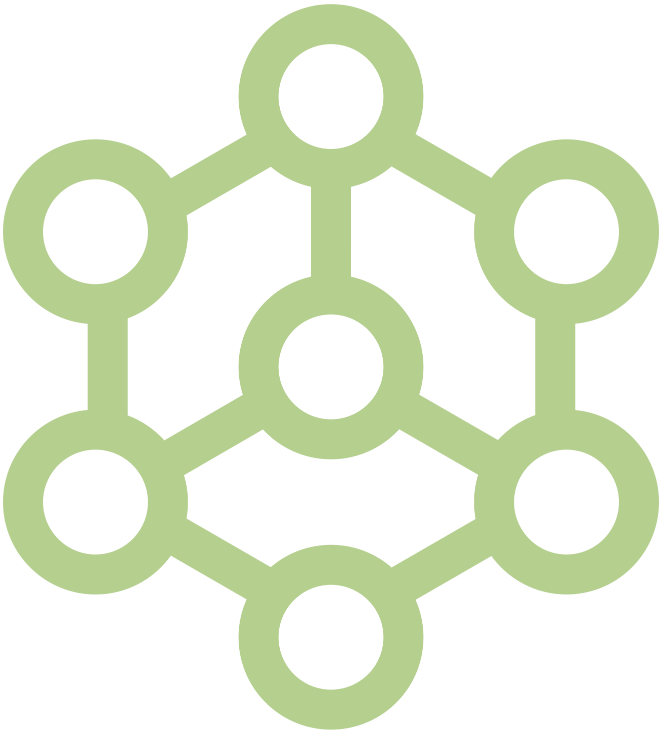
SUSI PARTNERS
SUSTAINABLE INVESTMENTS

2018

Blockchain

Disrupting the Renewable Energy Landscape



A SUSI Partners AG white paper in cooperation with the
Center for Innovative Finance, University of Basel

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GLOSSARY

Throttling	Reduction of a plant’s power output
Adverse selection	Negative/undesirable self-selection
B2B	Business-to-business
CER	Certified Emission Reductions
IEA	International Energy Agency
Internet-of-Things/IoT	Global network of connected everyday objects
IPCC	International Panel on Climate Change
kWh/MWh/GWh	Kilowatt hours/Megawatt hours/Gigawatt hours
Oracle	Information source that prepares information and provides it for use in smart contracts
Prosumer	Mix of producer and consumer
Redispatch	Ordered adjustment of power plant schedule
Stable coin	A crypto-asset with very low volatility in its buying power and/or w.r.t. the respective (stable) state currency
Smart contract	Automatically executed instructions on a blockchain
Smart meter	A power meter equipped with additional functions
Levelized cost of electricity	Costs required to convert another energy form into electricity
Token	Virtually transferrable value unit
Tokenization	Virtual representation of arbitrary value units via a token
UNFCCC	United Nations Framework Convention on Climate Change
State channel	Channel for the bilateral exchange of crypto-assets, where not every transaction but only the aggregated total of the blockchain needs to be added. Makes microtransactions possible

KEY FINDINGS OF THE STUDY

This study, performed by SUSI Partners AG in cooperation with the Center for Innovative Finance of the University of Basel, provides an overview of the applications of blockchain technology in the field of renewable energies. We show that the use of blockchain technology can generate new and promising approaches for solutions to the current challenges facing the electricity and energy market. The most important insights of the study are summarized in the following four points:

- This white paper identifies 14 use cases of blockchain technology in the area of renewable energies and divides them into five categories.

- Some of the applications have a disruptive character and could thus result in great changes in the respective area. In particular peer-to-peer (P2P) electricity trading but also applications in the field of “asset management & operations” fall into this category.

- Other areas of application can also be used in today’s system. In this way, possible efficiency increases could be achieved primarily in the areas “asset transparency” and “grid operations”.

- The market overview (Chapter 4.2) shows a great interest in the potential applications of blockchain in the energy market. New blockchain start-ups and established companies are already active on the market.

Since blockchain technology is very young, only few of the use cases have been able to reach market maturity at this point. One also has to consider that a regulatory framework still has to be created for the comprehensive use of blockchain technology in the energy market. However, this study illustrates the versatile potential of blockchain technology in the different areas, in order to facilitate the early positioning of all involved actors. It makes sense for investors to study this topic now – blockchain represents a key technology similar to the internet and will replace or at least alter existing business models.

PREFACE

Thanks to ever more intensive climate protection efforts and the clear cost reduction of renewable energies, they have been able to achieve significant growth in the last few years. This increases the share of weather-dependent renewables in the electricity mix, which endangers grid stability since the existing grid is not designed for decentralized and irregular power production. In addition, in recent years, the traditional monopoly structures of the electricity market have been partly broken up and liberalization enacted. However, this process is still ongoing and until now primarily benefited the largest consumers and producers. Particularly in Europe, small actors such as households still do not have direct market access. Solutions have to be found in the coming years in order to ensure a stable and contemporary power supply.

A new technology that promises solutions to many of the challenges the energy industry currently faces is blockchain. Blockchain technology has become a topic of conversation after the tremendous price increases of the cryptocurrency Bitcoin over the course of 2017. While Bitcoin became a dominant topic, it does not completely encapsulate the potential of blockchain: many pioneers have been working for several years on developing the technology and finding alternative applications for it. With the programmable nature of the new blockchain Ethereum a milestone was reached in 2015 and the use cases of blockchain expanded. Since then, various new use cases of blockchain have been developed in various industries and their potential for efficiency increases studied. The energy sector is always mentioned as one of the most promising areas of application.

This white paper provides an overview of the use cases of blockchain for renewable energies and shows what potential blockchain has for the asset management of renewable energies. It also provides an overview of which companies have already developed and/or use blockchain-based solutions for the energy market.

Chapter 1 provides an overview of the future of renewable energies and the effects of the Paris Climate Accord. Chapter 2 focusses at the current situation of renewable energies and explains the associated challenges in the electricity market.

Chapter 3 provides an introduction into blockchain and its underlying technology. The chapter provides readers who are new to this topic with the necessary knowledge for the following chapters.

After explaining both the problems of the electricity market and how blockchains work, Chapter 4 will discuss the use cases of blockchain in the energy market. They are split into 5 areas and show what solutions blockchain technology permits. After this, a market overview will introduce the most important actors in the respective areas of application, presenting two projects in the form of case studies.

1 THE INCREASING NEED FOR RENEWABLE ENERGY SOURCES

1.1 COP21 – THE PARIS CLIMATE PROTECTION ACCORD

The Paris Climate Accord (with the official title United Nations Framework Convention on Climate Change, 21st Conference of the Parties, short COP21) was signed on December 12, 2015 and marked a historic event. For the first time in history, 195 countries signed a commitment to fighting climate change. The main goal of the Paris Climate Accord is the limitation of the global temperature increase in this century to 2.0 degrees Celsius. In addition, it encourages efforts to limit the warming to only 1.5 degrees Celsius above the pre-industrial level.[1]

The fact that the US under President Trump want to leave the accord temporarily does not appear to alarm the COP21 states much: On one hand, China is ready to take a global leadership role here and on the other, the accord was formulated in a way that the US could effectively not leave before November 2020. A period in which much can change. The requirements of the Paris Climate Accord for global CO_2 emissions and thus energy production are illustrated in Figure 1.

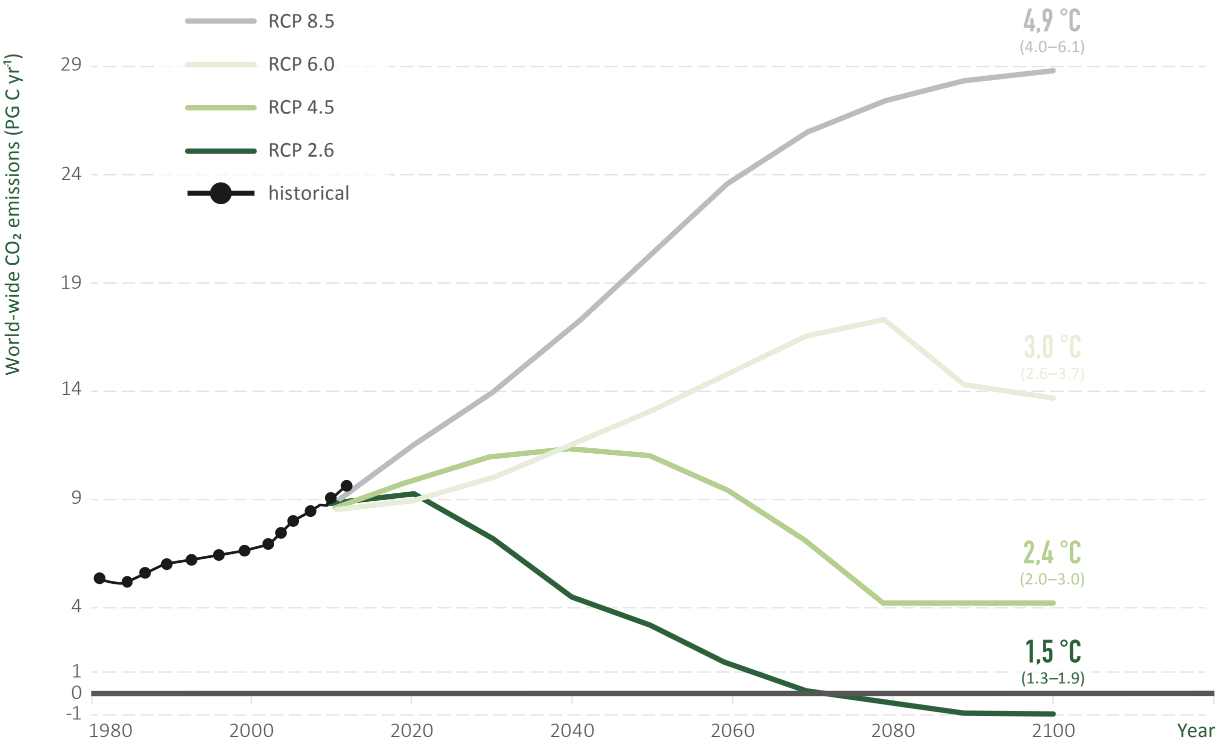

Figure 1: Probably necessary CO_2 reduction for the 2-degree target[2]

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[1] (United Nations Framework Convention on Climate Change 2015)

[2] (Sanford, et al. 2014)

The figure shows the four representative concentration pathways (RCPs), as they have been defined by the Intergovernmental Panel on Climate Change (IPCC) in its fifth progress report.[3] The concentration pathways serve for climate research and modelling. They describe climate scenarios that could occur in the coming years depending on the amount of greenhouse gas emissions. In order to achieve the "less than 2 °C target" in this century, RCP 2.6 would have to be implemented as the only program that is able to limit the temperature increase to less than 2 °C by 2100. As can be seen in Figure 1, we would have to start immediately with reducing global CO_2 emissions. This illustrates the need to move from fossil fuels to renewable energy sources as quickly as possible.

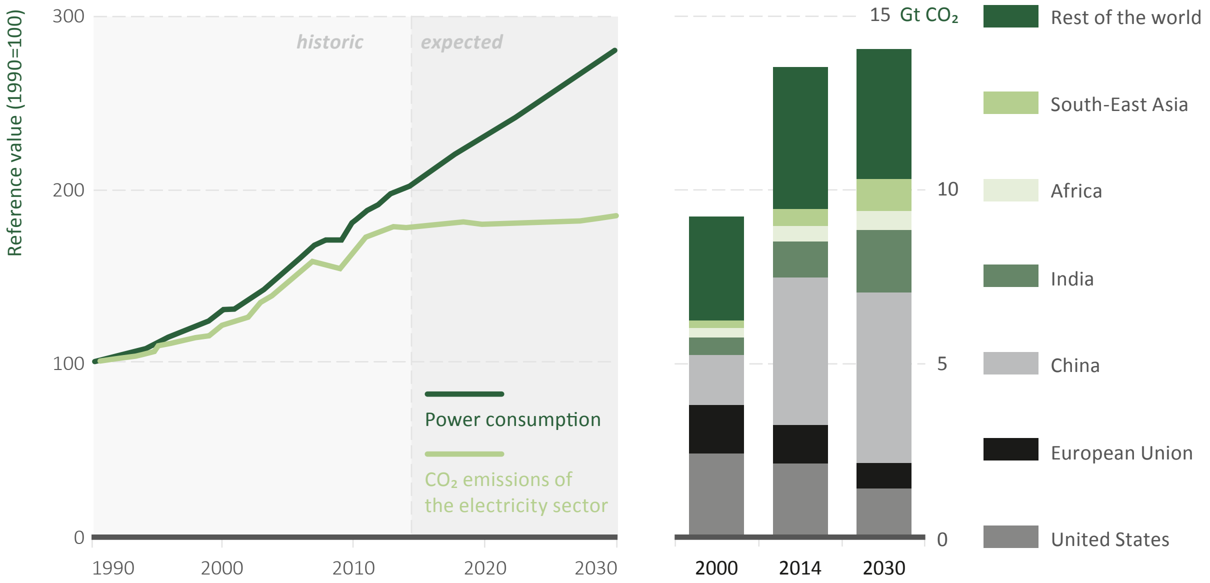

Figure 2: Development trend of world-wide energy requirements, CO_2 emissions of the electricity sector, and regional CO_2 emissions[4]

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[3] (Intergovernmental Panel on Climate Change 2015)

[4] (International Energy Agency 2015)

1.2 SIGNIFICANCE OF COP21 TARGETS FOR THE ENERGY SECTOR

The role played by the energy sector in the implementation of the COP21 targets becomes clear when you consider that this sector makes the greatest contribution to global warming. In 2010, the energy sector was considered responsible for approx. 35 % of all greenhouse gas emissions.[5] The energy industry must accordingly take a leading role in the fight against climate change. Or, as the International Energy Agency (IEA) puts it: "Actions in the energy sector can make or break efforts to achieve the world's agreed climate goal."[6]

In its forecasts of future CO_2 emissions generated by the energy industry, the IEA states that the majority of new power generation capacities comes from low-carbon technologies, i. e. renewable or nuclear energy. As depicted in Figure 2, the emission level of power generation will remain constant, while it is estimated that the global demand for electricity will increase by more than 40 % by 2030.

