases do not take into account the complexity of energy prices. In the Netherlands one pays besides the price of the energy, also for the DSO, ODE ('opslag dure energie'), tax and energy tax. In an ideal design these additional fees are automatically paid by logic included in the smart contract. This can be done by giving these parties their own account and let them receive tokens. One can withdraw these to receive fiat currency or this can be done automatically.

Unfortunately, EXE could not provide such a trading system themselves to small suppliers. Due to the decentralized markets they are not allowed to buy and sell energy and so, to take the energy supplier role. Therefore another party should provide the trading system. In the next section the opportunities and advantages of such a system are outlined.

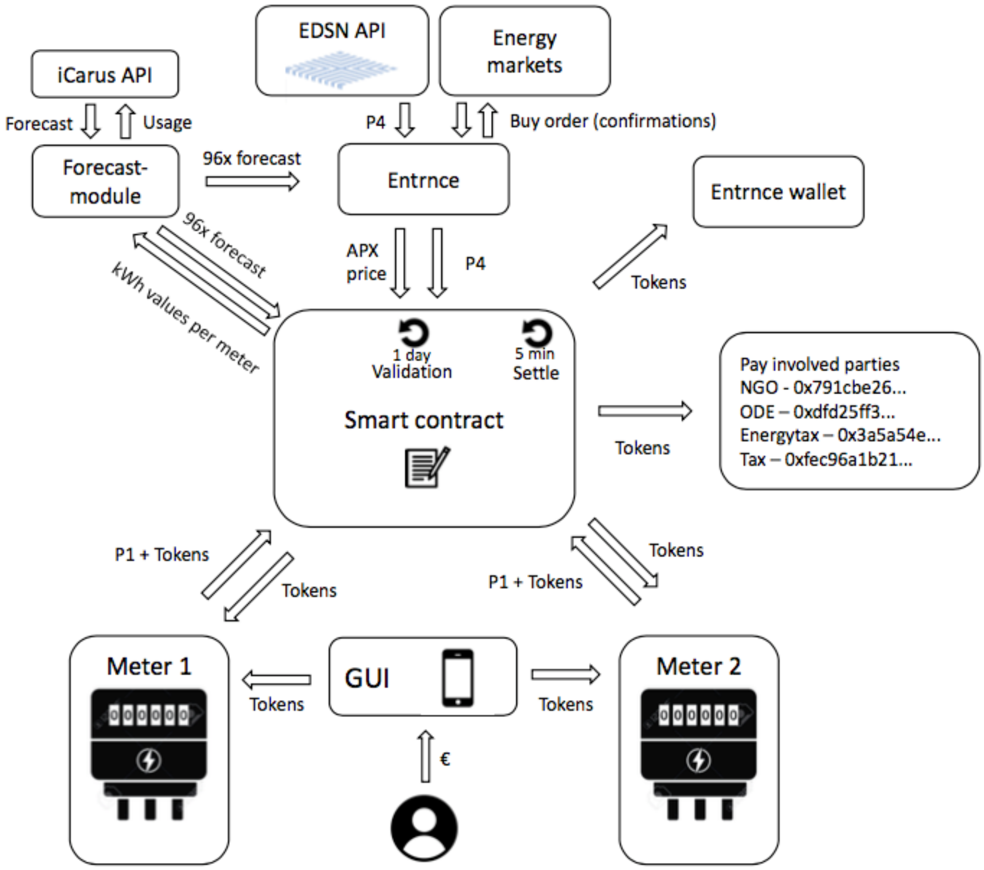

FIGURE 28: GENERALIZATION OF ENERGY TRADING

7.1.2 ADVANTAGES FOR THE SUPPLIER

The problem with the current energy suppliers is that they are big established companies with legacy systems, expensive software, high overhead costs and they provide most of the times fixed prices for energy or a day and night price. This is based on the old system with central supply. When breaking down the price per kWh, one pays for 17% in the UK (Energy UK, 2017) and 12% in Australia (Energy Aurora, 2017).

An energy supplier using this system does not need a complicated reconciliation process between a lot of parties since this is automated with Entrnce and the smart contract. The energy supplier can offer prepaid energy with flexible pricing. Direct APX prices can be provided or users can choose their own price, for instance to family or friends. It might also be possible to get a reduction on energy tax when the 'postcoderoos' would be supported. People get freedom in choosing their energy source through an app and every 5 minutes the settlement could take place. They can also see their real-time usage and active devices consuming energy, since they can be recognized by their energy usage profiles.

By offering direct access to the energy markets and remove overhead cost of the energy supplier, people might be able to reduce their costs with probably up to 15%. Current energy supplier costs are 17% in the UK (Energy UK, 2017) and 12% in Australia (Energy Aurora, 2017) and such initiatives could get tax reduction as for instance is the case with postcoderoos projects and real-time energy trades in Eemnes (Binnenlands bestuur, 2018). More cost reduction could be achieved by putting effort in reducing the imbalance between prediction and actual in real-time. This can be achieved in two ways. The first option is to use the intraday market to buy shortcomings or sell surplus, or the energy supplier could try to balance supply and demand by offering financial benefits to the users when they increase or decrease demand from the grid.

7.1.3 TECHNICAL DESIGN

The Ethereum blockchain is in almost all initiatives used as technology. It is also processing the most transactions per second worldwide. Most of them also use their own cryptocurrency which is achieved by using ERC-20 tokens (Ethereum Github, 2017). An ERC-20 token is an interface contract declaring the required functions and events to meet the standard. In the BlockEnergy concept the central smart contract implements the ERC-20 contract by implementing the ERC-20 interface which is shown in code snippet 1.

```
contract ERC20Interface {
    event Transfer(address indexed from, address indexed to, uint256 value);
    event Approval(address indexed from, address indexed spender, uint256 value);

    function totalSupply() constant returns(uint256 supply);
    function balanceOf(address _owner) constant returns(uint256 balance);
    function transfer(address _to, uint256 _value) returns(bool success);
    function transferFrom(address _from, address _to, uint256 _value) returns(bool s
uccess);
    function approve(address _spender, uint256 _value) returns(bool success);

    function allowance(address _owner, address _spender) constant returns(uint256 rem
aining);

    function symbol() constant returns(string);
    function decimals() constant returns(uint8);
    function name() constant returns(string);
}
```

CODE SNIPPET 1: ERC-20 TOKEN INTERFACE CONTRACT

Any smart contract can only interact with other smart contracts. It cannot read API's or webservices by calling an URL. To get data from a service not having its data in the blockchain, oracles are required. Oraclize is a company providing on-chain oracles so you can retrieve data from outside the blockchain through their services. One can send an url to their smart contracts and when they have pushed the data into the blockchain, the callback function from your own smart contract is called with as parameter the result. The Oraclize smart contract is an abstract class extended by the central smart contract which is shown in code snippet 2. To use the Oraclize services on the live Ethereum blockchain one has to pay them for their services and so, the function calling oraclize_query should be payable. BlockEnergy's smart contract uses Oraclize to retrieve P4, real-time APX data and forecast data. All calls to the Oraclize service are sending data back to the __calback function which should handle data from three different calls. One can distinguish between the different calls by saving the return value (an ID) from oraclize_query and connecting the type of request to it.

```
contract A is usingOraclize {
    function A() {
        OAR = OraclizeAddrResolverI(0x6f485C8BF6fc43eA212E93BBF8ce046C7f1cb475);
        call();
    }

    function __callback(bytes32 myid, string result) {
        if (msg.sender != oraclize_cbAddress()) throw;
        saveResult(result);
    }

    function call() payable {
        newOraclizeQuery("Oraclize query was sent, standing by for the answer..");
        oraclize_query("URL", "xml(https://url.ext/api?par1=a&par2=b");
    }
}
```

CODE SNIPPET 2: ORACLIZE IMPLEMENTATION

BlockEnergy's smart contract should also provide read access for the forecast module. In this way the forecast module can also make predictions based on the usage of the days before instead of older P4 data. With other functionalities, the abstracted BlockEnergy contract should implement the following BlockEnergyInterface.

```
contract BlockEnergyInterface {
    function registerMeter(uint _EAN, uint _time, uint _initialValue) public;
    function newMeterValue(uint _time, uint _value) public;

    function getLastValues(uint[] EANs) public constant returns(uint[]);
    function getValues(uint EAN, uint from, uint to) public constant returns(uint[]);

    function retrieveAPX() public payable;
    function retrieveP4() public payable;
    function retrieveForecast() public payable;
    function settle() public payable;

    function validateP4() public;
    function notifyAccount() public;

    /* Payment types: 1 = per kwh, 2 = per day, 3 = percentage over total */
    function registerParty(string name, uint paymentType, uint price, address account) public;
    function removeParty(string name) public;
    function payParties(uint kwh, uint totalDays) public;
}
```

