L17-1 & L17-2 FEASIBILITY STUDY ON THE COORDINATING ROLE OF BLOCKCHAIN IN LOCAL MARKET DYNAMICS

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SPARCS

Deliverable administration

No & name	**L17-1 FEASIBILITY STUDY ON THE COORDINATING ROLE OF BLOCKCHAIN IN LOCAL MARKET DYNAMICS**				
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Author(s)	Julian Böhme				
Description of the related task and the deliverable. Extract from DoA	Subtask 4.3.2 Blockchain supported energy services (LSW, WSL, CEN) It will be demonstrated how blockchain technology helpsto tackle the core problem when it comesto energy distribution: the integration of millions of small scale distributed energy resources in an energy system that is currently not designed for having a large amount of individual market participants. Focus of the demonstration activity will therefore be on the conceptualization and application of a public blockchain for transactions between energy consumers, producers, service providers and grid system operators in a microgrid. The task includes: • Feasibility study on the coordinating role of blockchain in local market dynamics between generating plants and consumers and methods on how meter point operation and meter data management might be done more efficient and cost effective via blockchain (Action L17-1, LSW) • Developing new potential blockchain-based solutions to enable prosumers to sell their surplus electricity on a Peerto-Peer marketplace to con- and other prosumers (Action L17-2, LSW) • Demonstration of the integration and interactions of IoT devices e.g. distributed power production and storage backed by blockchain. (Action L17-3, LSW)				
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About SPARCS

Sustainable energy Positive & zero cARbon CommunitieS demonstrates and validates technically and socioeconomically viable and replicable, innovative solutions for rolling out smart, integrated positive energy systems for the transition to a citizen centred zero carbon & resource efficient economy. SPARCS facilitates the participation of buildings to the energy market enabling new services and a virtual power plant concept, creating VirtualPositiveEnergy communities as energy democratic playground (positive energy districts can exchange energy with energy entities located outside the district). Seven cities will demonstrate 100+ actions turning buildings, blocks, and districts into energy prosumers. Impacts span economic growth, improved quality of life, and environmental benefits towards the EC policy framework for climate and energy, the SET plan and UN Sustainable Development goals. SPARCS co-creation brings together citizens, companies, research organizations, city planning and decision making entities, transforming cities to carbon-free inclusive communities. Lighthouse cities Espoo (FI) and Leipzig (DE) implement large demonstrations. Fellow cities Reykjavik (IS), Maia (PT), Lviv (UA), Kifissia (EL) and Kladno (CZ) prepare replication with hands-on feasibility studies. SPARCS identifies bankable actions to accelerate market uptake, pioneers innovative, exploitable governance and business models boosting the transformation processes, joint procurement procedures and citizen engaging mechanisms in an overarching city planning instrument toward the bold City Vision 2050. SPARCS engages 30 partners from 8 EU Member States (FI, DE, PT, CY, EL, BE, CZ, IT) and 2 non-EU countries (UA, IS), representing key stakeholders within the value chain of urban challenges and smart, sustainable cities bringing together three distinct but also overlapping knowledge areas: (i) City Energy Systems, (ii) ICT and Interoperability, (iii) Business Innovation and Market Knowledge.

Partners

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

TABLE OF CONTENTS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 864242
Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 864242
Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

LIST OF FIGURES

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 864242
Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

LIST OF TABLES

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 864242
Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

LIST OF ABBREVIATIONS

%	Percent
€	Euro
§	Paragraph
bspw.	not applicable
bzw.	not applicable
ca.	not applicable
CO_2	Carbon Dioxide
i.e.	that is to say
dena	German Energy Agency
dt.	German
ibid.	in the same place
EC	Electronic Cash
EE	Renewable Energy
EEG	Renewable Energy Act
EEX	European Energy Exchange AG
EnWG	German Energy Act
EU	European Union
EU-DSGVO	European General Data Protection Regulation
EVU	Energy Supply Companies
EWF	Energy Web Foundation
GmbH	Limited Liability Company
i.d.R.	not applicable
kV	Kilovolt
kWh	Kilowatt Hour
kWp	Kilowatt Peak
LSW	Leipziger Stadtwerke GmbH
MaStRV	Market Master Data Register Ordinance
mbH	with limited liability
P2P	Peer-to-Peer
POA	Proof of Authority
POS	Proof of Stake
POW	Proof of Work