According to the predictions of the IEA, in the case the COP21 targets are implemented, the electricity requirements in the OECD states will increase by approx. 10 % by 2030, but the CO_2 emissions of the energy sectors decrease by one third. For non-OECD countries, predictions call for an increase of power demand by almost 75 % with a concurrent increase of emissions by 25 %. This means that at the global level, the impact of increasing power demand on emissions will decrease due to the integration of low-emission energies and higher efficiency levels. This is a very important step on the way to the decarbonization of the energy sector. The IEA expects that 70 % of the energy production capacity provided between 2015 and 2030 will come from low-carbon technologies, renewable energy, and nuclear energy. This makes significant investments into plants for generating renewable energies urgently necessary in the coming decades.[7]

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[5] (Intergovernmental Panel on Climate Change 2015)

[6] (International Energy Agency 2015)

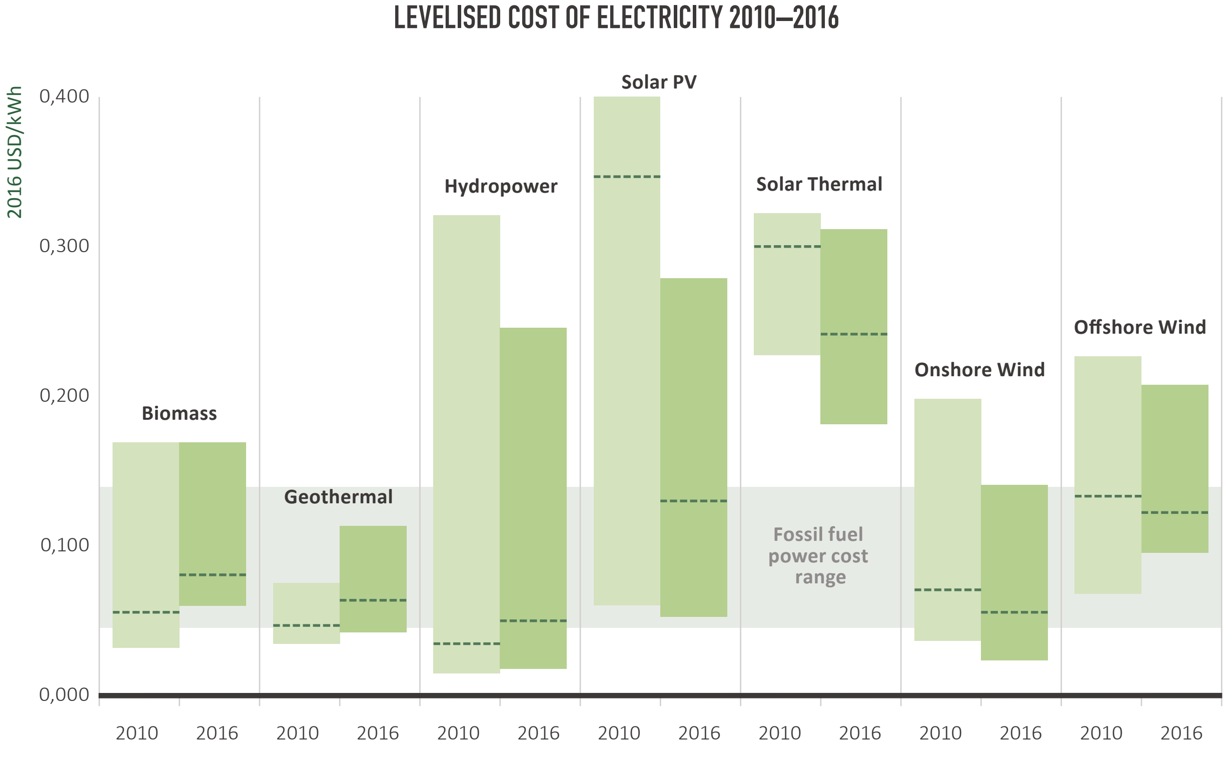
[7] Parts of Chapter 1 were taken from (SUSI Partners 2017).

2 STATUS QUO OF RENEWABLE ENERGIES

2.1 PRODUCTION AND TRADE OF RENEWABLE ENERGIES

This chapter provides an overview of how renewable energies are produced and made available to consumers today. We also look at the causes and consequences of the predicted increase of renewable energies and the associated challenges.

Over the past two decades, renewable energies have achieved important milestones in their development and can be used more and more cost-effectively to produce electricity. For instance, solar energy has experienced a tremendous efficiency increase, which led to a four-fold decrease of module prices just from 2011 to 2015, due to the rapid development of installed solar capacity.[8] Compared to traditional energy sources like oil, coal, and natural gas, renewables were also able to make up ground. Figure 3 provides an overview of the levelized cost of electricity of renewable energies, i. e. the cost per kWh that arise during power production from different technologies.



Note: All costs are in 2016 USD. Weighted Average Cost of Capital is 7.5 % for OECD and China and 10 % for Rest of World. Preliminary data for 2016.

Figure 3: Levelized cost of electricity of different renewable energy sources.[9]

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[8] (IRENA 2016)

[9] (IRENA 2017)

Renewable energies have experienced a massive upwards trend in recent years, which is reflected in the increase of wind and solar production by 16.8 %/29.7 % respectively from 2014 to 2015. However, in 2015 renewable energies (including hydroelectric) still only made up approx. 4 % of global energy production.[10]

The World Energy Outlook 2016 of the IEA[11] notes that in particular in the power sector, the move to renewable energy sources can be felt, while other energy sectors like industry, transportation, or heating still lag behind. Renewables already held share of 20 % of the world-wide electricity in 2015. More than three quarters of the electricity from renewable energies were generated by hydroelectric plants. In addition to hydroelectric power, primarily wind and solar produced a significant amount of renewable electricity. Overall, from 2006 to 2015 renewable energies experienced an average annual growth rate of 7.73 %, which was due to the enormous growth rates of solar and solar-thermal energy. For the OECD countries we already have more current figures, which show that growth of renewable energies in these countries also remained stable in 2016. This development is still primarily driven by "non-hydro renewables".[12]

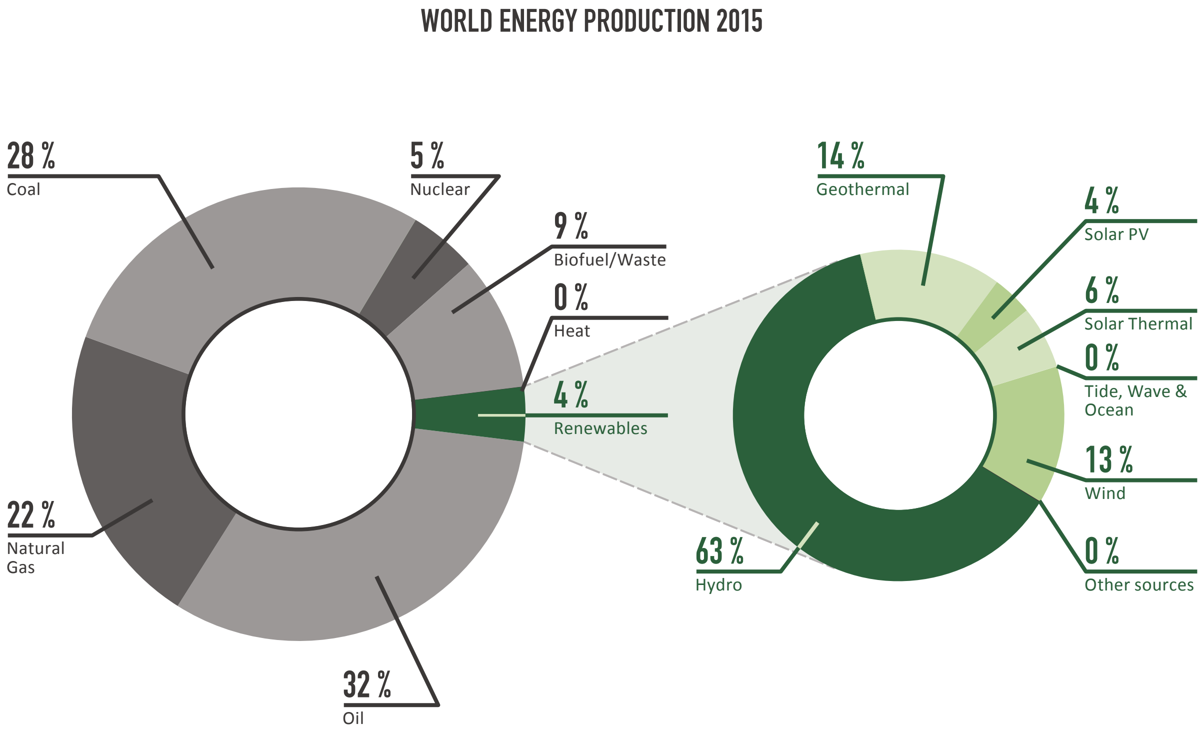

Figure 4: World Energy Production 2015.[13]

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[10] (International Energy Agency 2018)
[11] (International Energy Agency 2016)
[12] (International Energy Agency 2018)
[13] Own representation with data of (International Energy Agency 2018)

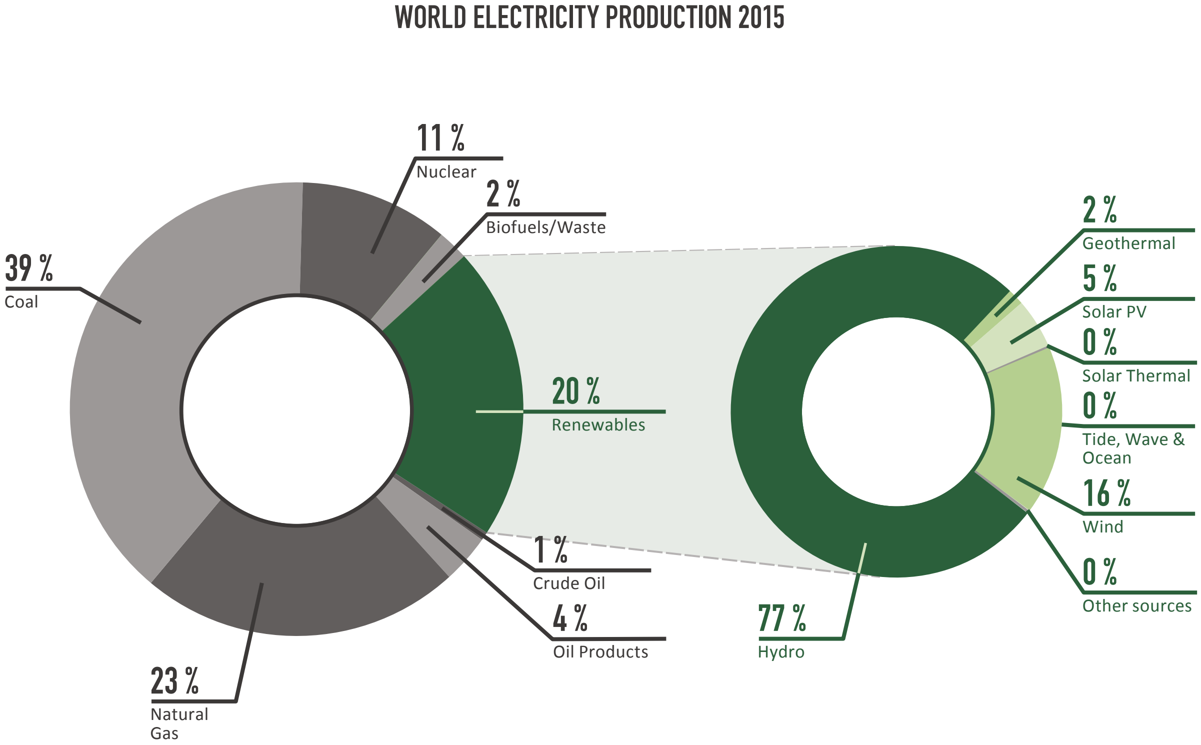

Figure 5: World Electricity Production 2015[14]

Since the renewable energies are primarily used to generate electric energy, we focus on the electricity market in this white paper. The heating market, as second area of application for renewables, is only discussed on the side. All use cases of blockchain technology in the energy sector listed in Chapter 4.1 can be explained using the example of the electricity market.

In many countries, the electricity market has been going through fundamental changes for a few years. As a result of the liberalization of the electricity markets, traditional and monopolistic market structures have been broken up world-wide and competitive markets created. The trade of electricity is increasingly moving from future to spot markets.[15] However, in many places the liberalization of the power grids has been dragging (e. g. in Switzerland) and access mostly restricted to major producers and consumers. Small providers and consumers are still unable to participate in a market directly but have to conclude a contract with a licensed electricity dealer in order to participate in a market, pooled with other small providers. This affects the operators of renewable energy plants. Today, power from renewable sources is partly generated in large plants (e. g. wind and hydroelectric power plants), but in particular solar energy is generated in small, distributed plants.[16] These small providers of electricity are called prosumers (consumer who also produce). They feed their excess electricity into the grid and usually receive flat payments

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[14] Own representation with data of (International Energy Agency 2018)
[15] (Merz 2016)
[16] (Federal Grid Agency 2016)

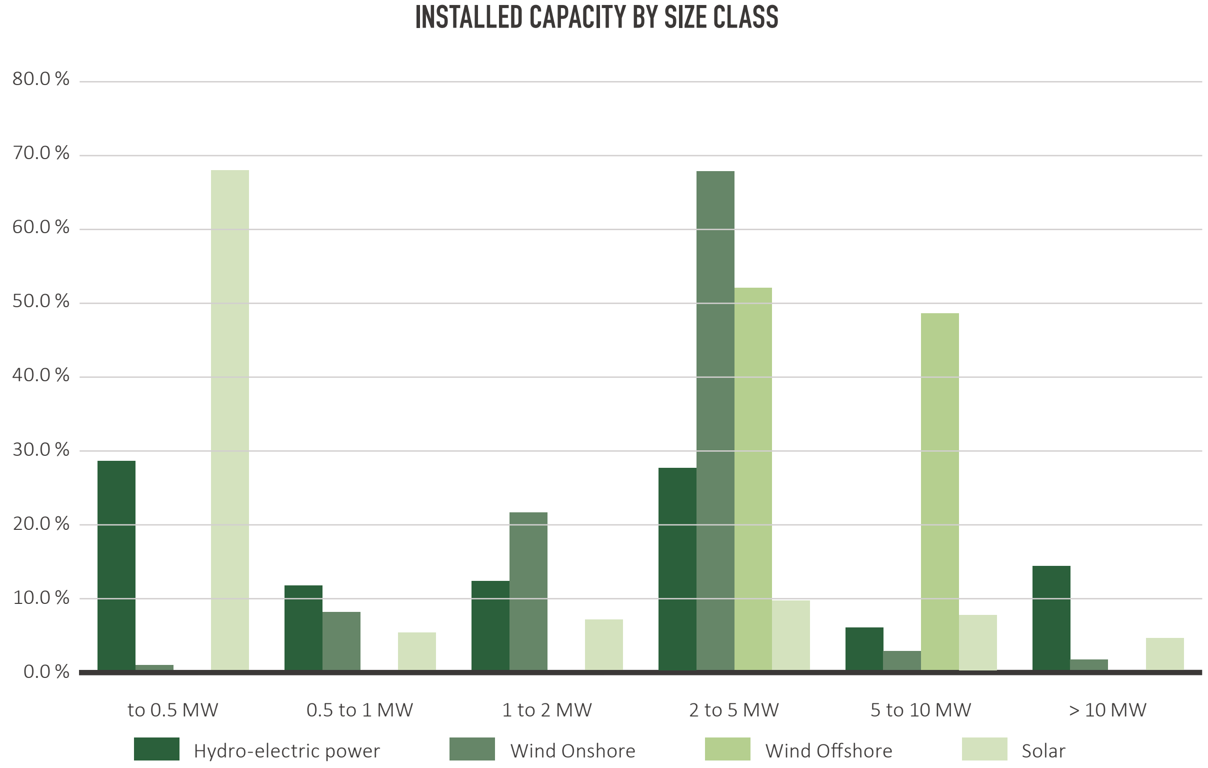

Figure 6: Installed capacity by size classes in Germany.[19]

for the provided energy, i.e. a fixed price per fed kWh. Examples for this are the feed-in remuneration in Switzerland (KEV)[17] and in Germany (EEG)[18].