CODE SNIPPET 3: BLOCKENERGY INTERFACE CONTRACT

The smart contract can register involved parties involved to pay them. Three different payment types have been classified according to energy bills in the Netherlands. These are a fixed fee per kWh or per day and a tax over the total price. This has been based on the following parties:

- DSO – Fixed price per day. Price is depending on the connection but for small customers it varies from 0,49 till 0,59 eurocents per day (excl. VAT) depending on the DSO (Independer, 2017).
- ODE – Fixed price per kWh. For small customers 0,0074 (excl. VAT) per kWh in the Netherlands (Belastingdienst, 2017)
- Energy tax – Fixed price per kWh. For small customers 0,1013 (excl. VAT) per kWh in the Netherlands (Belastingdienst, 2017)
- VAT – Percentage over total price. 21% in the Netherlands (Belastingdienst, 2017)

Since smart meters in the Netherlands are not equipped with Wi-Fi (November 2017) an additional dongle will be required to publish meter values live into the smart contract. This is an overall barrier all initiatives face and a general solution is to provide a dongle which can be a microcomputer smaller than a Raspberry Pi submitting the data. BlockEnergy should keep a registration of which smart meter is connected to which EAN. Also, one could use a P1 as a service provider like HelloData who provide direct access to P1 data (HelloData, 2017). Since data could be manipulated between P1 port and the dongle, there is a verification process build into the smart contract. Entrnce provides the smart contract with P4 data from the day(s) before, this data is now used to settle difference between predictions and actual usage. This could also be used to settle on the blockchain to avoid integrations with Exact's financial software, sending and paying bills and transactions costs.

There are no timed events possible in a smart contract, so one has to create a solution for the loop shown in the design shown in figure 28. The 5 minutes loop is chosen arbitrary and is up to the further development in the markets. It could also be useful to take the 15 minutes from the PTU but probably it is more attractive to choose a smaller timeframe but not too small due to blockchain transaction fees. Possible solutions for the timing event are:

- Let dongles publish their values exactly every five minutes. If they all do it at the 5th, 10th, 15th, etc. minute thirty seconds later one could settle the usages of the 5 minutes before.
- Let an external cronjob (IT term for scheduled job) call a certain function in the smart contract to settle usages since the last time the function was called.
- Every time new meter values are received, check if 5 minutes have passed. If more than 5 minutes have passed, interpolate the usage to fit the timeframe.

Limitations currently exists in the EVM since a public function cannot return dynamic arrays from any kind. This might be a disadvantage of the design in figure 28 since meter values from all meters are subtracted from the smart contract. In addition, transaction fees still delay the adoption of such systems but Ethereum is developing solutions like the Raiden Network. An example, minimal implementation of BlockEnergy has been made to provide a demo. The implementation uses the code from code snippet 2 and implements the interfaces shown in code snippet 1 and 3. The demo was used to create support and understanding of the concept among EXE employees and was used as example for the validation. A screenshot of the Dapp is shown in figure 29.

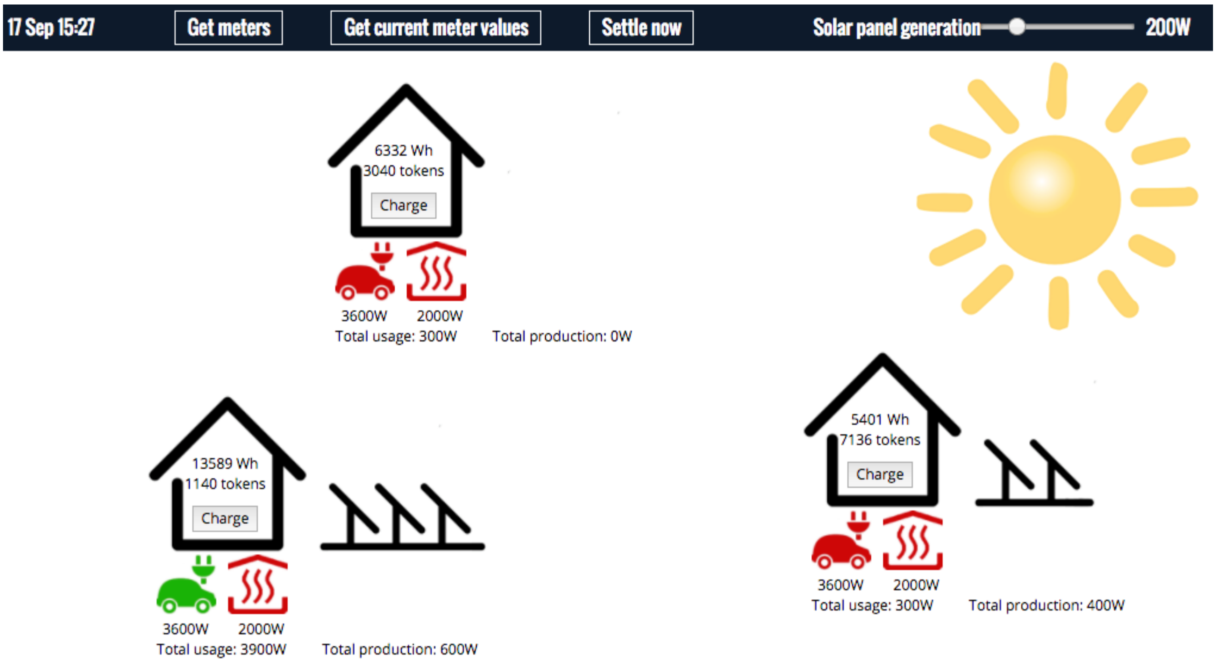

FIGURE 29: BLOCKENERGY DEMO

7.1.4 ADVANTAGES OF BLOCKCHAIN

The potential for using blockchain in a concept as BlockEnergy is mainly its scalability, easy repeatable for creating different markets, cost reduction and micropayments. It fits the decentralization perspective grassroots take since blockchain is totally decentralized. Smart contracts can take care of settlement between users and uses low cost micro transactions. People can become an active consumer setting their own price and create deals between each other. These deals can be settled in a smart contract. Especially when looking at the future it has high potential when there is no salderingsregeling anymore and prosumers will almost get no value for the energy delivered to the grid. A blockchain allows for easy and cheap transfer of value under certain conditions and it also provides transparency to all involved parties, if required.

7.1.5 VALIDATION

The validation of the concept was done in a session with the general manager of EXE and 4 energy market experts from whom one was the IT architect of Entrnce and one was the Business Manager of Entrnce. The BlockEnergy design and architecture was discussed in a session of 2 hours and the reasons for such system to be used in the Netherlands. The discussion was achieved by presenting BlockEnergy as a party who wants to cooperate with Entrnce to enable peer to peer energy trading.

About the architecture the followings points were discussed:

- Questioned was what the added value of blockchain is. A similar concept could also happen without blockchain. It is argued that a cost reduction is achieved compared to a nonblockchain solution but there is no calculation. But still a lot of parties are developing such concepts so it seems to be profitable.

- In the Netherlands a smart meter is not equipped with Wi-Fi (in contrast to for instance Australia) which makes integration of such concepts more difficult and more expensive. The cost of a dongle can be significant.
- When using an own token, it should besides being exchangeable for fiat currency also be possible to exchange it with other cryptocurrency like Ethereum. This creates interoperability between smart contracts and blockchains. Other cryptocurrencies do not have a fixed exchange rate so the exchange rate to the used tokens depends on the cryptocurrency/fiat rate. For Ethereum and ERC-20 tokens this is easy to implement in a smart contract.
- The flow from euro's to Entrnce is not clear enough. Entrnce has a wallet in the concept to get paid but users from the Entrnce software need a positive balance to use the Entrnce system. How does the system make sure there is upfront to the start a positive balance in the Entrnce system? While the money flows through the blockchain the fiat currency has to be saved on a bank account. Legislation determines this should happen through special third-party account since you manage other people their money.
- If energy is bought at the APX this is seen as grey energy. The system should buy certificates at for instance CertIQ to make the energy green so it becomes more attractive to users.
- It is questioned what will happen with the guarantee of origin certificates given to people producing energy. In the current situation, you can request the certificates from CertIQ for your solar panels as small customer and one can sell these to for instance energy suppliers.
- It is at the moment obligated to send small customers clear invoices with their usages and cost. This will require extra systems and overhead cost.
- The ACM requires you to settle energy bills based on P4 data. So a yearly settlement is also required to settle any difference between the P1 and P4 data. This could happen based on an average APX price from that year.