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

PV	Photovoltaic
SMGW	Smart Meter Gateway
SPARCS	Sustainable energy Positive & zero cARbon CommunitieS
StromNZV	Electricity Grid Access Ordinance
v.a.	not applicable
cf.	confer
e.g.	for example

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

EXECUTIVE SUMMARY

Motivated by global warming and the need to reduce CO2 emissions globally, the energy industry sector is facing major challenges. This industry also includes Leipziger Stadtwerke, which supplies the city of Leipzig with electricity, natural gas, district heating and other energy services.

As part of the five-year European funding program SPARCS (**S**ustainable Energy **P**ositive & Zero C**ar**bon **C**ommunitie**s**), a study was conducted to determine the extent to which blockchain technology can contribute to the goal of increasing the use of renewable energy while reducing CO2 emissions. In any event, it can be said that the technology has a large number of applications in the energy industry and will represent one of the forward-looking technologies of the 21st century. Development within the framework of SPARCS, however, is not recommended, since the project risks are too great due to the lack of evidence from comparable projects on the German market and a high investment risk, coupled with legal and bureaucratic obstacles. One conceivable application would be future Smart Cities that collectively participate in the energy transition by guaranteeing the efficient use of renewable electricity.

The blockchain technology is a new and therefore not yet fully researched technology, which owes its popularity in particular to the crypto-currency Bitcoin. Essentially, it is a distributed database that is publicly managed and operated, with information stored in encrypted form on all participating computers (nodes). The blocks are comparable to data records that are encrypted by a so-called hash value. A blockchain is therefore a chain of several blocks sorted chronologically by the hash values. What's more, when a new block is added, all the information from the previous block is stored, making falsification impossible and providing near-absolute security. Through distributed storage, more than 50% of the computers involved would have to be hacked in order to manipulate the existing blocks.

The way a blockchain works can be understood by means of five sequential processes. In the first step, a transaction must be initiated by a network participant. In the second step, the transaction is transferred to the network and distributed. After that, the transaction is checked for validity by the nodes and validated using consensus building. In the next step, all valid requests are encoded and linked to the blockchain (via the hash value). In the final step, the transaction is completed by attaching the block to the existing chain and by the nodes storing a copy of the new, expanded blockchain. Smart contracts are used as the contractual basis for this. These are contracts based on software, in which the various contract details are stored in the same software. Based on if-then decisions, automatic processes such as pay-outs are set in motion, so that a high degree of automation is achieved.

Blockchain validation, i.e., checking the validity of individual transactions within the network without intermediaries (such as a bank directly for card payments or indirectly via cash withdrawals), differs in terms of the consensus mechanisms. Since all nodes in the network are interconnected, they must also follow the same rules and require uniformity in order to confirm that a transaction is valid. The selection of the validation method is based in particular on the trust that the network participants have in one another. In the case of public blockchains, the proof of work (validation via computing power, e.g. Bitcoin) is normally used, whereas in the case of private or consortium blockchains the proof of stake (trust of the stakeholders involved in the blockchain, e.g. stakeholders such as investors) or proof of

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

authority (central validation authority in which the remaining blockchain participants trust) approach chosen.