The upswing of renewable energies thus results in a deeper change to the electricity market. The renewable energies cause a geographic shift of electricity production. In particular wind energy, which is also used in larger plants (see Figure 6), changes the requirements for the power grids since the electricity is now additionally produced at new locations in the grid.[20] However, electricity from wind energy plants depends on the wind conditions, which is why it fluctuates with the change in wind speeds. In combination with the rigid base load this results in increasingly frequent grid bottlenecks, which occur when the power grid cannot transport the available electricity capacities.

In addition to this geographic shift, there is also a shift to decentralized and renewable energy generation, in particular in the emerging solar energy market. Many households and companies can cover their own power and heating needs by installing their own renewable plants. However, renewable energy sources (primarily sun and wind) depend greatly on weather conditions, which is why prosumers have too much energy at their disposal on some days and too little on other days. This can cause so-called bi-directional electricity flows, when (for instance on sunny days)

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[17] (Federal Ministry for Energy 2018)
[18] (Federal Ministry for Economy and Energy 2018)
[19] Own representation with data of (Federal Grid Agency 2016)
[20] (Federal Grid Agency 2018)

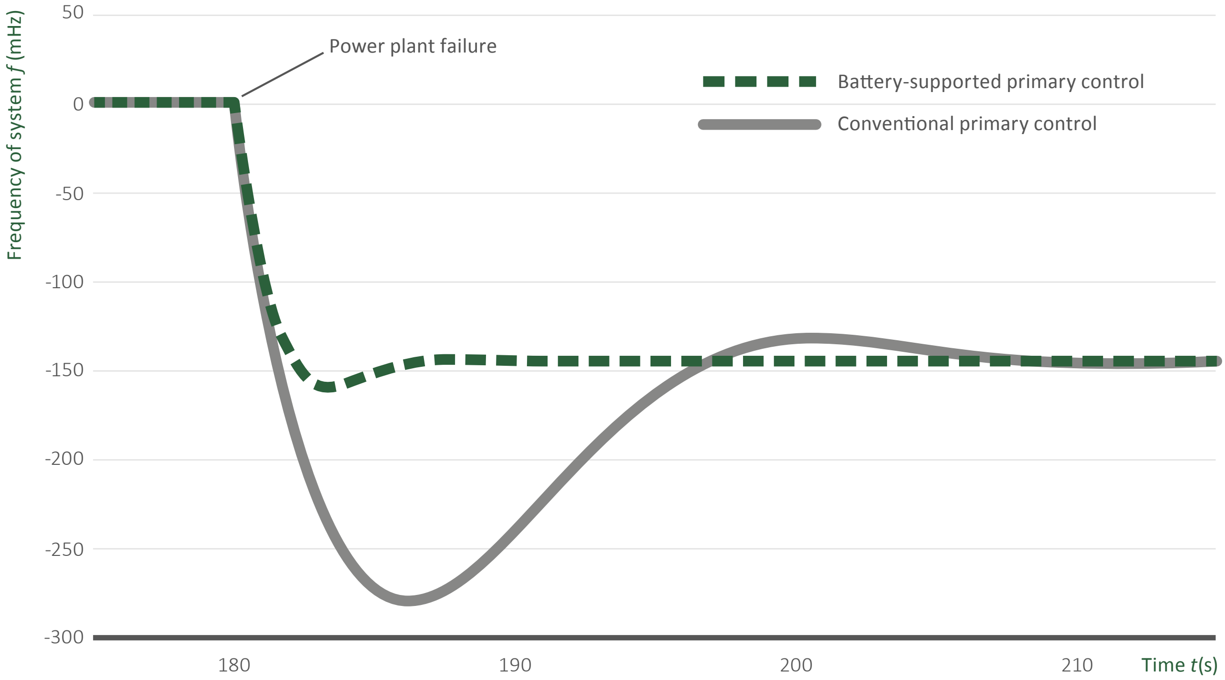

Figure 7: Comparison of the balancing power after the loss of a power plant.[22]

end consumers do not draw electricity from the grid but instead feed their own excess capacity into the grid. These short-term fluctuations endanger the safe operation of the power grid through a disruption of the grid's voltage and frequency balance. The fluctuations in the grid must therefore be compensated by the grid operators in fractions of a second. Among other things, Switzerland uses pumped-storage power plants to accomplish this balancing act. However, these power plants cannot be regulated fast enough to be able to react to very short-term fluctuations, which is why batteries are increasingly recommended for the short-term balancing of the grid.[21]

In other countries, like Germany, pumped-storage power plants make up a smaller portion of the electricity mix due to other geographic circumstances. For this reason, these countries achieve grid stability more frequently through the expensive throttling of renewable energies and the redispatch of power plants. For instance, this means that wind energy parks may not produce maximum capacity despite sufficient wind or conventional power plants need to deviate from their planned production volume on short notice. These production reductions are ordered by the responsible transmission grid operator and result in great opportunity costs in the form of unused capacity.

Other possibilities that are used to ensure grid stability are so-called Demand-Side-Management and the trading with neighboring countries. In Demand-Side-Management, a bottleneck is controlled via the demand side instead of the supply side, i.e. the

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[21] (Ulbig, Borsche, and Andersson 2016)
[22] (Ulbig, Borsche, and Andersson 2016)

demand for electricity. However, the possibility of cross-border grid balance is increasingly restricted since for instance neighboring countries of major producers of renewable energy (e.g. Poland as neighbor of Germany) are no longer willing to accept large electricity volumes on short notice which endanger their own grid stability. As a result, there are negative electricity prices and more and more frequent so-called “brown-outs”, i.e. voltage fluctuations in the grid that in extreme cases can result in a “black-out”, i.e. the collapse of a grid. It is essential to prevent the latter, since the high interconnection of the European power grid means that black-outs could lead to the collapse of other parts of the power supply and a restart could take days. This would result in tremendous economic costs.

In connection with protecting grid stability and the development of the power grid, the focus currently lies on so-called “smart grids”. The goal of smart grids is to connect the production, consumption, and storage of electricity with each other and controlling them efficiently using intelligent measurement, information, and communication technologies.[23] The power grids of the future should thus become more transparent with the use of additional measurement data, so that more is known about the current status of the grid and one can react to fluctuations faster. One of the technologies that could make our grids more intelligent are so-called “smart meters”, i.e. electricity meters equipped with additional functions. They are supposed to collect measurements at the lowest grid level, i.e. the consumer, and pass it on to the grid operators. In order to coordinate and transmit all these meter readings and the additional data volumes generated by other new technologies, a powerful information and communication technology is needed that also meets privacy protection requirements.[24]

In addition to the mentioned topics, there are additional developments that drive change in the energy sector. The increase in electric vehicle charging is changing the entire car sector and will shift the demand from conventional fossil fuels to other energy storage technologies like batteries in the future. With the goals of greenhouse gas reduction, many countries introduced tradeable emission rights, in order to reduce emissions with correcting taxes and/or internalize the social costs.

2.2 POTENTIAL IMPROVEMENTS IN BUSINESS

Until now, we have looked at specific attributes of the energy market. In analogy to many other industries, the energy sector will also be affected by digitalization in the more general sense. In particular, we expect great changes and process optimizations in business-to-business (B2B) communication. When exchanging data and comparing information, there often are no standardized protocols and communication forms that would permit automation. This can result in significant inefficiency and problems.[25]

Many business processes today also need an intermediary. Due to trust and coordination problems, these intermediaries are necessary, but they also result in inefficiency and systematic dependencies. For instance with insurances, part of the premiums goes to the insurance company itself, since it must maintain

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[23] (Federal Ministry for Energy 2015)
[24] (Federal Ministry for Energy 2015)
[25] (Merz 2016)

its business activities and provide a central infrastructure. This means that costs are covered which have nothing to do with the insured loss and thus could be reduced using distribution and automation of the processes. Similar examples can also be found in the more classic business fields of the energy industry, for instance trading electricity or implementing contracts. Contracts in turn incur costs for services of different third parties that have nothing to do with the original contract and only occur due to the lack of trust between the companies. If the fulfillment of the contractual terms could be monitored on an ongoing basis or the automatic execution of contracts be ensured, enormous efficiency gains could be achieved.

In summary, we can state that the sector of renewable energies has tremendous potential, but also faces numerous challenges. This white paper gives an introduction to the blockchain technology and shows how many of the discussed problems could be solved by applying this innovation. After a brief introduction of the technology, Chapter 4 describes the use cases of blockchain in the electricity sector. The areas discussed in this chapter are picked up again and we show how blockchain technology allows new approaches in many of the mentioned areas and can contribute to the digitalization and automation of the electricity sector.

3 BLOCKCHAIN – AN INTRODUCTION

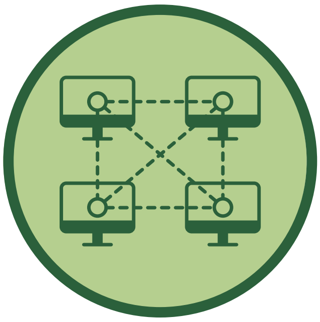
3.1 WHAT IS A BLOCKCHAIN?

Blockchain technology is a tremendous innovation. For the first time, databases can be kept and verified in a distributed form. Before that, databases always had to be managed by a centralized intermediary. This intermediary had full control of the modification and acquisition of entries and thus also of the current state of the database.

The need to assign exclusive accounting rights is due to difficulties in reaching a consensus. For instance, if one were to waive this exclusivity in a classical database and let all involved persons keep their own version of a database, the different versions would quickly diverge. This would result in conflicts that would make it impossible to synchronize the database and reach a consensus about which is the valid version. Depending on who you ask or which version of the database you are looking at, you would get a different state. These differences in opinion concerning the current state of the database would be fatal.

This is exactly where blockchain comes in. It is a special form of database, managed by a community according to precise rules. Each participant has a copy of this database and can generally add new entries to the database; precisely defined and controllable rules prevent any abuse. They ensure that there is a consensus concerning all contents at all times and that the different versions are synchronized. All participants can verify any change to the database and reject it if it is fraudulent. The blockchain is therefore more than just a database. It is a collective memory with an associated process for consensus-finding.

The distributed management of a blockchain has various advantages over classical databases. In summary we can point out the five following points:



Distributed system
Blockchain is based on a distributed architecture. Data is exchanged via a peer-to-peer network, i. e. a network of actors with equal rights. None of the network nodes takes on a system-relevant role, which prevents abuse and makes an attack significantly more difficult. If a node is lost, communication can still be continued. The consensus-finding process also occurs via the distributed system.

Immutability

Once saved on the blockchain, data cannot be changed easily. Depending on the consensus protocol of the respective blockchain, unjustified changes, i.e. changes of a manipulative kind, are considered difficult if not completely impossible. The states of the database are secured by a type of cryptographic finger print (hash value of the data) and sequentially linked. Any change is immediately visible.

Availability

In traditional databases, a lot of money must be invested into backup concepts with regular backup intervals. Blockchain-based systems, on the other hand, offer a certain protection against loss of data by default. Each network node contains a complete copy of the database and can share it (or parts thereof) with the other nodes. Should a node lose its data, it can request it from the other nodes and verify the data's legitimacy independently.

Structured data

In order to process data efficiently, it must be available in digital and structured form. Blockchains meet both criteria. Since the databases are managed by several participants, a common format standard is significantly easier to enforce than would be the case for isolated databases.

Reactive scripts

Blockchains can react to transactions. In the simplest case, these are simple scripts that, for instance, verify the legitimacy of a transaction. More complex reactions are based on so-called smart contracts or chain code and can range from the classic execution of classic contracts to complex governance structures of a distributed autonomous organization (DAO).

3.2 THE FUNCTION OF A BLOCKCHAIN

A blockchain consists of transaction data that propagates through a network, is verified, and then integrated into the database. Berentsen and Schär[26] explain this function using the following division: transaction capacity, transaction legitimacy, and transaction consensus. This segmentation allows a stepwise analysis of the structure, function, and components of a blockchain.

3.2.1 Transaction capacity

Each participant of the network can initiate new transactions. The transactions are created in a defined form (step 1) and then communicated to an arbitrary node of the distributed network (step 2). The different nodes continually exchange transaction data, so that a new transaction is transferred from node to node until all participants of the network have been informed. New transactions are not yet valid at this time. They are treated as announcements for a payment order and thus the intention of adding this transaction to the blockchain.

3.2.2 Transaction legitimacy

Each transaction that is distributed across the network in this manner can be verified completely independently by all participants for its legitimacy (step 3). The legitimacy verification ensures that the transaction is valid in itself, i. e. whether the information makes sense and is true. If someone does not follow the formal rules or references invalid data/balances, this can be detected immediately, and the transaction rejected. During the legitimacy verification, cryptographic methods (verification of the signature) can be used to check whether the original sender/initiator of the transaction is authorized to issue this information. Nodes will only accept and pass on those transactions which pass the tests successfully and thus can be shown to be legitimate.