Furthermore, there is the following direct improvement:

- Entrnce only get the P4 data for the whole portfolio per DSO. So it is not possible to validate the meter values received on the blockchain through the P1 port with the P4 data using Entrnce. For this validation, a direct connection should be made with EDSN which can provide P4 data per meter.

In general, the feedback was very positive. There is for sure potential to integrate such a system into Entrnce. As was known, Entrnce cannot offer such a system to small customers due to legislation. Therefore there are the following options: (1) develop and offer this as white label system B2B2C without supplier role, (2) cooperate with an external company to develop it and let the external party take the supplier role or (3) let an external party create such a system and make sure Entrnce is involved quickly to take the BRP role (white label or not).

In the discussion, the multiple options were evaluated. At the moment, the management determined it most attractive when a party would build such a white label system and also offers the supplier role. At the moment ERP systems for energy suppliers are very expensive and it is almost impossible to generate revenue when you have below 10.000 customers. A white label blockchain system might make it possible to create such a lean system that is already attractive when having only 1000 or 100 customers. EXE experiences a lot of these parties due to the grassroots phenomenon where community led initiatives happen and for instance 'energiecoöperaties' want to create their own, self sufficient region. For non-white label systems or initiatives that do take the supplier role Entrnce still wants to take an active role since they see blockchain as high potential, and integration with their systems doable.

The possibility also exists that a company who builds this software and takes the supplier role, also takes the BRP role. In this case it becomes a competitor of Entrnce since they both facilitate EAN 2 EAN transactions. The role of BRP is complex and not that many parties have a license so the difficulty might be an advantage for EXE.

7.2 MULTIPLE ENERGY SUPPLIERS: SMARTCHARGE

This section outlines how the Entrnce platform can support the case where multiple energy suppliers are available at one connection. The potential to use blockchain in a case with multiple energy suppliers is high since it provides a transparent platform for all parties involved. The case has been built around electric vehicles since they play an important role in the energy transition due to their high energy demand, countries banning sale of fuel cars in a few decades and the ability to use their batteries in a demand response setting. Furthermore, EXE cooperates with charge point operator Allego to create an open charging infrastructure. There is also a high request from the public sectors to create energy source transparency and a solution for multiple energy suppliers at one connection (Energeia, 2017).

7.2.1 DESIGN

In this concept, called SmartCharge, a customer is able to choose his own energy source at the electric vehicle charging station. Each energy supplier that is connected to the charging station offers a set of energy sources which are available to the customer only if they supply energy to the grid at that moment. The price per source is flexible and made up of two dependencies: the energy supplier price and the DSO price. In this situation, the price of the DSO is depending on the congestion level of the local grid. The proposition SmartCharge is taking, is as follows.

SmartCharge enables free choice of the energy source at EV charging stations,

creating source awareness,
guarantee of origin, and
support DSO's in lowering grid congestion

The guarantee of origin is given real-time and this is achieved by publishing meter data from energy sources as well as the charging station into the blockchain. This is done by two different type of smart contracts; the source contract and the central contract. An energy source has its own instance of a source smart contract to publish meter values in the blockchain and validate the real-time guarantee of origin. One central smart contract is responsible for registering charging stations and to create and finish deals between sources and charging stations. This smart contract is also responsible for the energy settlement between the suppliers and value streams from customer to energy source and DSO's.

Blockchain adds a transparent platform for all parties involved and processes payments automatically. The current landscape of parties involved in charge stations is very complex. Besides the TSO, DSO and BRP there is a eMSP (e-mobility service provider), clearing house and CPO (charge point operator). In advance, four similar cases have been analyzed to learn from their experience:

- Alliander 'open laadinfrastructuur' where they want to prove that it is technically and administrative possible to let users choose their own energy supplier at the charging station. This project is still running with Alliander, EXE and Allego. The most important stakeholders were interviewed to have an indication of the barriers they face. This seemed mostly the fact that not all charging stations have smarts meters and the difficulty of getting energy suppliers and eMSP's involved.
- Enexis 'logische allocatie' case where they did a pilot in the south of the Netherlands with having multiple energy suppliers at one charging station. They had setup a central administration by a third party for these charging stations. Their main problem was the registration in the C-AR and to enable multiple energy suppliers at a charging stations. They proposed to add transmission connections to an EAN in the C-AR to support the administrative process for multiple energy suppliers at one charging station.
- Liander research about blockchain usage for having multiple energy suppliers at charging stations where the result was that blockchain is still not mature enough to use at large scale. Case specific, they found that sector processes are not made for it yet, measuring technology in charging stations is not sufficient, market parties are difficult to involve and one should pay for the imbalance. The first two are not experienced by the interviewed stakeholders in the Alliander case and the fourth one can be solved by using Entrnce. The third is still accurate according to the interviews.
- Elaad was consulted to talk about the case and their experiences. They are working on cases and are also applying certain blockchain protocols in their EV charging stations. However, they did not look into 'free choice of the source' at charging stations using blockchain yet.

SmartCharge is a total new concept which is very attractive for the energy transition since it enables the grassroots concepts since it focuses on local energy usage. By offering flexible charging as option, where people can select the time frame in which their car is charged for the selected range, peaks in grids can be reduced. It extends the ideas of the researched cases by offering an energy source choice to the user.

The Entrnce product from EXE perfectly supports such cases where there are reasons for multiple energy suppliers at one charging station. Since one still has to take responsibility for the grid staying in balance for all charging points, Entrnce can take the role of BRP to stay within the regulatory framework. It can do so in the same way as shown in figure 28. By having a central smart contract with meter values, Entrnce can make sure the E-programs for the charging station portfolio is submitted to the TSO. If wanted by the energy suppliers, Entrnce could also provide the app with current energy prices.

7.2.2 TECHNICAL DESIGN

As said in the previous section there are two types of smart contracts, these are shown in code snippet 3 and 4. In the design two external parties are present, the supplier and the DSO. Both provide an API which is used to make their prices available to the users' app and they both have an address on the blockchain to receive payments. There are also three objects which are also present in everyday live: the source, app and charge station. In the demo, they are built standalone to create a real-world environment. A demo controller takes care of the interface and the three objects and two smart contracts register themselves at the demo controller.

The demo controller takes care of the interface rendering using JavaScript and ReactJS, a worldwide library delivered by Facebook for managing interface elements through a state library. Events in a smart contract can trigger functions in the interface when the interface is listening to these events. Figure 30 shows an UML sequence diagram with the interactions happening between the components when the demo starts, a car starts charging and finishes charging when its battery is full. Green objects are smart contracts, red are real-life objects and blue are involved parties.

```
contract sourceInterface {
    address public owner;
    address public supplier;
    uint public impossibleDeliveries;
    mapping(uint => uint) public meterValues;
    uint[] timestamps;
    struct saleDeal {
        uint chargeSpeed;
        uint chargestationId;
    }
    mapping(uint => saleDeal) public saleDeals;
    uint[] public activeDeals;
    event DropUser(uint dealId, uint chargestationId, uint meterValue);
    function sourceInterface (address _supplier) public;
    function newMeterValue(uint time, uint value) public;
    function validateAvailability(uint oldValue, uint newValue) public constant returns(boo
l);
    function getLastMeterValue() public constant returns(uint);
    function newSaleDeal(uint chargeSpeed, uint dealId, uint chargestationId) public;
    function stopSaleDeal(uint dealId) public;
    function getDeal(uint dealId) constant returns(uint);
    function removeFromArray(uint[] array, uint index) internal returns(uint[] value);
}
```

CODE SNIPPET 4: ABSTRACT CONTRACT SMARTCHARGE FOR THE SOURCE

```
contract dealInterface {
    address public owner;
    struct deal {
        address source;
        uint sourcePrice;
        string supplier;
        string dso;
        uint dsoPrice;
        uint chargeStation;
        uint startValueStation;
        uint etherPaid;
        uint chargeAmount;
        address user;
    }
    mapping(uint => deal) public deals;
    uint[] dealIndex;
    struct chargeStation {
        bool isEntity;
        address walletAddress;
        mapping(uint => uint) meterValues;
```

```
        uint[] timestamps;
        string dso;
    }
    mapping(uint => chargeStation) chargeStations;
    event StartCharge(uint chargeStation, uint chargeAmount, uint dealId);
    event StopCharge(uint chargeStation, uint endValueStation);
    function FCSdealInterface() public;
    function registerChargestation(uint id, string dso) public;
    function newMeterValue(uint id, uint timestamp, uint initialMeterValue) public;
    function getChargestationInfo(uint id) public constant returns(uint, string);
    function newDeal(address source, uint sourcePrice, string supplier, string dso, uint dsoPrice, uint chargeStation, uint startValueStation, uint chargeAmount) public payable;
    function finishDeal(uint dealId, uint endValueStation) public;
}
```

CODE SNIPPET 5: ABSTRACT CENTRAL CONTRACT SMARTCHARGE

The demo interface as shown in figure 31 allows users to simulate real life situations. Energy sources are supplying energy to the grid and this is consumed by the charging stations. Cars can be driven to the charging stations and as soon the car arrives the app popups which is shown in figure 32. When a source is selected deals are made between the source and charge station. When clicking on an energy source its supply will dropdown so it is only generating enough energy for 2 charging stations. This simulates a real-life situation and proves our real-time guarantee of origin statement. When the source does not have enough energy for all his deals for 5 minutes long, one deal is finished. In the case of SmartCharge, the charging station will look for a similar kind of energy source (for instance solar energy close to the charging station).