3.2.3 Transaction consensus

Steps 1 to 3 give each node a set of transactions that were shown not to be fraudulent. There is still the problem that these transaction bundles can differ from node to node. In general, there is no guarantee that a certain transaction is present in all nodes and theoretically there could even be contradictory transactions in circulation, where part of the network nodes holds one of the transaction, while another part of the network nodes holds the other transaction. To counteract this problem and ensure that the network agrees on the current state of the database, a so-called consensus mechanism is needed.

For this purpose, the participants add their transactions into a so-called block candidate (step 4). This block candidate can be viewed as a candidate for a spot in the blockchain. A type of lottery decides which participant may add his block candidate to the blockchain or more specifically which block candidate

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[26] (Berentsen and Schär 2017)

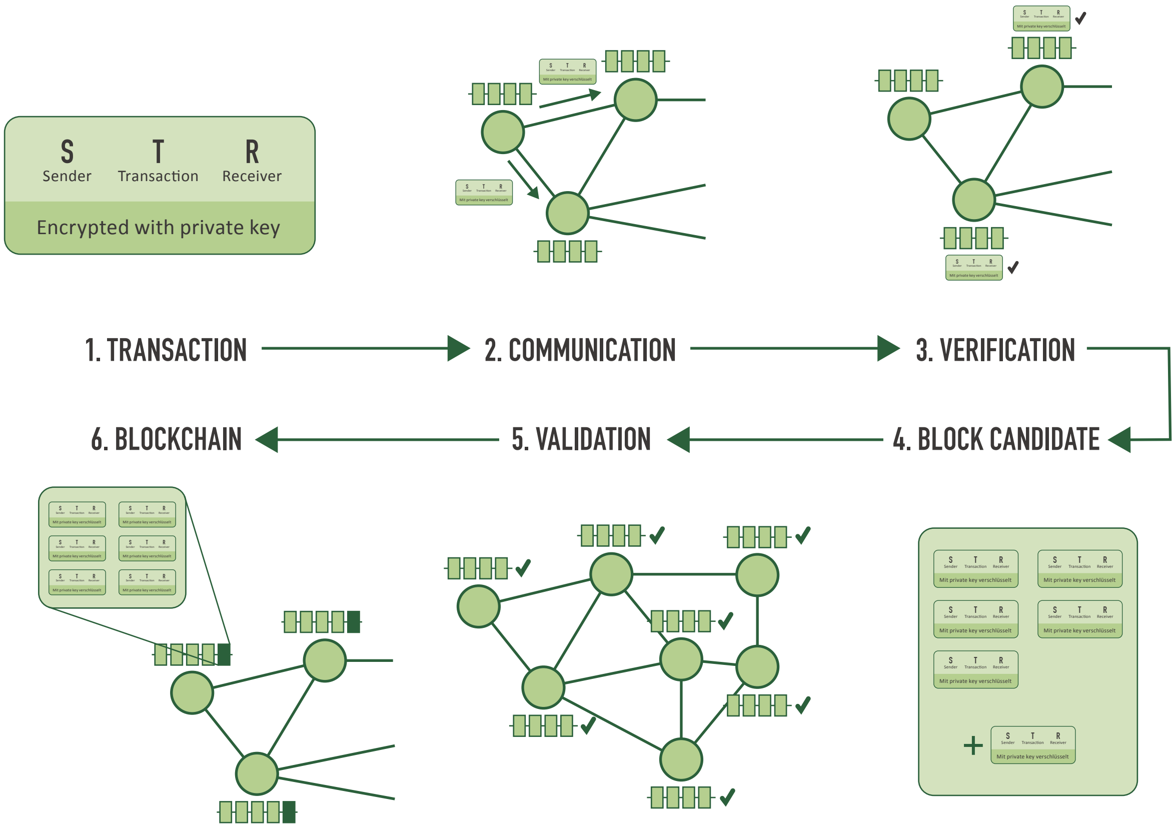

Figure 8: Function of the blockchain.[27]

is accepted by the other participants. The precise form of this lottery differs depending on the implementation of the consensus protocol (see info box). If a node wins the lottery, it communicates its block candidate to the other network nodes, including the proof. These other nodes check all contents and the proof (step 5). If all tests are passed successfully, the other network nodes add the block candidate to their own version of the blockchain (step 6) and the lottery begins anew.

Consensus protocols

Achieving a consensus is absolutely essential. Without a functioning consensus protocol, the different versions of the database would diverge, and no clear state could be determined. For this reason, it is essential that a blockchain has precise consensus rules.

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[27] Based on (Evry Financial Services 2015)

A simple consensus rule for instance would be that a single node equipped with special rights is permitted to contribute the respective next block and thus to determine the current valid state. However, this kind of consensus protocol would factually create a monopoly and thus undermine many of the benefits of the blockchain. More common are systems in which there are several such consensus nodes that decide the acceptance of the next block via some sort of vote. Depending on the number of these consensus nodes one can create a certain degree of decentralization. However, in this type of consensus protocol one also has to decide ahead of time which nodes are equipped with these rights, which would again result in some sort of centralization.

Completely open and distributed systems are based on more complex consensus protocols. This is in particular necessary to protect the system from so-called Sybil attacks in which an individual person creates several nodes to trick his way to additional voting rights. Proof-of-work, the consensus protocol that is used by Bitcoin and other blockchains, uses elaborate computations that have to be performed again and again until a result with certain attributes is found by chance. The node that can deliver such a result is permitted to contribute the next block. Proof-of-work has many benefits but is often criticized due to its high computing and energy requirements.[28] A possible alternative is proof-of-stake. This consensus protocol does not require computing power. Instead, the participants have the possibility to stake units of value (so-called tokens) that are represented and traded on this blockchain for a certain period of time. Depending on the number of blocked crypto-assets, the network nodes have probabilities of being able to contribute the next block. In terms of efficiency, proof-of-stake is superior to proof-of-work. However, it has a few problems that are not yet solved, which in extreme cases can lead to a split of the network.

There are several other approaches and mixed protocols in addition to the ones we described.

3.3 USE CASES OF A BLOCKCHAIN

The most familiar use case of the technology is the Bitcoin blockchain. The public and distributed database contains all Bitcoin transactions and records precisely what pseudonym can use which Bitcoin units. The concept was published at the end of 2008 in a white paper[29] and the reference implementation released at the beginning of 2009. The Bitcoin unit is the native unit of account of the database which does not represent any other claim. Due to its rarity and thus associated willingness to pay, the Bitcoin unit was nonetheless able to record a tremendous increase in value.

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[28] (Berentsen and Schär 2018)

[29] (Nakamoto 2008)

The success of the Bitcoin blockchain resulted in the creation of other blockchains, which in turn use their own native units of account. In many cases, they are simple copies. But in some cases, fundamental components were changed in the implementation. A blockchain that is clearly different from Bitcoin has become known under the name Ethereum[30]. While the Bitcoin protocol deliberately uses a simple scripting language, Ethereum uses a Turing-complete (i. e. fully-fledged) programming language and offers the possibility of performing complex instructions on a virtual machine. This leads to clearly more versatile potential applications, but at the same time also creates more complexity and potential attack vectors. Today, Ethereum has a solid developer basis and many projects building on top of its technology.

Enterprises often use closed networks or blockchains with access restrictions. In many cases, private instances of Ethereum or Hyperledger Fabric[31] are used. Both blockchains are very flexible due to their smart contract/chain code functionality and can form the basis for various applications.

3.4 THE FUTURE OF RENEWABLE ENERGIES

As already hinted in Chapter 2.1, the electricity sector offers numerous use cases for blockchain technology.

In the following Chapter we will present 14 applications, segmented into five areas. They represent a selection of all the applications we identified in our research (16) and stand out due to their direct relevance for the electricity sector. The use cases in the "Others" category are not discussed in this white paper. Since the underlying mechanisms are not always strictly delineated, there may be overlaps between some of the applications, while other applications clearly differentiate themselves. A few use cases are explained using examples. These reflect the most usual use of the blockchain in this area, but do not represent a final explanation of all the possibilities. Start-ups and major companies are engaged in research and first proof-of-concepts in almost all presented areas of application. However, until now (Q2 2018) there are no productive systems with high market penetration. But we expect that some of the presented use cases may become market ready in the near future and thus become available to the general public. At the moment we cannot predict which areas of application will prevail in the long term. In this respect, this study should be viewed as an overview of the current efforts and as a preparation and timely positioning of the readers.

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[30] (Nakamoto 2008)

[31] http://www.hyperledger.org/

POTENTIAL APPLICATIONS

Asset Transparency	Asset Management & Operations	Energy Trading	Grid Operations	Certificate Trading	Others
Asset history	Standardization & automation	Retail & settlement	Monitoring & measurement	Emission certificates	Client Services
Supply chain management	Insurance & hedging	Peer-to-peer	Ancillary services	Certified renewable energies	Incentive for energy efficiency
	Contract management	EV charging	Virtual power plants		
	Tokenization				

Asset transparency: Thanks to the immutability of blockchain, the entire lifecycle of assets can be traced on the blockchain. Any incidents, such as failures or repair work, are recorded on the blockchain. This use of blockchain technology can reduce or completely eliminate the problem of asymmetric information between buyer and seller in many areas. In addition, it can increase the transparency and overview in supply chains and simplify the cooperation of the involved companies.

Asset management & operations: Blockchain technology can improve many processes in asset management. For instance, the communication between the companies can be standardized and automated. Blockchains are also used for contracts and insurances, which are set up in the form of smart contracts and can thus function without intermediary. It is also possible to represent and trade assets via a blockchain using so-called tokens.

Energy trading: An often-considered application of blockchain technology in the energy sector is electricity trading. A blockchain allows the trade between households (peer-to-peer) without a central intermediary. Electricity trading is also interesting for electric vehicle charging since blockchains can potentially help extend charging possibilities for electric vehicles to every household on the grid.

Grid operation: With the emergence of the Internet-of-Things (IoT), several new possibilities in the area of data collection and measurement arise, as in the development of the “smart grids”. So-called IoT devices can be found more and more frequently in our homes and could be controlled by grid operators for grid management purposes. The connection of battery storage devices via a blockchain opens new possibilities for the ancillary services of grid operators. The connection of different power plants via a blockchain can also make the use of virtual power plants more efficient.

Certificate trading: Similar to energy trading, the trade of emission certificates can also be organized in a distributed manner via a blockchain. As an alternative, certificates for renewable electricity could also be used. They could be purchased and used for the verifiable coverage of electricity consumption.

4 BLOCKCHAINS AND RENEWABLE ENERGIES

4.1 USE CASES OF BLOCKCHAINS

4.1.1 Asset transparency

With the progress of digitalization in almost all areas in private and business life, many new possibilities open for optimizing processes and make them smoother. In the entire world there is a trend towards replacing outdated paper registries and databases with modern, digitized systems. This makes information easier to find and distribute. Blockchain technology is an innovation that promises efficiency gains in B2B cooperation and in everyday transactions. It can facilitate the interaction between parties without them having to trust each other and, thanks to the immutability of its transaction history, offers a safe platform for information that is to be stored safely.

With its distributed structure, blockchain technology can also simplify the cooperation between several parties and make it safer and more transparent. Based on these characteristics, blockchains are very well suited for developing supply chains and equipping them for an increasingly global and flexible world.

Asset history

In economics there is the phenomenon of “markets for lemons”. The problem is often explained using the used car market since the information asymmetry between sellers and potential buyers is especially strong in this market. The seller can hide defects in the car or attributes with a negative impact on the price. The rational buyer is aware of this situation. He expects hidden defects and adjusts his willingness to pay accordingly. The result is that honest suppliers with well-preserved cars no longer have an incentive to sell their car in this market since they are unable to convince potential buyers credibly of the good condition of their car. This leads to an adverse selection of badly maintained used cars.

Something similar can also be observed in other markets with information problems. Due to asymmetric information, good quality assets are driven out of the market and only the “lemons” remain. This problem can be partially counteracted by reputation systems. A better approach would be to have reliable information about the actual condition and history of the asset. Blockchains can help accomplish just that. Blockchain technology allows manipulation-proof and chronological storage of data, which records the entire lifecycle of an asset on the blockchain. If the asset has to be repaired, for instance, the initial problem and the repair service is stored on the blockchain. In this manner, the entire history of the asset can be verified at the time of purchase, overcoming the information asymmetry. The improved information basis also alleviates the problem of adverse selection.

This use case of blockchains can bring greater trust into asset trading and thus prevent market failure. Of primary importance here is the gapless and manipulation-proof storage of data, which the blockchain can easily offer due to its structure. We should note, however, that for such an implementation of blockchain one has to ensure that the recorded data is correct. For this purpose, the entries into the blockchain must be made by authenticated actors such as regulatory and testing institutions. In the example of used cars, this could be the mechanics and state vehicle inspection agencies; however, this would again lead to a certain degree of monopolization and centralization.

Smart contracts could be used to assign unique ID numbers to assets on the blockchain. In this case one speaks of a digital representation or identity, which can be enriched with secure off-chain information. For instance, it would be possible to continually store the sensor data of a wind turbine on the blockchain to disclose the entire lifecycle to a potential buyer.

Supply chain management

In today's globalized and connected world, many products are composed of components from different origins. The supply chains of companies cover the entire globe and the complexity often leads to supply chains not being easily traceable. We hear again and again that respected companies use suppliers that employ child labor or that mine or grow raw materials under inhumane conditions. This often happens without the knowledge of the affected company since it cannot track its entire supply chain.

The involvement of many actors in the supply chain process and the still popular use of paper documentation can lead to additional significant inefficiency.[32] The cooperation between state regulatory and customs agencies, logistics companies, and the value-added chain results in reduced transparency and difficult cooperation. This can also lead to the fact that possible additional functions of the supply chain remain hidden and unused.[33]

Blockchain technology offers a series of solutions in the supply chain that can also be used in the energy sector. Thanks to the distributed structure, all actors in the ecosystem can be integrated into the value-added process and thus receive a more comprehensive overview of the supply chain. One can also store the entire production and transport process of an asset on the blockchain, where the immutability of the data allows secure traceability of the product.