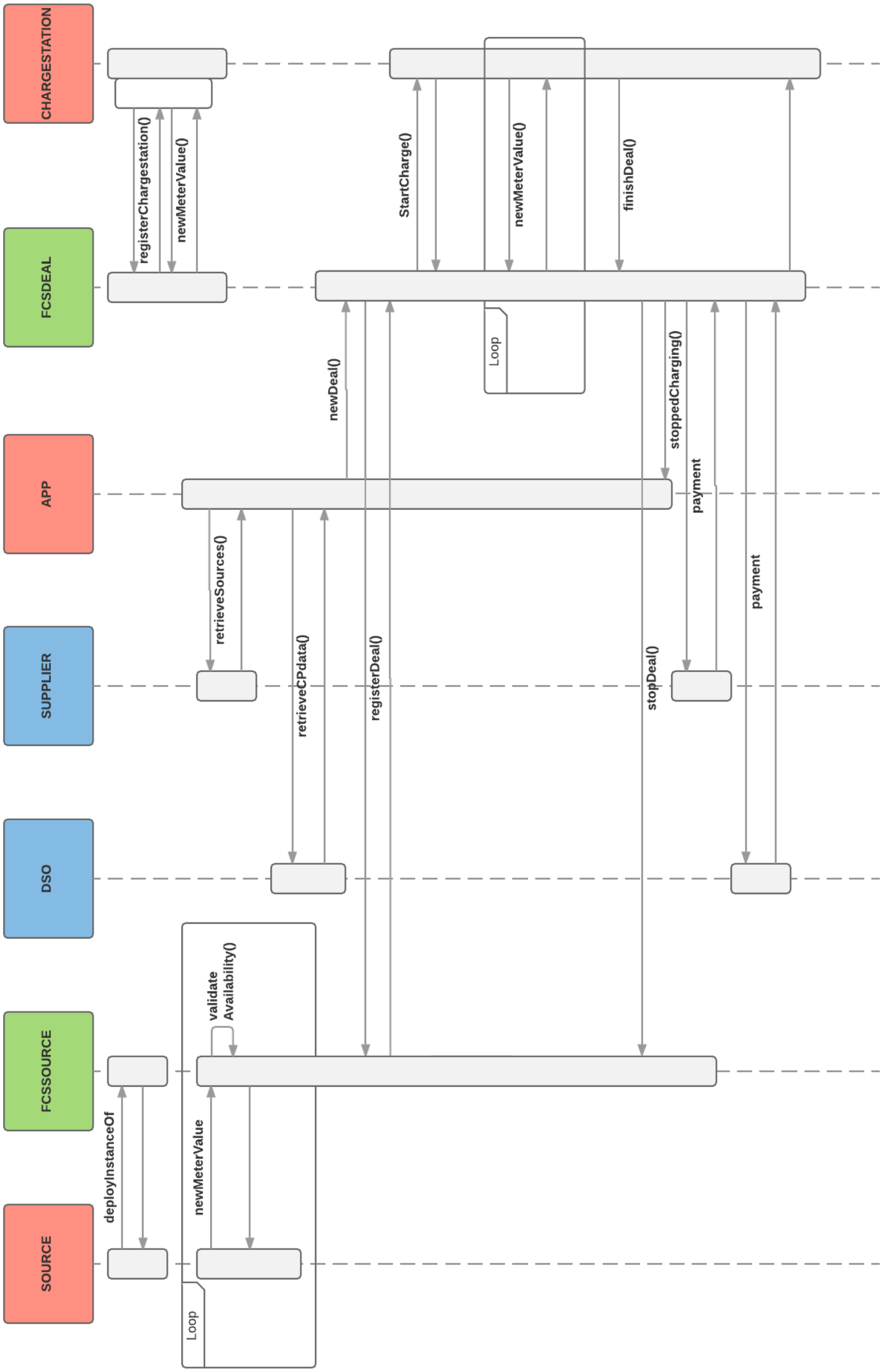

FIGURE 30: UML SEQUENCE DIAGRAM SMARTCHARGE

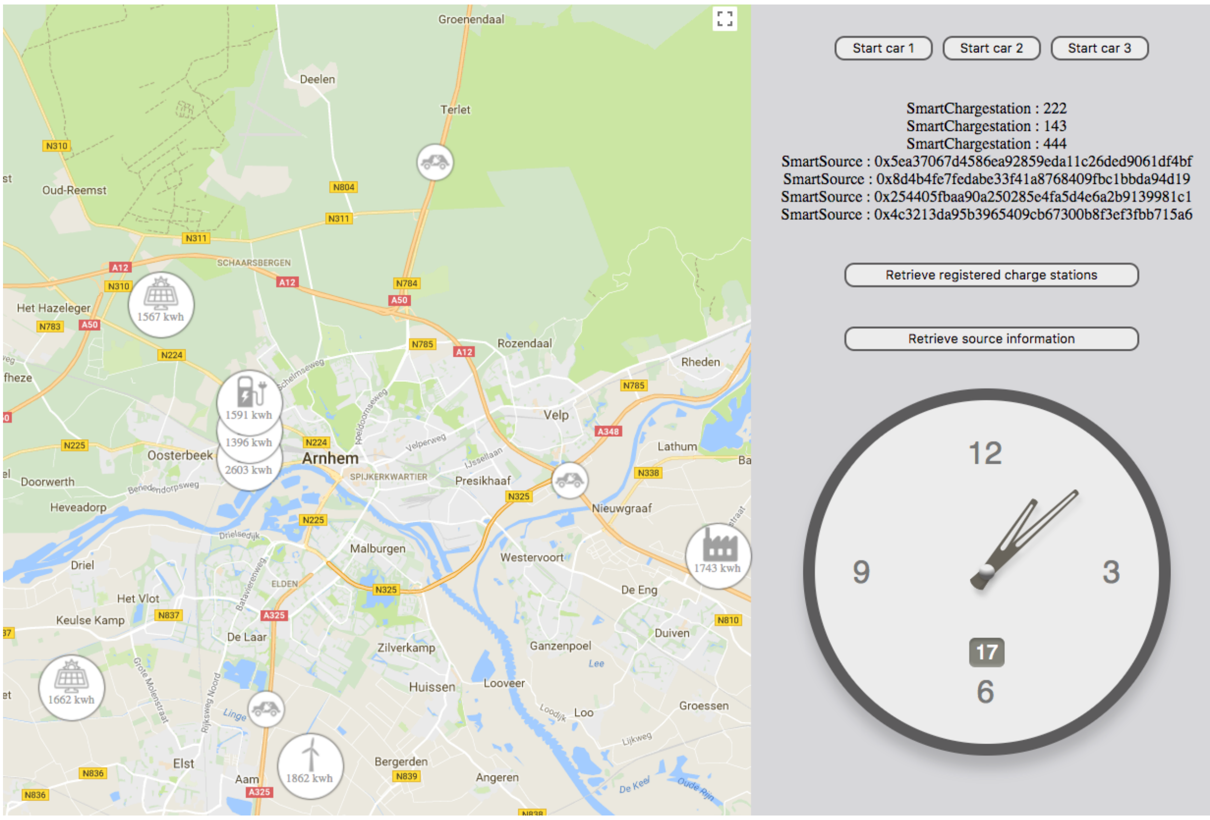

FIGURE 31: INTERFACE SMARTCHARGE DEMO

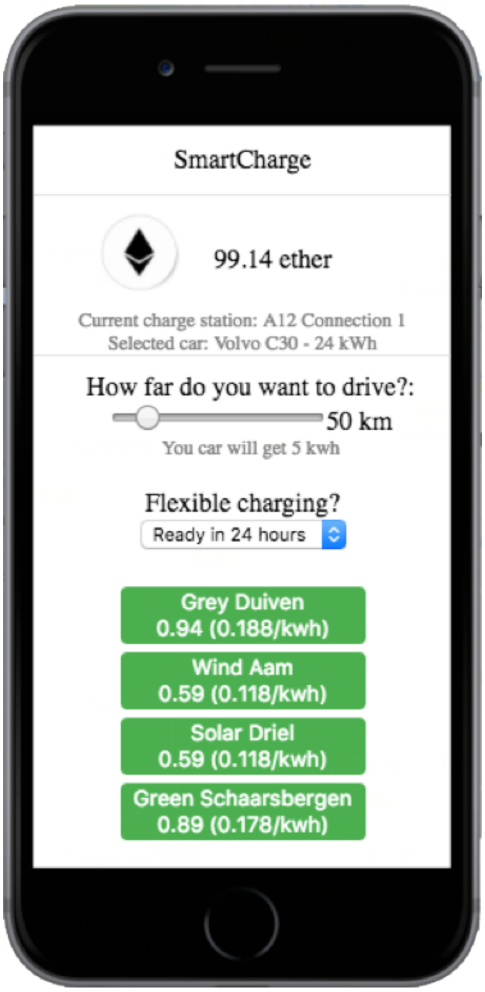

FIGURE 32: APP INTERFACE SMARTCHARGE DEMO

7.2.3 ADVANTAGES OF BLOCKCHAIN

Blockchain adds an automated real-time payment infrastructure between all involved parties when sharing a connection with multiple energy suppliers. Since settlement has to be done every PTU or even each minute, a blockchain reduces the transaction costs of these settlements. It also creates a transparent platform for all parties so they can validate the payments are correct. On top of this, in this use case a real-time guarantee of origin is given. In the current system guarantee of origin is based on yearly aggregated supply so even though you buy certificates as guarantee of origin, you are always using energy when the source is not supplying any energy. These certificates are also maintained by a third party and energy suppliers buying these certificates have to cross out all energy themselves which they have sold as green energy. Blockchain adds a transparent decentral system accessible for anyone.

7.2.4 VALIDATION

The validation of this concept was done in multiple ways. The most important expert feedback was received from two energy market professionals and two blockchain specialists. Furthermore, the concept and demo was explained in a whitepaper and together with a video it was the submission for an international blockchain hackathon. It became the runner-up in the energy & environment category and internationally, multiple parties were interested and still are interested to implement it. The last feedback was received from a blockchain event at grid operator Alliander where multiple electric vehicle drivers, blockchain specialists and energy specialists were present.

For the architecture, the following was the most important received feedback:

- Since the concept exists of a machine to machine economy with a lot of data transactions being made, a possible implementation for the Ethereum blockchain as well as the IOTA tangle was made. In the current state of both technologies, IOTA would add value with transactions without fee and transactions without value. However, IOTA is not supporting smart contracts yet. A solution architecture without smart contracts was almost possible, however a guarantee that an energy source would not sell more energy than it has available could not be given easily without smart contracts. Also other concepts became more complex without smart contracts so an implementation was made on the Ethereum blockchain. This resulted in multiple feedback about the high transaction costs and scalability issues. For now these are unacceptable, but according to Ethereum's roadmap these will be solved in the near future.

- The reason to use blockchain in this concept was discussed in multiple sessions. However, in such a situation with a lot of parties involved, where guarantees have to be given for real-time GoO and where value is exchanged, blockchain is a promising technology. Especially since it was proven that in other solutions not using blockchain, a third party was required such as in the Enexis case where Elaad took the third-party role. Privacy and reliability was discussed during some feedback sessions and a consortium blockchain in these cases will probably be most useful.

- In the current scenario value transfers are made in the beginning and the end. The most popular blockchain or DAG solutions also provide payment channels (for example Ethereum will offer the raiden network in the future and IOTA provides flash channels) to do instant (micro) payments. This happens off-chain in a secure environment and requires only two transactions on the blockchain. This allows to pay per kWh received by the car. Elaad will build a proof of concept for IOTA flash channels in the beginning of 2018 and such a concept could also be used in this case.

- In the current architecture, a grid operator can determine a flexible price depending on network congestion. However, at medium and low voltage grids most DSO's do not have modern automated measuring technologies present. So it is not measured real-time and only physically available at transformer stations. DSO's are implementing real-time, from distance available grid congestion measurement technologies at the moment. In the future they want to use this to prevent network congestion real-time and so, these systems can also be used in the architecture of SmartCharge.

- Flexible charging (not using the full charging speed) is a concept that is widely discussed. It offers great potential for DSO's and TSO's to balance the grid and avoid grid congestion. Without even being known to the customer, it was discussed that this is already happening when there are peaks in the local grid. Therefore a transparent option is required where customers are aware of the possible and current charging speed.

The concept was also validated and received the following most important feedback:

- The process for the customer becomes more extensive. At the moment a customer only has to offer his card to the charging station and the car will start charging. With SmartCharge, one has to use an app, scan the code, select the driving distance and energy source. For customers not interested in energy this might be a barrier. Therefore the following upgrade in user experience might be desirable. The NFC chip in a mobile hpone can be used to let the app known which charging station the car is using and a customer can only at first usage select his preferred category of energy source. In this way, a customer only has to touch the charging station with his phone after first usage. In the future it could also be possible to connect the car and app, so all data can be transmitted over the cable transmitting the energy to the car and no user interaction is required at all.

- When using flexible charging, a parking spot might be required for a longer time then necessary. At the moment, one can get a fine for keeping a parking spot occupied which has a charging station when the car is fully charged. When cars are charged slowly or with interruptions, they keep parking spots occupied for longer times. When charging stations are limited in a certain area, a solution should be created for this problem.

- Not all energy sources and charging stations are equipped with a smart meter. In order to retrieve real-time data one should be equipped with a smart meter. If existing charging stations would use a SmartCharge concept this implies extra financial costs.

In general the concept and technical solution was retrieved very positive by all parties. It also perfectly fits within the current steps made in the markets, for instance the European tender for 4.500 charging connections where smart charging is required and a user should be able to select his energy source (Energeia, 2017).

8 PROSPECT

Blockchain seems a technology that suits the energy transition. As outlined in the previous sections, a blockchain implementation has some barriers within the current regulatory framework and with the current state-of-the-art of the blockchain technology. This section gives answer to the subquestion:

7. Which next steps can be taken by research and by EXE to extend blockchain support in the energy transition?

8.1 BLOCKCHAIN TECHNOLOGY

Although developing quickly, the blockchain technology is still too immature to be applied at large scale. However, the basics will remain the same so a lot of companies are spending a lot of resources to research the possibilities for blockchain. It is expected that in one or two years the currently most important problems are resolved. Main issues in blockchain are scalability, transaction fees, security and its high usage of electricity. Scalability issues are twofold, it involves the amount of transactions per second possible and the size of the blockchain and so the required hard disk space to have a blockchain node. Scalability for the first type is mainly solved by creating side chains and the size can be solved by sharding or snapshots. Transaction fees depend highly on the type of blockchain used, but are also reduced by side chains or for instance IOTA.

High usage of electricity is mainly a problem in proof of work consensus blockchains which have proven their security the last nine years. New consensus algorithms should solve this issue but their safety still has to be proven. For instance, Ethereum's release Casper mid 2018 will be a hybrid PoW/PoS blockchain, which is at the moment already available on the test network for testing purposes. Casper is also using a hybrid chain/BFT-style consensus, which are both explained in section 2.1.4.2. A combination of the algorithms should be able to create a network which is resistant to double spending attacks (Buterin & Griffith, 2017). Regarding reducing the chain size, the sharding method still is only researched theoretically and does not have a (test) implementation yet. Another security issue are the public readable smart contracts which can contain errors. Since a blockchain is immutable anyone can use a coding error to transfer value to their own account. This is one of the negative implications of blockchains immutability.

Another important technology arising, sometimes called the successor of the blockchain technology, are distributed ledgers with a DAG structure. Important characteristics of DAGs are the elimination of the extreme energy usage, transaction fees and if allowed by the network, the ability to do transactions without value. This could allow for one system being able to do (feeless) data as well as value transactions. Only some PoW has to be conducted when one executes a transaction.

For each of the nine different appliances of blockchain in the energy transition, research could be done into the most suitable blockchain. Since solutions are created within the energy transition, an blockchain implementation using a significant amount of energy is discouraged. This means currently using a (delegated) PoS algorithm or DAG are the most suitable type of blockchains. Other requirements can for instance be the necessity for smart contracts and/or the need for feeless transactions, probably depending if data only transactions are required and on the transaction volume.

8.2 REGULATORY FRAMEWORKS

As a consequence of the disruptive decentralized blockchain technology, governments, supervisory bodies, and authorities for consumers & markets lose control. Daily billions of cryptocurrencies are transferred over blockchain without paying taxes and knowing the sender and receiver. Consumers own large amounts of cryptocurrencies without paying wealth tax and disruptive business concepts are created outside regulatory frameworks. This makes authorities losing control and in some cases, they try to slow down the growth of blockchains by blocking cryptocurrencies (for example in Ecuador (Panampost, 2014))

Within the energy sector in the Netherlands, the electricity act (1998) determines parties and responsibilities for distributing and suppling energy. Even though this act is regularly updated and the Dutch government recently has obligated companies to separate the distribution and supply of electricity in separated companies to encourage market forces, it is also limiting developments. Permission from TenneT to become a BRP is a very complex and to become an energy supplier, one has to go through an extensive process at the ACM (Authority for Consumers & Markets in the Netherlands) and has very explicit obligations to the consumer. For instance, one should settle a customer by the P4 data from a smart meter, should send invoices, should announce their energy prices to the ACM and the name of the registered energy supplier should be named on the bill. Also, to get access to electricity markets there is a complex process so this is limited to a few parties.

All these factors can, and will reduce the potential for opportunities in the energy sector, especially for the blockchain concepts in this thesis. Therefore, authorities should research the opportunities to loosen regulations to accelerate the energy transition. As PwC (2016) also predicts, the energy sector could move to a decentralized system without all required parties.

An implementable roadmap could be researched where each step leads to a more decentralized energy grid. In an ultimate scenario, local neighborhoods are self-sufficient and no top-down control is required from TSO's and BRP's. This means one doesn't have to predict and create E-programs and only real-time energy markets are required (no ENDEX and APX). To create such a grid in a wealthy country with the luxury of having energy when required for an affordable price will be a challenge. A roadmap could create steps to achieve such a system which should be supported by the government. In this way, also in the first steps the energy becomes affordable.

8.3 EXE & BLOCKCHAIN CONCEPTS

For the blockchain concepts as given in chapter 7 there are some practical issues open for research:

- Privacy might be an issue when meter values are published into the blockchain and/or when value is transferred from and to accounts. It might be unknown to the public which wallet belongs to which person, house or building but it could somehow be traceable or the decentralized ledger could be hacked. Solutions can be found in blockchain protocols like Monero or zero knowledge-proof protocols like zk-SNARKs or ZKRP's (Koens, Ramaekers, & van Wijk, 2017) for the Ethereum blockchain. When transferring data like meter values over the blockchain, one should probably require a quantum proof algorithm so the data does not become readable within decades.

- Downtime of the smart meter or the dongle connected to a smart meter is dangerous in settings where real-time data is used in the grid (van Wylick & First+ Consulting, 2016). According to this report, P4 data of smart meters are not that reliable. It is unknown how reliable the P1 port is, however downtime should always be taken into account. For settlement one could interpolate once the device gets back online and for longer periods the user could get a financial sanction.

- Interconnectivity between other blockchains could be very important in for instance the identity question. A lot of banks or regulatory frameworks focus on digital identity in the blockchain (IBM, 2017) . Revealing attributes could identify the user and for instance his creditworthiness to other parties in the blockchain.

- Similar protocols and blockchain solutions can be applied in the gas or oil sector. Especially gas is of interest since this is most of the time delivered to customers by the same party as electricity (although not required). For a concept like BlockEnergy it might be valuable to also provide gas. However, supply of gas is more centralized and therefore suits the blockchain's peer to peer concept less. Another appliance of blockchain within the energy sector is to settle district heating on the blockchain when multiple suppliers and consumers are present. A prototype for this type is currently being created by Eneco and CGI in the Netherlands.

- The financial advantage of using blockchain was questioned in the BlockEnergy concept. It would be of interest to make an extensive calculation of an energy supplier using blockchain to draw conclusions on the financial advantages for the customer. There are still significant overhead costs involved for the C-AR register, dongles, fiat currency bank accounts and marketing and customer support cost. Also in complying to the regulatory framework costs are involved.

It is highly recommended for EXE to get involved in blockchain initiatives since they can position those perfectly within the energy markets with their Entrnce product. This could be achieved by cooperating with large companies like Shell and BP who do research on this topic as well as smaller municipality initiatives creating local markets. Having a responsible R&D person with extensive blockchain knowledge could be highly beneficial.

9 CONCLUSION

This section draws a conclusion from the whole research. In the first section this will be done by answering the research questions in a short summary and in the consecutive section a higher level conclusions will be drawn from the current landscape. The most important lessons learned will be outlined together with a future vision in the landscape of energy transition and blockchain. In section 9.3 shortcomings in the research are explained and in section 9.4 the limitations of this research.

9.1 ANSWERS TO RESEARCH QUESTIONS

In this section all subquestions will be answered first and in the end an answer to the main research question is given.

Sub questions:

1. **What are the characteristics of the blockchain technology?**

   This question has been answered by performing a literature research on the most important aspects in chapter 2. A blockchain's distributed ledger stores transactions in blocks which are chained to each other by saving a hash of the previous block. In this way transactions becomes immutable and are transparent. The blockchain technology solves the Byzantine Generals' Problem and the double spending problem which often exist in online currencies. Important design decisions in creating a blockchain are which consensus algorithm is used (for instance proof of work or proof of concept), creating a public, consortium or private chain and decide if miners of new blocks should be rewarded and so, if new coins are generated over time. Blockchains are applied in hundreds of different cryptocurrencies nowadays and the highest potential lies in the financial, insurance, public and energy sector for first business adoption. Some blockchains also feature smart contracts which is a set of code which runs on the blockchain and makes it possible to set certain conditions before transferring value. Companies like Microsoft and IBM are offering Blockchain as a Service (BaaS) which makes it possible to create your own blockchain quickly. However, limitations exist in safety and enabling the full potential of blockchain when running your own or consortium blockchain, since a traditional database with an API might be more efficient. In general, only in cases where trust is an issue and/or a robustness is required, blockchain adds advantage. Private or consortium blockchains can still be useful for development and testing and to use it in a production environment as long as public blockchain still face challenges. The main challenges nowadays are scalability (processing a high volume of transactions and chain size), transaction fees, security, invulnerabilities in smart contracts and its energy usage.