A sample use case for blockchains in a supply chain is the guarantee of origin of an asset. In contrast to asset transparency, the entire value-added chain of an asset is stored on the blockchain, recording every single step (including time stamp) and thus creating a complete audit trail. From the reduction of contained resources to the purchase of an asset by the end customer, all processes are stored on the blockchain. This makes it possible to trace the entire production process of the asset and provides, for instance, the

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[32] (IBM 2017a)
[33] (Deloitte 2017)

possibility to verify what companies were involved in its production. In case of production errors, the origin of the defect can also be found quickly in this manner, corresponding products recalled, and the defective production segment repaired.[34]

Blockchain technology can also ensure efficiency gains within the supply chain by allowing a globally distributed, manipulation-proof system, in which work steps are digitized and transport paths are transparent. In addition, blockchains can make the communication between the involved actors simpler and safer.[35]

Blockchain technology brings many benefits in the area of transparency and improves the coordination and smooth operation within supply chains. While most companies that have currently studied this application are not from the energy industry, the concepts and implementations can be applied to this industry.

4.1.2 Asset management and operations

Many business processes have a high degree of inefficiency that is due to problems in communication and data exchange and a low level of automation. Media discontinuities and non-standardized interfaces lead to a high need for manual work steps and an enormous administrative effort. The fact that the energy industry is in a period of transition and is in constant exchange with many other sectors, including the financial industry, makes efficient implementation even more difficult.

The technology company IBM and the logistics corporation Maersk implemented a pilot project for the transport of tulips from Kenya to the Netherlands. All information and permits, such as export and import guidelines, were communicated via a blockchain. The blockchain made it possible to track the current location, as well as all completed and required next steps in the process – at any time.[36]

The Smart Containers Group[37] permits the safe transport of goods in containers that record certain values and works with LOGI CHAIN on a blockchain platform, which should enable a digitized, automated and distributed logistics process.

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[34] (Deloitte 2017)
[35] (IBM 2017a)
[36] (IBM 2017a)
[37] https://smartcontainers.ch/

Blockchains can help with these problems in many ways and contribute to efficiency increases both in the area of operations and asset management. Jointly managed databases make the exchange significantly easier. They create implicit standards and communication can be performed directly through the network of the blockchain. The immutability of the blockchain records the process steps in a transparent manner. Exception handling, i. e. processing special cases, becomes more efficient due to the availability of information. In addition, smart contracts can be used to automate many standardized processes to a great degree.

Asset management can be accomplished through tokenization of individual machines or entire plants. For instance, it would be possible to represent asset shares as a token and to manage and trade them as crypto-assets on a blockchain. This could create more liquid markets for previously illiquid assets. In addition, the tokenization also allows small shares of an asset, opening the markets to investors with small financial means.

Standardization and automation

The automation of processes requires that data can be exchanged and processed in a standardized form. Blockchain technology creates the foundation for possible standardization through jointly managed databases.

The basic problem in many computer-aided industries consists in the diversity of the used applications and data models. Interfaces are often very complex or do not exist at all, so that a part of the data has to be transferred and compared manually. In addition, the large number of historically grown applications in many cases leads to a chaotic architecture. There is a risk of dependencies, as well as high operating and maintenance costs.

However, if data is stored in a standardized form on a blockchain, an efficient data exchange is ensured. Of course, a blockchain by itself does not guarantee standardization of the data models; but a jointly managed database creates the ideal conditions for this. Instead of a number of interfaces, the data is exchanged via the native protocol of the blockchain. Ideally, maintenance and operating costs can be minimized, and a more agile environment created.

In addition, smart contracts allow simple processes to be performed directly on the blockchain. Currently, there is still a certain problem in scaling: today's versions of many consensus protocols are not capable of handling the large number of transactions that would be necessary for processing large amounts of data. But one can expect that the many scaling projects and/or alternative consensus protocols will result in solutions soon.

Contract management

Contract management using a blockchain can be split into two segments. Securing classical contracts and using smart contracts. Both segments are very interesting and have a wide range of applications in the energy sector.

Classic contracts can be secured in blockchains using a kind of digital finger print.[38] The so-called hash value of a pdf contract is calculated and stored on the blockchain. The transaction with the hash value is signed cryptographically by both contractual parties. Should one party try to adjust the contract later, this would result in a deviating hash value. The attempted manipulation would be uncovered immediately by the blockchain and all necessary evidence stored on the blockchain. The time stamp of the transaction and cryptographic references would even permit securing different versions of a contract.[39]

Using smart contracts, agreements can be concluded directly on the blockchain. They can be used to record an agreement but, even more importantly, they can also implement it automatically. The blockchain guarantees the execution according to a well-defined agreement. This is an enormous innovation as ensuring contract execution means that neither trust between the contractual parties nor an intermediary is required. Such smart contract scripts usually correspond to simple “if” clauses; i.e. for instance, a certain transaction triggers a certain event on the blockchain. States that can be read directly on the blockchain can be integrated into the contracts without any problem. So-called “oracles” are used for exogenous events, i.e. for evaluating states that are not stored on the blockchain. They are suppliers of data that are needed to execute the smart contract. In order to avoid dependencies and receive the most reliable data possible, the data points are usually provided by a number of such oracles. Smart contracts can thus solve a variety of the problems of classical contract management.

The Swiss company Proxeus[40] makes the creation of flexible document workflows possible. Documents can be secured on a blockchain and their existence and authenticity used as a decision variable for business processes.

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[38] https://poex.io/

[39] (Factom 2014)

[40] https://proxeus.com/en/

Insurance and hedging

Smart contracts can generate more than just simple contracts. The possibilities are clearly more versatile, so that complex contract constructs or even entire organizational structures can be represented and automated in smart contracts. One such possibility in the energy sector is the collateralization and insurance of assets and claims.

In order to insure damage events or loss of income due to price fluctuations, a counterparty is always needed, meaning a person or organization that is willing to assume the risk for a fee. Due to the counterparty risk, such contracts are usually only concluded with insurance companies. The risk of payment inability in case of damage would be too great if the risk were insured with a private person or a company without the corresponding reputation. This exclusivity in insuring risks results in economic cluster risks as well as expenses for infrastructure, administration, and refinancing. In addition, the trust problem limits participation in the market and makes it impossible for a great number of potential investors to accept parts of a risk.

Insurance based on a smart contract counteracts many of these problems. Smart contract generate trust based on the underlying blockchain and collateral stored in the smart contract itself. An intermediary is no longer needed and potential investors can themselves accept small parts of a risk and earn premiums. This results in greater diversity on the demand side, which makes laborious refinancing obsolete and the market more competitive.

However, insurances based on smart contracts also have a few limitations. For instance, an individual loss assessment is very difficult to automate. Instead, so-called parametric insurance constructs are often used, which couple payments not to an event of actual damage but rather to objectively observable data, such as average wind strength, precipitation level, or any earthquakes in a certain area. A clever combination of such objectively observable criteria can be used as a proxy and as a basis for deciding whether a compensation should be paid out.

Tokenization of assets

Infrastructure assets such as renewable energy plants can be represented, managed, and traded on a blockchain using tokens. In general, this so-called tokenization is based on the ERC-20 or ERC-223 token standard via the Ethereum blockchain. The respective issuer creates new tokens via a smart contract and links these tokens to a payment promise. It guarantees the current owner’s entitlement to the corresponding promised asset. Of course, such promises depend on the reputation and credibility of the issuer. However, if an asset is represented by a token it can be traded much more efficiently. Such asset tokens become especially interesting when linked with the other applications of a blockchain. For instance, tokenized assets can be used in a smart contract or the entire history of the asset linked to the token (see 4.1.1). We distinguish fungible and non-fungible assets in tokenization. Fungible assets are homogeneous and can be replaced by any other asset of the same type. Non-fungible assets are unique and must be treated as unique. The latter are usually represented by the ERC-721 token standard.[41]

In addition to claims to entire objects, e.g. an individual battery or solar panel, it is also possible to represent fund shares. This results in a certain degree of diversification, at the same time retaining the process efficiency gains of tokenization.

4.1.3 Energy trading

Chapter 2 described in detail how renewable energies are produced and traded today and discussed a few problems that accompany the upswing of renewables. For instance, in many places, despite electricity market liberalization, small providers are unable to participate directly in a market since it is only accessible to major providers and consumers. Instead they receive a fixed feed-in remuneration per kWh. A majority of the electricity is also produced in central power plants and has to be transported over long distances to the end consumers. This results in tremendous transmission losses.

Blockchain technology stands out in particular due to its property of being a distributed system. In combination with the often-distributed consensus-finding, it is possible to create systems that work without intermediaries. It is exactly this basic property of blockchains that can be applied to energy trading. Similar to cryptocurrencies, the blockchain permits the actors in electricity trading to trade directly with each other. Second-generation blockchains, like Ethereum, can even implement market mechanisms in the form of smart contracts. These make it possible to automate more complex processes, such as a double auction for the iterative determination of the market price. The high availability of blockchains also permits the realization of quasi-real-time markets that can profit from fast transaction confirmation.

Electric vehicle charging can also benefit from blockchain technology and the absence of intermediaries. In the future, owners of an electric vehicle can charge their vehicle at any outlet registered on a blockchain, without needing to conclude a contract with the local energy provider in advance or having to pay high transaction costs. This also addresses the problem of the few available charging stations for electric vehicles, setting another milestone for a future with green mobility.

Retail and settlement

In contact between energy suppliers and customers, for instance when settling electricity costs, blockchains can achieve efficiency gains. The regular settlement of the electricity costs of customers can be

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[41] (Nash 2017)

automated relatively easily with a blockchain. For this purpose, a smart meter records electricity consumption every, say, 15 minutes and automatically writes it on a blockchain. At the same time, the costs are deducted from the personal (cryptocurrency) wallet of the house owner. In particular when so-called stable coins[42] are used to counteract the volatility problem and the resulting exchange rate risk, this type of settlement would represent a valid option.

The scalability debate triggered by capacity bottlenecks of the two major public blockchains has again moved the focus of the blockchain community on the topic of state channels, since blockchain state channels promise a solution to the scalability problem. State channels are used to avoid having to process consecutive transactions individually via the blockchain. Instead, the partially signed transactions are exchanged bilaterally via a separate state channel. For settlement, the transactions can be added to the blockchain in aggregated form. Yet, each individual transaction is indirectly secured by the blockchain. This is due to the option that the already signed transaction could be published at any time. The concept makes micro-transactions and immediate confirmation possible. It also reduces transaction costs since only two blockchain transactions are necessary; one to open and one to close the state channel. State channels can be used when a transaction consists of consecutive individual transactions, such as for instance when consuming electricity. Energy utilities can introduce quasi-continuous payments of the electricity bill of their customers in order to almost completely neutralize the counterparty risk.

Further developments like the lightning network (in the case of Bitcoin) permit the interconnection of several state channels. Payments can be conducted through several state channels. This permits a person to send Bitcoin units to any participant of the lightning network without sender and recipient having to have a common state channel.

With this use of blockchain technology, the energy utilities remain in their current role. However, the automated payment processes and greater flexibility can result in efficiency gains and permit end consumers to access a quasi-real-time market through their energy supplier. This makes it possible for the price curve to reflect scarcity in the market short-term and helps the participants to optimize their consumption and adjust it to the current prices. This results in more efficient and competitive markets that are based on market prices instead of fixed feed-in remuneration.

The American start-up “Grid+”[43] has developed a smart agent that adjusts the feed-in of the household independently to the current electricity price of the energy utility (Grid+). In this manner, a household can bridge low price periods using energy storage and sell excess electricity to the grid when there is high demand and willingness to pay. The household thus contributes to smoothing supply fluctuations.

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[42] A crypto-asset with very low volatility in its buying power and/or w.r.t. the respective (stable) state currency
[43] https://gridplus.io/

In connection with this use case, we can ask the question as to what the future of energy utilities look like, since the tokenization described in Chapter 4.1.2 can also be applied to production plants and blockchain can create a direct connection between producing plant and consumers. The producing plant could also be operated by a prosumer. This case is covered in the following Chapter.

Peer-to-peer trade

Peer-to-peer trade is currently the most familiar and possibly most obvious use case of blockchain technology in the electricity market. Instead of merely establishing quasi-real-time markets with an energy utility, a blockchain could also permit the direct, local trade between prosumers and consumers. This removes the need for an intermediary. The blockchain serves as a platform on which participants trade within so-called microgrids with each other. Microgrids are local energy grids that, depending on design, can also operate autonomously, separate from the power grid (island mode). There are several initiatives that want to permit P2P trade on a larger scale as well.

There are several different ways to design trading in the market. The approaches differ mainly in how flexibly the suppliers can be selected and how the blockchain is used. The company Elblox[44] for instance offers a variation based on the use case “Retail and Settlement”. Consumers can select from which (green) power plants in the region they want to draw their supply on a blockchain-based platform. They can also compile their own electricity mix and acquire the electricity directly from the suppliers of their choice.

Many blockchain start-ups chose a different approach. Several companies are developing solutions that allow the market-based energy trade in microgrids. For this purpose, the smart meters of prosumers and consumers send forecast-based bids for volume and price for the next time interval to a smart contract on a blockchain. This smart contract acts as central order book and is set up to perform a double auction in regular intervals in which supply and demand are matched. The specification of volume and price determines the local market price for the next time interval. If an actor deviates from his bid for the time interval, his excess- or under-capacity is covered from the superordinate grid or another third instance (e. g. neighborhood battery) at local prices. In this manner, both prosumers and consumers receive access to a market in which the prices reflect local scarcity.[45]

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[44] https://www.elblox.org/ (The company will be introduced in more detail in Chapter 4.2.)