2. **What is the current architecture of the electricity market and how are reliable electricity connections provided by all parties?**

   This subquestion is answered in chapter 3 by doing a literature research and study multiple reports of consultancy companies. The complex energy market is set by the Electricity act (1998) in the Netherlands and was introduced to create a fair, liberalized and stable electricity grid by

decoupling utilities and supply. To keep the grid in balance (meet demand and supply), a lot of responsibilities are required from each party. The grid exists of the high voltage grid provided by TenneT and the lower and medium voltage grids provided by multiple DSO's. To stay balanced, each connection is having a balance responsible party which creates electricity-programs one day ahead and sends them to TenneT. TenneT aggregates these and uses regulating and reserve capacity during the day to keep the grid in balance and emergency power in extreme cases. Large customers can be directly connected to a BRP while small customers are connected to an energy supplier which takes the role of BRP, or is cooperating with one.
The electricity market is used to trade energy for a specific day, which will be given as 'D'. Trading for day D can start from 4 years before at the ENDEX future market which provides long term contracts. The APX is the day-ahead market and OTC deals can be made even the day after D. E-programs are submitted by the BRPs D-1 at 14:00 and contains the supply and demand per PTU for the portfolio. Intraday markets make it possible to lower difference between the e-program and actuals. Allocation and reconciliation processes take care of the settlement for any imbalances in the e-program and actuals and invoices are sent from TenneT to the DSO's. These complex processes form an obstacle in the energy transition due to the unpredictable supply from renewable energy sources.

3. What are the challenges of today's energy transition?

Worldwide a lot of programs focus on phasing out the usage of fossil fuels and increase the share of renewable energy. For instance, the Paris agreement signed by 195 parties will commit them to mitigate global warming and report their contribution. The European Union has the goal to create a 20% renewable energy market share by 2020 and 27% in 2030. However, renewable energy gives almost no flexibility in production and is very unpredictable and unstable so it creates a lot of challenges. Also, the demand for energy is creating more peaks since gas is phased out in the heating of houses and so, houses are heated by heat pumps using electricity. The highly expected increase of electric vehicles also creates higher peaks, both are highly used at certain moments creating peaks. Solutions are for instance, but not limited to, the use of high voltage batteries, demand response systems and creating local self-sufficient communities. Thus, electric vehicles also provide opportunities since most of the times they provide flexibility in demand and can also supply the grid with energy. The energy transition is mainly led bottom-up with consumers and initiatives becoming more energy aware. The prosumer is investing together with initiatives focusing on municipality level. In research, one often refers to this phenomenon as grassroots, community-led solutions for sustainability. The main challenges are creating a 100% sustainable energy grid which is still reliable and affordable.

4. What are the lessons learned from the blockchain initiatives focusing on the energy transition and how can we classify them?

This explorative research question of existing initiatives has been answered in chapter 5. By far, most initiatives are enabling peer to peer energy trading on the blockchain. The decentralized supply in the energy transition suits the blockchain since it allows peer to peer transactions. Some of the peer energy trading initiatives also focus on the local aspect by creating smaller markets at municipality level, so one can only trade energy with geographically close customers and so demand and supply is balanced at a local level. Other types are rewarding cryptocurrencies for renewable energy, use cryptocurrency as payment method for sharing your energy connection and to balance the grid. In section 5.4 more opportunities for blockchain in the energy sector are outlined which were not found in current initiatives. These were derived from existing problems or limitations within the energy markets and grid recalled by energy market professionals. These opportunities are using the blockchain for demand response communication, real-time guarantee of origin, sharing meter data and to create a system where multiple energy suppliers can be used at one grid connection, for instance at EV charging stations.

5. What is the potential for blockchain for the EXE product portfolio?

The EXE product portfolio exists of three software products called Enwire, R.E.X. and Entrnce. Enwire is a B2B2C product and is a white label marketplace for local green energy. Consumers can choose their own local producer as energy source and Enwire is only involved in bringing the consumer and producer together. R.E.X. focuses on large consumers and producers and let them profit from changing energy prices by creating a demand response system. Devices flexible in their supply and demand respond on the energy price. Entrnce makes it possible to create direct transactions from EAN to EAN or let an EAN buy or sell their demand or supply directly at the energy market. It takes the role of BRP and so, submits e-programs to TenneT and Entrnce settles with their customers for any imbalance.
The potential for blockchain for the EXE product portfolio is given in table 8 and the highest potential is for Entrnce the peer to peer energy trading (with or without local markets) and facilitating multiple energy suppliers at one connection. Most peer to peer energy trading solutions do not take into account all required parties by the regulatory framework and so, they give the responsibility for keeping the grid in balance to other parties. Entrnce could be an enabler of such initiatives in the current market. Blockchain adds value by cheap, transparent and high frequent settlement through a decentralized platform, so no third party is required.

6. How to develop a blockchain proposition for EXE that fits their product portfolio best?

Two concepts for blockchain propositions that could be supported by the Entrnce product have been outlined in chapter 7. Peer to peer energy trading can happen when Entrnce would take the BRP role and so submit the e-programs for the portfolio of the users to TenneT. These e-programs are based on predictions for the next day where the prediction exists of supply and demand. A know your customer (KYC) perspective is therefore important. Since those initiatives have access to real-time meter data and use this in the blockchain, the information should be retrievable for parties outside the blockchain to make the most precise predictions. Pricing of energy and the use of tokens are important and highly differ between initiatives. The energy transition makes timing more important and so this influences energy prices throughout the day. A dynamic price should therefore be paid for each kWh. The high-level architecture is shown in figure 28. For supporting multiple energy suppliers at one connection blockchain adds value with a transparent, short-term settlement process where value can directly be distributed across all involved parties. The problem with such connections is that one has to take the BRP role, which Entrnce can perfectly do. A concept for such a solution is given in section in section 7.2. The architecture for integrating this system with Entrnce is similar to the peer to peer energy trading architecture.

7. Which next steps can be taken by research and by EXE to extend blockchain support in the energy transition?

As outlined in chapter 8, the energy transition is already complicated. The immense and expensive infrastructure is focused on central and adjustable supply and so are the involved parties, while the energy transition stimulates growth of decentralized and unmanageable supply. The regulatory framework is delaying the energy transition and so do large established companies. Especially now technology is evolving and the decentralized blockchain seems to fit the decentralization in the energy transition enabling peer to peer transactions, regulations should be loosed and instead of increasing energy tax every year for everyone to enable the energy transition top-down, let disruptive startups led the energy transition. A future vision on this is given in section 9.2. It should be stated that the blockchain technology is not ready to enforce a transition on large scale as outlined in section 8.1, but might be able to do so in a few years when technology is matured.

How can the blockchain technology support and accelerate today's energy transition?

Important topics and challenges in the energy transition are creating a sustainable reliable energy grid where energy is affordable. Sustainably energy is most of the time created through solar panels and wind turbines. Challenges are the decentralization and therefore shifted load on the grid. The increased load and uncontrollable sources lead to the increased importance of local energy, flexible energy pricing and demand response systems. Blockchain could add value in the energy sector as described in chapter 5: energy trading, local markets, rewarding cryptocurrency, pay or receive with cryptocurrency, grid balancing, demand response communication, real-time GoO, sharing meter data and creating multiple suppliers at one grid connection. Most suitable for the EXE product portfolio would be to support the first or the latter with their Entrnce product, acknowledging the current barriers for parties operating in the energy markets and EXE's strategy. The amount of peer to peer energy trading initiatives using blockchain is increasing so a new market for EXE is opening up.

9.2 LESSONS LEARNED

The blockchain technology is still quickly evolving and not much scientific research has been done on the appliance of blockchain in various fields. Research paper are most of the time limited to blockchain as technology or as technology for payments. A few papers describe the possibilities for blockchain in microgrids and both PwC (2016) and DENA (2016) take a very high-level approach on the appliance of blockchain within the energy sector. Both do not go in-depth about how it can applied, do not study the current state-of-the-art and do not outline the limitations within the regulatory frameworks. Going more in-depth on the energy trading, literature is limited to the NRGcoin papers from the Vrije Universiteit Brussel. However, these papers are only theoretical and do not take any perspective on the current energy grid.

This thesis is the first scientific research taking a perspective of a wide range of different blockchain appliances within the energy sector and taking the existing current regulatory frameworks and energy markets into account. It adds knowledge to research by describing nine different types of appliances of blockchain in chapter 5 to support and accelerate the energy transition. Limitations in creating a fully decentralized, self-managing grid are outlined and in the next section recommendations to support blockchain initiatives and the energy transition in general are given.

At more in-depth level, two designs are created for a specific blockchain implementation. Their concepts are placed within regulations and so taking all required processes into account. For energy trading, the existing state-of-the-art initiatives have led to a generalized energy trading concept on the blockchain. The architecture is created within the Entrnce software product that facilitates the BRP role. The multiple suppliers at one grid connection concept shows the flexibility of a blockchain based platform and how it can facilitate real-time guarantee of origin by making deals between supplier and demand. Both concepts include a demo and implemented smart contracts of the interface contracts shown in this thesis. Section 9.4 outlines next steps for scientific research.