[45] (Mengelkamp, et al. 2018)

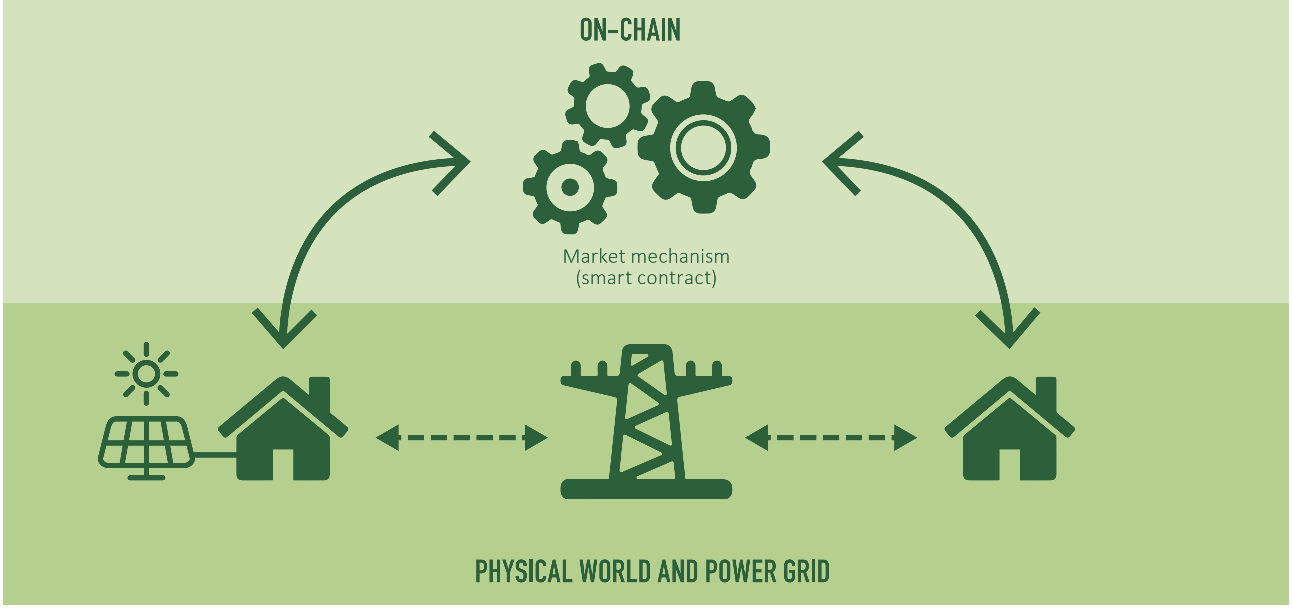

Figure 9: Own representation of a possible P2P trading system

In its design of a competition-based P2P market, the Australian company PowerLedger[46] strives to integrate grid operators. For this purpose, the company offers a platform on which energy utilities can temporarily install semi-closed markets. Over time, these should then increasingly transition to pure P2P trade. In this manner, the energy utilities have time to study blockchain technology and find their future role in this system.

Matching prosumers and consumers in local markets comes with several benefits. Access to a market in which the prices reflect local scarcity allows the actors to adjust their consumption behavior. For instance, using batteries prosumers can shift their feed-in to high-price periods and thus achieve greater profits than before. Having their own electricity storage, combined with market mechanisms, helps smooth out electricity fluctuations. This use case is studied in more detail in the sub-chapter “Ancillary services”.

Another great benefit that comes with trading in local electricity markets is more efficient electricity transmission. Today, electricity is usually transported from large central power plants to consumers over long distances. This results in great transmission losses (in Switzerland about 7 % of the entire country’s electricity consumption[47]). Trading electricity directly between neighbors and achieving a local balance between supply and demand reduces these transmission losses.

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[46] https://web.powerledger.io/
[47] (Federal Ministry for Energy 2016)

In addition to the dezentralized trade among prosumers and end consumers, there is a concept to implement wholesale electricity trade between energy companies via a blockchain. Here, too, blockchain technology is used to eliminate intermediaries and automation and standardization of the trade process result in efficiency gains.

Electric vehicle charging

For decades, there has been only little progress in EV charging. It was defined by barriers like short vehicle range and other technical deficits. However, the industry has developed very rapidly in the past few years. With its Model S, Tesla[48] proved that EV charging has made great progress and can now compete technically with fossil combustion engines in many areas. In addition, almost all major car manufacturers today have added at last one hybrid vehicle to their range. While there are signs that electric vehicle charging will become the rule rather than an exception in the near future, the industry still faces a few hurdles. One of these is the small number of charging stations for electric vehicles. Most charging stations require users to conclude a contract with a local electricity supplier ahead of time, which makes charging one’s vehicle in a foreign city almost impossible.[49] If a charging station accepts credit card payments, this incurs the usual fees, which increases the costs unnecessarily.

Blockchain technology offers the possibility of employing the P2P electricity trading introduced in the previous chapter for EV charging. Electric vehicles can thus be charged using private outlets without having to use an intermediary due to trust issues. The technical implementation is simple: an external outlet (ideally in combination with a parking spot) is linked to a smart contract and can be activated by it. If the owner of an electric vehicle wants to charge his vehicle, he connects it to the outlet and activates it by paying for the received electricity (with a cryptocurrency) using the employed blockchain. This process can be designed in such a way that micro-transactions are continually signed via a state channel and are thus paid in quasi-real-time, almost completely eliminating the counterparty risk for the received electricity. This ensures that the vehicle owner receives all needed electricity without having to trust the charging station. If the person that is charging their vehicle stops paying, the flow of electricity also stops.

Using blockchain technology in electric vehicle charging thus helps potentially extend charging to every parking spot with an external outlet. It would even be possible for two parked vehicles to trade electricity. The whole use-case would address one of the greatest problems of electric vehicle charging. The possibility of vehicles charging P2P without any trust requirement bears enormous potential.

4.1.4 Grid operation

Monitoring and controlling power grids and thus the responsibilities of transmission and distribution grid operators is a much-discussed and promising use case for a top-down implementation of blockchain technology in the energy market. Many processes in this highly automated field can be made safer and more efficient with blockchains.

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[48] https://www.tesla.com/models

[49] (Blockchainfirst 2017)

One use case of blockchain is the networking of IoT devices for monitoring power plants and automated production sites. Only a blockchain can permit devices not only to communicate with each other but also exchange value units and secured information in a distributed context without creating central points of attack.

Recording measurement data is important for various ancillary services. Here, blockchain technology could be used as a platform for data traffic and for automation, where its distributed structure really comes to bear. Another potential use case also arises from the fact that it creates a market for so-called demand response. In this concept, production side does not address fluctuations in the power grid (expensive throttling and redispatch) but, instead, demand is changed.

Virtual power plants are one idea in the development of smart grids, virtually combining different renewable plants to achieve a more even flow of electricity. The high safety standards of blockchain technology and automation via smart contracts can contribute to a more efficient and safer system. Other benefits arise when the use cases from the “Energy trading” chapter are integrated into such a system.

We note for all three areas that many of the efficiency-increasing measures could also be achieved without a blockchain. Blockchains, in particular public blockchains with a widely-based consensus protocol, can only exploit the full potential if, in addition to information, values/virtual balances need to be transferred or states secured. Blockchains are not needed for pure information flow.

Monitoring and measurement

In a highly technological world in which processes are implemented at an ever increasing speed and more and more machines take on the responsibilities of people, the reliable and flexible monitoring of these automatic processes becomes a must. In the subchapter “Contract management” (4.1.2) we already discussed the possibility of using oracles to record and process exogenous events on a blockchain. This possibility also applies to recording measurements and monitoring infrastructure networks. The monitoring electronics serves as oracle and writes exogenous states onto a blockchain. There, they can then be sent, for instance, to a smart contract that automatically performs an action when predefined thresholds are met or missed. In this manner, so-called “Supervisory Control and Data Acquisition” (SCADA) systems can be installed on a blockchain.

Thanks to the emergence of the IoT, there are more and more possibilities of monitored machines and devices interacting and communicating with each other. This opens many new possibilities for monitoring systems and collecting measurements.

In the electricity market, monitoring the power grid plays a particularly important role. Power grid operators record the frequency and voltage at different locations in the grid in order to be able to react to fluctuations in the power grid. Smart contracts could be used to activate connected storage capacities automatically if the measured frequency deviates to far from the desired 50 Hertz.

Blockchain technology could serve as a platform for exchanging measurement data, where many of its inherent attributes come in extremely handy. In particular in the area of data integrity and authenticity, blockchain-based monitoring systems have a decisive advantage. There are no individual nodes that can decide the current state and have a system-relevant position. The asymmetric encryption of the communication between the individual nodes in the blockchain also implements a high standard for data encryption that prevents sensitive machine information from being read by third parties.

Ancillary service

As already explained in Chapter 2.1, the weather-dependency of renewable energies creates bottlenecks in the power grid more and more often. The grid operators are responsible for ensuring grid stability at all times. For this purpose, they interfere with electricity production by re-dispatching power plants and throttling renewable energy sources.

Thanks to milestones in the development of energy storage technologies (e.g. lithium-ion batteries or flywheel storage power plants), the electricity market increasingly uses distributed storage in different ways to increase profit.[50] Combined with a solar power system and battery storage, more and more households can autonomously cover their electricity needs for the whole day. Batteries are also increasingly used for services in power grid stabilization. They give grid operators the primary benefit of faster reaction times than would be possible with the previously used pumped-storage and gas power plants.[51]

With the emergence of the IoT, more and more devices enter our households that can interact with their environment and with each other. Using blockchain technology, these IoT devices could be used for grid-serving purposes by having them adjust their electricity consumption to current electricity prices. For instance, if there is a bottleneck in the power grid, demand can be decreased automatically by having a refrigerator or an air conditioner throttle their consumption or shutting down completely for a specific period of time (so called demand-response). If this process is organized competitively, it creates a completely new market for end customers, since they can earn money by managing their IoT devices to serve the grid.

As an alternative, battery storage could also be connected via a blockchain. It has the benefit that it can be used more flexibly than IoT devices, which usually have a different primary purpose.

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[50] (SUSI Partners 2016)

[51] (Ulbig, Borsche, and Andersson 2016)

At the end of 2017, the German transmission grid operator TenneT started a pilot project with the Dutch company Vandebron, in which the battery storage of electric vehicles connected to the power grid for charging was provided to serve the grid. In the case of an imbalance in the grid, the EV charging is throttled or even completely interrupted.

In this area, the blockchain can act as a platform over which the devices can communicate or even trade. Thanks to its distributed structure, they can also support widely spread and complex grids and permit the integration of the involved grid actors without reducing security. The reactive scripts made possible by smart contracts can also achieve a high degree of automation in ancillary service applications. The security of the system is an important factor since the data collected in the power grid is sensitive and could show third parties possible weaknesses in the grid.

Virtual power plants

As a logical consequence of the two use cases just mentioned, we will briefly discuss virtual power plants at this point. Due to their weather dependency, renewable energies create short-term supply fluctuations in the electricity market. Combining different power plants with different renewable energy technologies is supposed to achieve that the combined output of the virtual power plant remains constant (or at least fluctuates less). This requires automated coordination and monitoring of the connected power plants.

Blockchain technology with its smart contracts can help automate this process. The distributed structure can also help combine several virtual power plants with each other and coordinate them. In combination with the use cases from the “energy trading” area, many new marketing possibilities can also be developed. Blockchain technology thus helps virtual power plants achieve more flexibility and represents an alternative to central coordination.

4.1.5 Certificate trading

The use case “certificate trading” employs many of the already discussed applications of blockchains in combination. Emission certificate trading has many parallels to cryptocurrencies as well, as it uses the benefits of blockchains that are known from the use case of energy trading. For a certification system for renewable energies, the proof or origin mentioned in asset transparency plays an important role.

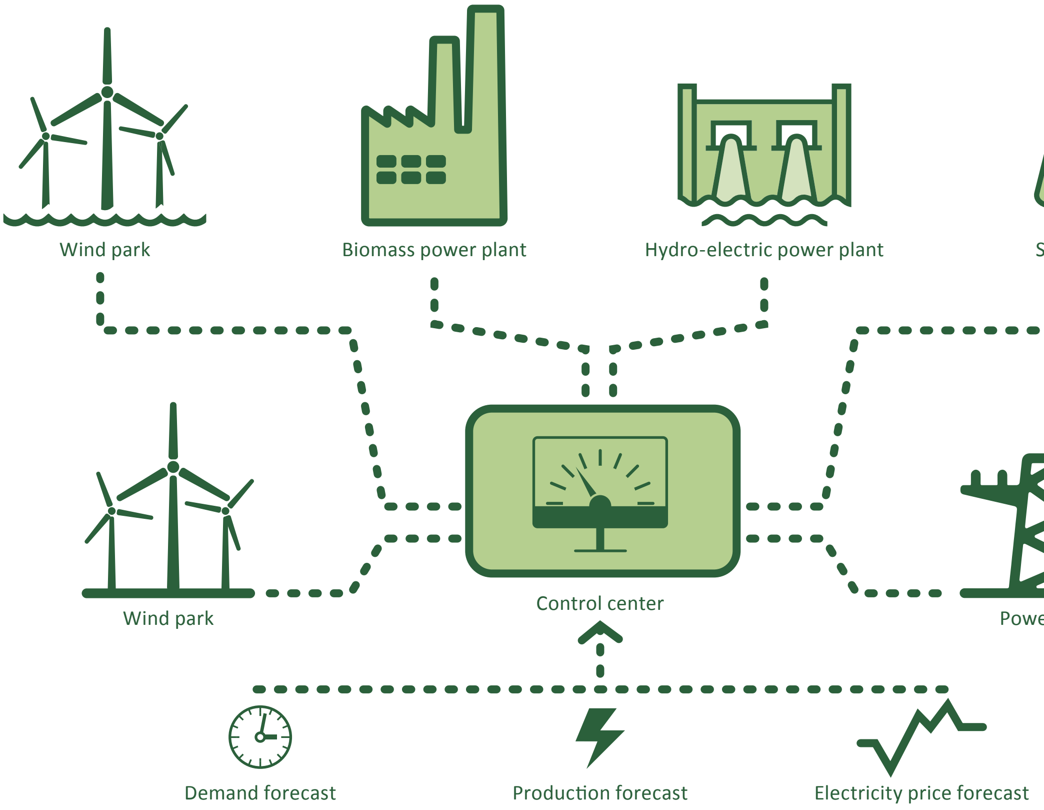

Figure 10: Graphic example of a virtual power plant[52]

Two areas are distinguished in the blockchain use case for emission certificates: in emission trading systems, the actors can acquire the right to a one-ton CO_2 equivalent of greenhouse gas emissions and trade it with each other. In the emission reduction system, saved emissions are traded. Both applications can benefit from the use of blockchain technology by implementing trades more flexible, safer and without a trust requirement.

In certification systems for renewable energies, a blockchain can ensure that the consumed electricity comes from renewable energy sources. For this purpose, the operators of a renewable power plant are allowed to issue a certificate, for instance per kWh. This certificate can be traded via the blockchain and guarantees consumers that one kWh of their electricity consumption comes from renewable energies.