9.3 RECOMMENDATIONS

The energy transition is a topic discussed on every scale, from neighborhood to the worldwide Paris agreement. Billions of dollars are spent to accelerate the transition from a top-down perspective. The price a customer pays for his or her energy is merely a third of the direct cost for the energy, the other part are fees and tax. Grassroots, in the Netherlands mainly 'energiecoöperaties', tend to take initiative as groups of citizens, and startups, are creating new ideas to accelerate the energy transition. However, they face huge barriers to enter the energy markets. Becoming a legal energy supplier is an extensive, complicated and expensive progress and sufficient ERP software requires a huge investment. As energy supplier, you should also take the BRP role or you can outsource this responsibility. This creates an environment where they cooperate and sign contracts with large energy suppliers.

The current top-down approach is not solving the real problems. Time is a dimension not taken into account in most projects while it is extremely important in the energy transition. Prosumers are mainly generating energy with their solar panels when they are not at home at all and so their surplus is fed back to the grid and often used again at peak moments. Peak moments force grid operators to upgrade the grid which is very expensive and depreciation of the grid happens up to 20 years earlier than expected due to extreme peak loads. Prosumers can now use the 'salderingsregeling' which aggregates supply and demand over one year and so is not taking time into account at all. Also, smart meters in the Netherlands are behind on technology and not even implemented nationally. The goal is to implement smart meters at each connection by 2020, but they are not that smart. No direct real-time access can be given to meter values by the customer. Whereas in other countries smart meters are really smart and Wi-Fi enabled, giving real-time access to meter data and so for instance create possibilities for peer to peer energy trading, real-time guarantee of origin or (verification of) demand response, the grid in the Netherlands is not ready for this.

As outlined in this thesis, the blockchain technology has a high potential to support the energy transition. This is not achievable out of a sudden but could be achieved step by step. If the blockchain technology is not the most optimal technology in a specific case, another technology should be used. However, this thesis suggests the world to take the following steps to accelerate the energy transition:

- **Enhance smart meters so third parties have real-time access to meter values** in order to let people directly trade energy with each other and to give them real-time insights in their energy usage. If financially beneficial, enrich the current smart meters with a dongle. Privacy issues are present in such integrations but are also solved in the current P4 ports. It would be extremely beneficial to offer P1 as a service. Currently one can become an independent services provider (ODA) at EDSN which gives access to P4 ports for customers that signed a contract. However, these parties are certified and controlled regularly. In a future system, it would be beneficial to give the customer real-time insight in who can read their meter values and let them handle the access. This enables peer to peer energy trading, rewarding people for, for example helping with grid balancing or reducing peaks and real-time GoO.

- **Loosen the regulations that apply for energy suppliers**. The process to become one is extremely extensive and not accessible for smaller parties. Also, unnecessary tasks like settle on the P4 port value instead of P1, having third party bank accounts and providing invoices to the customers make integration of for instance the blockchain technology more extensive. ERP systems are almost always creating loss when having below 5.000 customers since prices start from around 50.000 euro. Blockchain might be able to implement automated low-cost systems for energiecoöperaties having only 100 or 1.000 customers.

- **Allow for more bottom-up experiments** like the postcoderoos to create more financial benefit for renewable energy initiatives. As also said by Stedin, the only way to let initiatives like them become attractive is to create a financial advantage. With the postcoderoos one has to invest in renewable energy supply to get a tax reduction on their kWh in the future. This system is not taking time into account and one has to invest upfront. Taking time into account would be most realistic and investment of renewable energy parks or roofs can happen in other ways. Therefore it is suggested one can use energy from a postal code in the postcoderoos with the same energytax reduction as the postcoderoos, only if there is a real-time guarantee of origin. Governments should be open for similar regulations when set up by energiecoöperaties.

- Respond to the extreme predicted growth of EV and **implement grid control systems at charge stations**. The disadvantage of EV is the huge peak load at often predictable moments but the advantages are that they are often flexible in charging moment and speed and their battery can help in grid congestion management and grid balancing.

- Implement **open demand response systems** at local scale which are also available at national scale. At smaller scale they can be used for grid congestion management while at national scale it could help with balancing the grid. Anyone should be able to connect to the system and it should be integrated in hardware. For instance EV charging stations and heat pumps in buildings and houses (especially houses without gas and/or nul-op-de-meter houses). This could for instance be achieved with IOTA using the Tangle which is focused on M2M interaction. People could be rewarded when enabling the demand response system in their hardware.

- **Do not limit parties to certain roles** they are allowed to take. For example, at the moment it is legally defined that a network operator is not allowed to buy or sell energy. Lawsuits are taking place against them since other parties suspect them from handling outside their legal domain. This separation between transferring and supplying energy has been made to enable market forces and give customers cheap energy. However, two third of the energy price is made up of tax so there is almost no difference in energy price anymore. Furthermore, the separation has been made and network operators are serving every energy supplier on their network. Making also their own deals on the network is not directly disabling the market forces.

Since the salderingsregeling does not take time into account and currently there is no application to trade energy between prosumers and consumers, the largest potential to develop a blockchain application is in peer to peer energy trading. This also fits the EXE product portfolio since Entrnce can give current initiatives on this topic a place within current markets by offering the BRP role. Blockchain technology still has to evolve to a mature level with smaller transaction fees and less energy consuming consensus protocols. As soon as public grid initiatives arise in the Netherlands, EXE should as soon as possible cooperate with these initiatives before they take the BRP role themselves. The likelihood for an initiative to build a technical implementation to fulfil the BRP role themselves is low due to high technical requirements and extensive procedures.

When energy is traded on the blockchain this could be extended towards more decentralization of the grid, for instance by using open demand response mechanisms and creating local markets. In the foreseeable future, it might even be possible to eliminate the BRP roles and so, to eliminate the requirement to predict usage and buy energy upfront. A self-managing grid is achievable when everyone acknowledges the responsibilities and characteristics of renewable energy. In the Netherlands we have such extensive systems that it might be useful to look first at microgrids, especially in third world countries. Developing countries are doing projects connecting the different microgrids and are using the blockchain technology in order to provide everyone with energy.

9.4 DISCUSSION & LIMITATIONS

Since the blockchain technology only exists since 2009 it is still immature. In 2016 and 2017 its popularity has highly increased with new features being enrolled. However, still a lot of problems are present to use it in everyday life. Therefore, this research did not focus on which blockchain technology implementation is the best to use for different cases. It is likely certain blockchains will evolve and enroll new features and new blockchains will arise. In different type of applications a different blockchain could be used depending on if smart contract are required, transaction speed, if zero value transactions should be possible (for transmitting data), if own tokens are needed, etcetera.

The blockchain technology has also quickly evolved during this research, carried out from June till December 2017. For instance, the Ethereum blockchain was updated with a new consensus protocol and ING announced a Zero-Knowledge Range Proof solution improving the confidentiality in public ledgers. Relevant innovations for the blockchain technology implemented before November 2017 have been processed in this master thesis.

Especially large established companies did not always want to provide all or even any information. Most of them did not want to provide project specific information. New startups and initiatives on the other hand provided a lot of information and whitepapers are provided with almost every ICO providing a lot of information. Technical information like smart contracts was never available.

If one would set up an energy grid now, this would be done in a total different way. There are so much new concepts possible with IT but the real world seems behind. Regulatory frameworks and established companies seem to slow down the energy transition. As soon as a party is not benefiting from a technology directly they are not implementing it. For instance, this seems the case with smart meters being behind on the technology since grid operators do not benefit from enabling them with real-time data. This is a difficult case in a market with so many parties and roles.

The most interesting steps for further research would be to research the technical requirements and financial feasibility of real-time energy trading on the blockchain with local markets at municipality level being nearly self-sufficient. The current salderingsregeling, together with the grid being overloaded and so the grid being quickly depreciated, makes energy more and more expensive. With real-time energy settlement and local markets, no salderingsregeling is required and grid congestion reduced. In order to not exceed nationwide energy prices, some reduction might be required in the energy tax in the short-term as long as the salderingsregelsregeling exists.

Privacy issues are not included in this research. Although it is well known these will arise when for instance meter data is shared real-time, this was out of scope. Probably consortium blockchains or quantum proof algorithms can provide a solution for this issue.

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