Emission certificates

A promising means for achieving the goals of the Paris Climate Accord is the introduction of emission trading systems. For companies, the reduction of emissions of greenhouse gases comes with major investments into more efficient or new plants. Due to the “tragedy of the commons” known from economics, the individual companies have no incentive for making

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[52] Own representation based on (Statkraft Markets 2018)

expensive investments into "greener" technologies to prevent emissions. However, the emission of greenhouse gases does create negative externalities for the general public. The goal of the emission trading system is to assign a price to the emissions generated by companies by specifying a maximum total emission volume that is decreased every year. The total emissions are split into individual certificates, which can either be distributed between the companies or auctioned among them. The companies can also trade emission certificates that provide permission to emit one ton of CO_2-equivalent greenhouse gases among each other. This results in a reduction of emissions where this is the most cost-effective to realize. Companies that can reduce their emissions at a relatively low cost can then sell their free emission certificates to companies that would have to incur greater costs to reduce their emissions (e.g. a coal power plant). A prominent example for such an emission trading system is the EU ETS of the European Union.[53]

The emission trading system easily could be organized via a blockchain. Instead of emission certificates, one would for instance trade "emission coins". They would correspond exactly to their traditional predecessors, with the difference that they could be traded more flexibly and, on a peer-to-peer basis, through a blockchain without having to trust the negotiation partner or a centralized intermediary. This use case of blockchains thus opens all the benefits of cryptocurrencies to emission trading. Using measurement devices that compensate generated emissions directly on the blockchain can also achieve a high degree of automation and thus efficiency increases.

Thanks to the blockchain, the trade could also be opened to private persons, who for instance want to cover the emissions of a long-distance flight and would find lower market entry barriers by using the blockchain.

In addition to applications in emission trading systems, blockchains could analogously also be used for trading certified emission reduction units (CERs). The trading system of CERs can be traced back to the Kyoto Protocol from 1997 and permits the trade of saved emission volumes. They are certified by the UNFCCC.[54]

On March 20, 2017 IBM announced that it would design a trade platform for the just mentioned CER in cooperation with the Chinese Energy Blockchain Labs. The goal of the company is to develop the Chinese CER market through their platform.[55]

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[53] https://ec.europa.eu/clima/policies/ets_en
[54] (United Nations Climate Change)
[55] (IBM 2017b)

Certified renewable energies

Using certificates for renewable electricity, consumers can prove that their electricity consumption comes from renewable energy sources. The production of renewable power plants is measured, and the corresponding number of kWh is certified for their owners. The power plant owner can sell the certificates to electricity consumers, who can thus cover their consumption with green energy. Of course, acquiring such a certificate in no way guarantees that they in fact consume electrons from a green source as they are transmitted via a mixed grid. The acquisition and the usually associated higher price is created to provide an incentive to produce green electricity.

Blockchain technology could simplify and automate this process. Using smart meters, the electricity fed into the grid could be represented on the blockchain by tokens. The tokens are credited to the owner of the plant in the form of a coin in their wallet. These can be traded and guarantee the buyer that one kWh of his consumption comes from a renewable source.

The application of blockchains in this area is mainly based on proof-of-origin, which also plays an important role in asset transparency. The buyer of the certificate receives a guarantee that his electricity comes from a defined source corresponding to his preferences. The blockchain can deliver this proof. However, the assumption is made that the smart meter that records the flow of electricity and propagates it to the blockchain can be trusted. One can trust the certificates for renewable energies secured by the blockchain only to the extent that one trusts the used measurement devices. The regular calibration of the smart meters can largely help ensure the authenticity of the data. The certificate trade can thus be significantly simplified – analogously to cryptocurrencies. Operators of renewable power plants can thus, for instance, trade directly with consumers without the need for an intermediary.

4.2 MARKET OVERVIEW

As part of this study, the Center for Innovative Finance of the University Basel created a comprehensive market overview of blockchain projects in the electricity market. The compilation of the relevant companies was created with the help of the market overview by SolarPlaza[56], our own research, and notes from the SUSI Partners AG and split into the already presented use cases.

Independent companies and projects are listed in the column “Projects/initiatives”. If such a project arose as a cooperation of several companies, it is assigned to them by the same text color. Among the founders of projects, we distinguish companies that already existed before the emergence of blockchains (established corporates) and companies that were founded only after blockchain technology and which mainly deal with the development of blockchain solutions for different industries (blockchain start-ups). Start-ups that implemented a single project by the same name are listed under projects/initiatives and are identified

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[56] (Montemayor and Boersma 2018)

by dark green text. If an established company or blockchain start-up (in the right columns) is marked in dark green, then it did not create a specific project or is merely a partner in a project in this area. These companies were still included in the overview in order to identify as many actors in the market as possible. Not listed are energy utilities and other actors whose only involvement in the topic of blockchain is the acceptance of cryptocurrencies as payment form. Despite the versatility of some companies and projects, we attempted to list them in the most appropriate use case.

USE CASE	PROJECTS/INITIATIVES	ESTABLISHED BUSINESSES	BLOCKCHAIN START-UP
ASSET TRANSPARENCY			
Asset history	EnergyChain		EnLedger
Supply chain management			
ASSET MANAGEMENT & OPERATIONS			
Standardization & automation	Tobalaba, Interbit, Clearwatts	Rocky Mountain Institute, Consortium of large energy corporations	Gem, BTL GridSingularity
Insurance & hedging			
Contract management			
Tokenization	SolarDAO, Farad, EcoCoin, SwissRealCoin	Aerospace Beidou, NextNature	Virtue Fintech
ENERGY TRADING			
Retail & settlement	Bankymoon, Grid+, M-PAYG, 4New, TheSunExchange, Utilidex, Impact PPA, Drift	Microsoft Azure, Marubeni, Fortum	ConSensys
Peer-to-peer	Powerpeers, Scanergy, PowerLedger, Elblox, Conjoule, Sunchain, SunContract, Brooklyn Microgrid, Prosume, DAISEE, PowerToShare, Verv, WePower, Energy Bazar, Dajie, Oursolargrid, Pylon, Divvi, OmegaGrid, SolarBankers, Prosume, Jouliette, Co-Tricity, Interbit, NRG Coin, StromDAO	Innogy (RWE), Vattenfall, Vector, Energisme, Bouygues Immobilier, Axpo, Siemens, Green Tech Verte, Energy21 & Stedin, Green Running LTD, Alliander, Spectral Energy, Innovation Hub, BTL, Vrjie Universität Brüssel, Enervalis	Rotterdam Blocklab, LO3 Energy, ConSensys, EnergoLabs, Cellabz, LaMyne, ToBlockChain ShellPay, ConSensys
EV charging	Share&charge, Oxygen, Everty, Blockchainfirst, Car eWallet	Innogy (RWE), UBS, ZF Firedrichshafen, Wanxiang Blockchain Labs	Slock.it

Figure 11: Market overview part 1

A number of projects are active in the area of energy trading and the established companies display great interest in this use case. Here, the focus of the established companies and independent initiatives clearly lies on P2P trade. The use cases “asset transparency” and “asset management & operations” appear relatively neglected. However, we should note that these use cases are not limited to the electricity sector. We only considered those companies in this overview that are explicitly active in the electricity sector. The use cases “standardization & automation” and “tokenization” already have a few actors.

We would like to point out the two consortiums of large energy companies around the blockchains Tobalaba[57] and Enerchain[58]. The latter is listed under “Ancillary services” in this overview but is also active in the area “standardization & automation”.

USE CASE	PROJECTS/INITIATIVES	ESTABLISHED BUSINESSES	BLOCKCHAIN START-UP
GRID OPERATIONS			
Monitoring & measurement	Filament, Smappee	Tavrida Electric, Engie	Qiwi
Ancillary services	Electron, EnerChain	TenneT, Vandebron, Sonnen, Consortium of large energy utilities and grid operators	Ponton
Virtual power plants			
CERTIFICATE TRADING			
Emission certificates	Climatecoin, Energy Blockchain Labs Inc, CarbonX, Greeneum, Veridium, Poseidon, Mito	UN Climate Change Secretariat, IBM, EnVision Corp	Era2 Ventures, SolarCoin Foundation, DAO IPCI
Certified renewable energies	SolarCoin/ElectriCChain, Grünstromjetons, Volt Markets, Evolution Energy, Linq	General Electric, NASDAQ	
OTHERS			
Client services			
Incentive for energy efficiency	AdptEVE, Energimine, Energi Token	Freeelio	

Figure 12: Market overview part 2

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[57] https://energyweb.org/blockchain/ (access on May 7, 2018)
[58] https://enerchain.ponton.de/ (access on May 7, 2018)

A few companies are also settled in the use cases "grid operation" and "certificate trade". In particular in "certificate trade" we note that mainly start-ups are active in this area. "Grid operation" is mainly dominated by already established corporates since they already have the corresponding infrastructure and thus an interest in familiarizing themselves with new technologies.

4.3 CASE STUDIES

4.3.1 Elblox

Businesses:	Elblox
Partner:	Wuppertaler Stadtwerke
Objective:	Personalized electricity mix through local trading via a blockchain
Project start:	November 20, 2017
Use Case:	Energy trading
Blockchain:	Ethereum (private chain)

Elblox, a registered brand of the Axpo Group, began in 2015 with research on a blockchain-based trade platform. In this market place, end consumers can put together their own personal electricity mix and receive a proof-of-origin via the blockchain and an overview of their electricity mix in quasi-real-time. The Wuppertal Stadtwerke (WSW) are the first municipal energy utility to use the Elblox platform for their own regional market place for renewable energy (Tal.market). The project went live on November 20, 2017 and is already used by more than 150 WSW customers.

On the platform, customers can select the desired electricity suppliers from an overview and give them percentage weights to put together their personal electricity mix. In return, they receive information about the technology of the power plant (e.g. wind energy, solar, etc.), its location, and customer prices per kWh. The producers can determine their sales price in competition with other suppliers. If a customer selects a production plant at a certain price, it is guaranteed for one year. A price change thus only affects new customers. The electricity flow is recorded by smart meters. At the same time, an algorithm on the blockchain checks the electricity portfolios of the customers and distributes the produced volume of electricity over the customers correspondingly. The electricity cost is calculated on a quarter-hour basis. If a supplier cannot completely cover his customers due to weather conditions, the difference is compensated by the WSW. Suppliers who produce more than their customers consume are paid by WSW for the excess electricity at the usual prices.

For its project, Elblox currently uses a private instance of the Ethereum blockchain. However, they are currently looking at alternative blockchain protocols like Tendermint, IOTA, and Hyperledger Fabric. Among other things, the blockchain is used when the electricity mix of the consumers is represented by individual smart contracts. The algorithm for the settlement checks the smart contracts and, based on the contained information, determines the respective demand for the produced electricity of the suppliers. In the prototype of the platform, the payments were performed directly in the native cryptocurrency of Ethereum (however, not on the main network). For reasons of comfort and user-friendliness, the live version does not yet use it. Payments are thus still made in the traditional manner.

With the platform developed by Elblox, end consumers can put together their own electricity mix and thus receive specific, locally produced renewable energy. This also gives the consumers the possibility to support the energy transformation. Thanks to the blockchain, the electricity costs can be tracked almost in real-time. It also provides manipulation-proof and gapless storage of the production and consumption history. This means that for every kWh there is a proof-of-origin on the blockchain.

In the meantime, and according to Yves-Denis Schönenberger, the CEO of Elblox, the Axpo Group has decided to found the Elblox AG as a spin-off. The company is in an advanced state of the foundation process and is already in touch with other energy utilities which also plan to offer a product based on the Elblox platform.

Schönenberger mentions the guaranteed coverage of electricity consumption with renewable energy as a possible future development of the Elblox platform. In contrast to the usual certificates for renewable electricity, Elblox would use the blockchain to guarantee that at the time of consumption the corresponding volume of electricity from renewable sources is actually available in the grid.

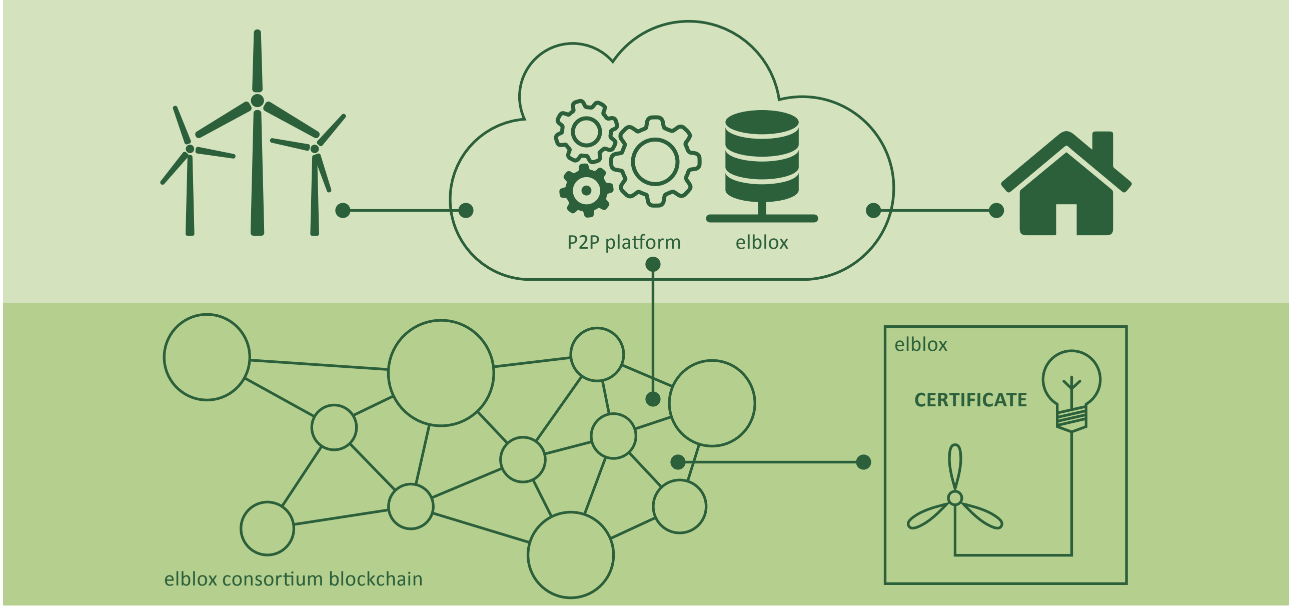
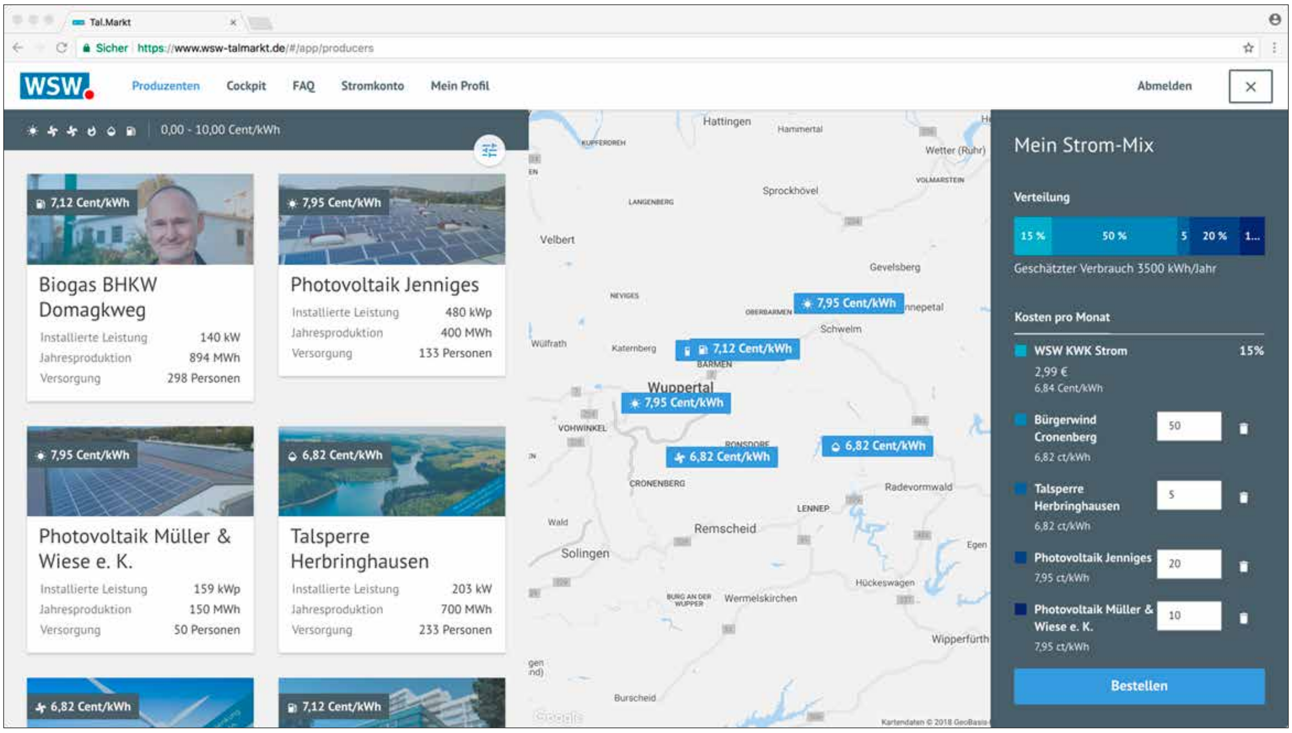


Figure 13: Structure of the Elblox platform

Consumers and producers interact directly with each other (P2P). The electricity flows are recorded in 15-minute intervals and immutably stored on the blockchain. The consumers receive a proof of origin for the received electricity. The consumers can select their suppliers online.



Biogas BHKW Domagkweg
Installierte Leistung 140 kW
Jahresproduktion 894 MWh
Versorgung 298 Personen

Photovoltaik Jenniges
Installierte Leistung 480 kWp
Jahresproduktion 400 MWh
Versorgung 133 Personen

Photovoltaik Müller & Wiese e. K.
Installierte Leistung 159 kWp
Jahresproduktion 150 MWh
Versorgung 50 Personen

Talsperre Herbringhausen
Installierte Leistung 203 kW
Jahresproduktion 700 MWh
Versorgung 233 Personen

Geschätzter Verbrauch 3500 kWh/Jahr

WSW KWK Strom 15%
2,99 €
6,84 Cent/kWh

Bürgerwind Cronenberg 50
6,82 ct/kWh

Talsperre Herbringhausen 5
6,82 ct/kWh

Photovoltaik Jenniges 20
7,95 ct/kWh

Photovoltaik Müller & Wiese e. K. 10
7,95 ct/kWh

Figure 14: User interface for customers

4.3.2 TenneT and sonnen

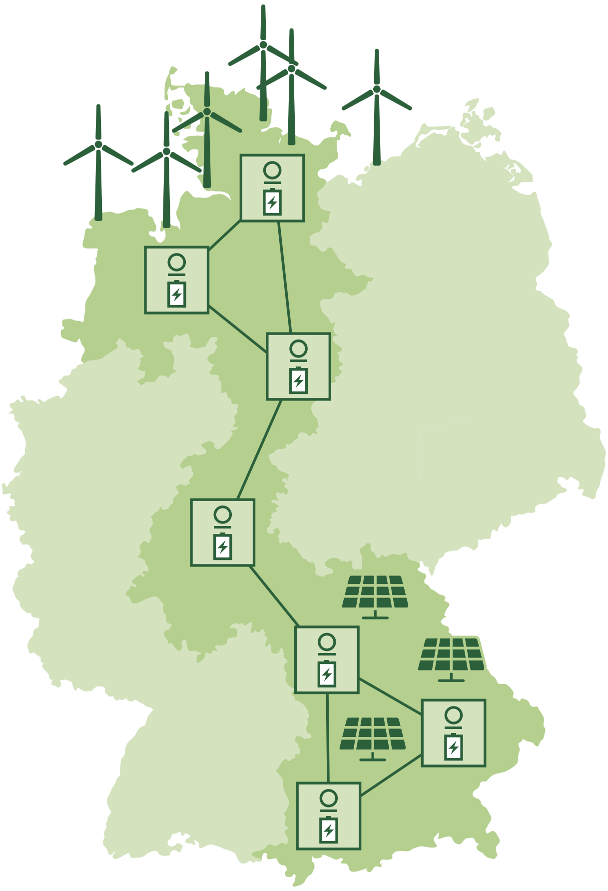
Businesses:	TenneT TSO GmbH & sonnen eServices GmbH
Objective:	Use of home storage batteries for use by grid.
Project start:	Thursday, November 2, 2017
Use Case:	Ancillary services
Blockchain:	Hyperledger Fabric

On November 2, 2017, TenneT (a Dutch-German transmission system operator) started a six-month pilot project for providing redispatch services. For this purpose, free capacities of private home storage batteries have been opened up for congestion management. sonnen GmbH, the world-leader in home storage batteries, was the first company to participate in the project through its subsidiary, sonnen eServices GmbH. TenneT uses blockchain technology to control the sonnen home storage units already connected via the SonnenCommunity platform to be used for grid purposes. Hyperledger Fabric is used for the project.

Until now, the home storage units were integrated into SonnenCommunity in order to trade excess electricity with each other. This enabled the energy community to appear as a unit towards the grid operators, since supply and demand within the community was balanced by external resources. The pilot project also connects these already connected home storage units with the TenneT station via a blockchain solution. sonnen provides available free flexibility to TenneT in aggregate form for a certain grid area at risk of a bottleneck. In case of a grid bottleneck, TenneT can call up the flexibility at a network node and monitor the behavior of the batteries via the blockchain solution. The home storage units are still combined into one unit and act like a virtual power plant. Thanks to the blockchain and the fast-reactive scripts of the battery storage, flexible capacity can be provided to the relevant network nodes within a fraction of a second.

The goal of the TenneT and sonnen project is to develop new possibilities for better reaction to short-term grid bottlenecks. The frequency of these bottlenecks has increased due to the upswing of renewable energies and has repeatedly led to solar or wind energy plants having to be throttled. Blockchain technology permits TenneT to use the home storage units distributed in the households for congestion management. This further simplifies the integration of renewable energies into today's system. Reducing congestion-related throttling of renewable energies also saves costs. This pilot project gives the owner of home storage units the possibility to generate additional income with their storage capacity.

Building on this pilot project, home storage units could be networked directly via a blockchain in the future and be available to TenneT even more flexibly. This would also allow the use of the batteries for additional ancillary services, like for instance frequency regulation. TenneT is currently testing this use case cooperation with the energy utility Vandebron in the Netherlands. In this second pilot project, electric vehicles are used via a blockchain for frequency regulation in the regulation zone of TenneT.



"It is our goal to make batteries available for grid purposes and thus integrate renewable energies optimally into the market and the system"[59]

-Axel Kießling-

(Digital Transformation Germany – TenneT TSO)

← Figure 15: Structure of the project

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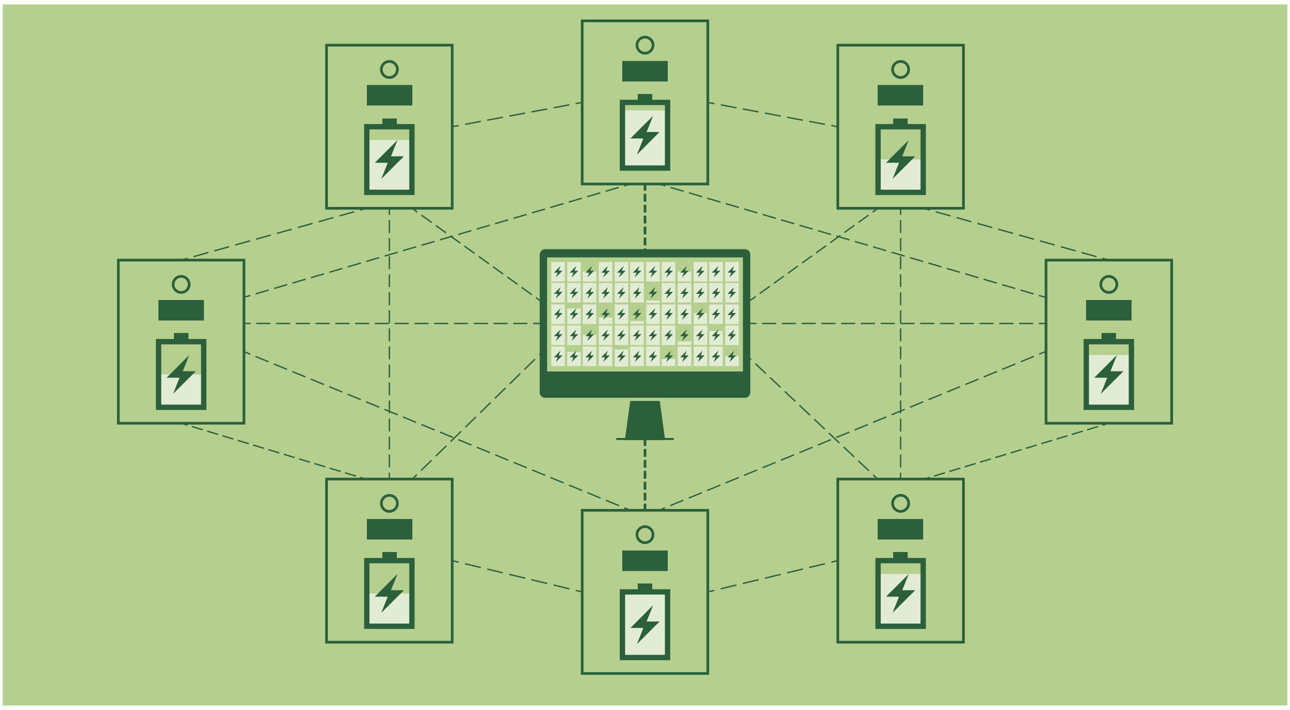
[59] (TenneT 2017)



In the future, the energy storage units could be directly linked via a blockchain.

5 CONCLUSION AND OUTLOOK

The upswing of renewable energies changes the requirements for our power grids and energy market actors. Chapter 2 presented the challenges that renewable energies pose for grid stability. In addition, the liberalization of the power grids, which was supposed to break up the old monopolies, progresses very haltingly in many countries. One should also expect that rapidly growing electric vehicle charging will impact different parts of our infrastructure. These challenges demand a solution within a few years and show that it is not if, but how the electricity and energy sector will change and adapt to the new requirements.

This white paper provides an overview of the different use cases of blockchain technology in renewable energies. We showed that blockchains generate a variety of new solutions to the challenges in the electricity sector discussed in the beginning. Some of the solutions have a disruptive character and would result in deep changes in the respective area if established on a large scale. We believe that these use cases include in particular peer-to-peer electricity trading since, in this case, the intermediaries (the energy utilities) would no longer be needed, as entire neighborhoods could self-sufficiently supply themselves with electricity and trade it with each other. In addition, some of the use cases in the area of “asset management & operations” have the potential to change the business landscape and established processes significantly.

Most other applications of blockchains in the electricity market could also be used by today’s actors and could result in efficiency gains in already existing processes. The solutions in the two areas “asset transparency” and “grid operations” fall into this category. While companies are active in almost all presented fields of application and there already are many proofs-of-concept, blockchain technology itself (and its application to the electricity market) is only at the beginning of its development. Only the coming years will show which use cases really have a future. The current development of a myriad of projects, start-ups, and ICOs is very reminiscent of the events leading up to the dotcom bubble at the start of this millennium. In many cases, the need for a blockchain application is not critically assessed.

In addition to the uncertainty as to which use cases of blockchains will actually establish themselves in the energy sector, we would like to mention at this point that (in particular in the highly-regulated electricity sector) one should also consider the influence of the regulators. In order for blockchains to be used in the market, laws must be passed that consider this new technology and regulate its legally compliant potential uses.

However, blockchains provide promising and new solutions and will very likely play an important role in the energy industry and the electricity market of the future. This development can already be observed today. The market overview performed by the Center for Innovative Finance shows very clearly that actors in the energy industry have already shown great interest in the new technology. In particular “peer-to-peer trade” is pursued both by established companies and by start-ups. Up to now, certificate trading appears to be mainly developed by start-ups, which is surprising in an area that is usually organized by governments. As to be expected, in the areas of “asset management & operations” and “grid operation” most actors are established corporates. We would like to point out the two consortiums of energy utilities and energy corporations that cooperate in many areas through the joint use of a proprietary blockchain and thus develop new solutions together.

It is essential for investors and asset managers to study the possibilities of blockchains today. What does it mean if wind and solar farms or electricity storage units are managed on a blockchain? What efficiency gains are possible? How can the 100% transparency and immutability of collected production data be used in purchase due diligence or does one have to expect discounts on assets to be sold that are not managed on a blockchain? After the expiration of feed-in tariffs, can electricity be traded directly via blockchain?

Particularly in times of low interest, every asset manager has to think about where there is potential for yield increases in operative assets. The use of blockchains for asset management very likely represents such a potential. At the same time, a forward-looking investor must also consider possible disruptive changes in the electricity market and if necessary already initiate disinvestments today. On the other side, interesting investment opportunities with new, blockchain-based business models will open in the next few years.

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