Based on a study by the German Energy Agency, some use cases relevant to the energy sector were developed in connection with blockchain technology. In addition to the fundamentally interesting and innovative topics such as asset and data management or market communication, SPARCS primarily focuses on over-the-counter electricity trading, so-called peer-2-peer electricity trading (direct marketing, "trade among like-minded people"). Along with the change in power generation from central to decentralized generation systems, a conversion of the power distribution network will also be necessary - this is referred to as so-called micro-grids. Successful examples of such micro-grids can be found, for example, in New York (USA), where a joint pilot project for electricity trading between local neighbours was initiated by the company LO3 Energy in the borough of Brooklyn. Households with their own electricity generation using solar panels can sell surplus electricity, or purchase electricity from neighbours if they have a surplus. At the same time, the households are still connected to the main grid to ensure the supply of energy even in times of low yield. New solutions are required for all energy management processes, since this type of trading platform can do without traditional energy supply companies.

An aspirational business model based on blockchain transactions is completely redefining the role of power supply companies. Instead of generating and marketing the electricity themselves, they take on the crucial intermediary function, provide physical and digital infrastructure, ensure efficient supply and act as a point of contact for consumers. Electricity is still transmitted via the distribution grid operators. In contrast to conventional electricity trading, blockchain-based electricity trading will involve the future supply of electricity directly from the generator to the consumer, meaning that not only will electricity suppliers have to redefine their role, but the electricity exchange will also become obsolete. This results in the following business model with the corresponding stakeholders: a platform operator ensures the efficient operation of the technology and is remunerated for this service by the platform user (e.g. the Leipziger Stadtwerke). Both producers and end users act as data suppliers, making their data available in return for platform use. Finally, data users can access the platform's transaction data with read rights in order to manage the portfolio, make forecasts or plan investments.

Therefore, a consortial blockchain based on proof of authority is recommended for this configuration, whereby the participating stakeholders are validated by a consortium, a task that would be assigned to the Leipziger Stadtwerke. The main advantage is based on specialization in the highly regulated energy market, which enables greater handling speed and the ability to adjust to changes in the legal landscape. In addition, the transaction speed is faster than in private networks, which is a significant criterion for high data volume in short intervals (e.g. delivery of electricity generated by a photovoltaic system every minute).

This concept however, which is very promising in theory, faces various obstacles. In addition to regulatory and bureaucratic hurdles, in particular the classification of prosumers (private electricity producers) as energy suppliers and the associated obligations that make it unlikely that producers will enter the market, the technical equipment of existing plants, cities, grids and homes is not suitable for the efficient deployment of the technology. Significant modifications and upgrades would be required to make peer-2-peer trading via blockchain feasible. A new product development within the framework of a smart city is a conceivable

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

option to determine market acceptance and test the maturity of blockchain technology in the energy sector.

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1. INTRODUCTION

Energy transition is the driving force behind a future in which climate and ecological systems can continue to exist without radical changes. A change is taking place, the energy supply is shifting from conventional large power plants to decentralized generation units with strong distribution throughout the country. At the same time, another transformation is taking place in society and industry that is also having a lasting impact on our lives: digitization. This is resulting in the continuous shift toward a networked and automated life with applications in every conceivable area. Since the two phenomena, energy transition and digitization are happening simultaneously, it is only natural that we look for solutions to problems that combine both. The ongoing digitization of the energy sector is of particular importance here. A key element of digitization is the reliable and secure handling of data. Until now, conventional databases with their centralized storage and management approach were considered the simplest and most reliable method. This centralization offers some advantages, but also comes with a few risks as well. Reliability, questionable authenticity, and internal and external attacks undermine the integrity of the data. Questions relating to the credibility of the data can also raise problems. Advances and developments in information technology and the Internet have produced many innovations in recent decades that have had a lasting impact on our lives. Examples include social media platforms, the availability of online shopping, streaming offers, and digital currencies, which have always attracted attention in a variety of settings in recent months and years. These open up a whole new avenue for digital payments. Conducting transactions with money but without the influence or control of a central authority, usually in the form of a bank, via a distributed computer network was a radical method of testing the established structures.

The digital currency "Bitcoin," which was the first of its kind, enjoys the greatest popularity. A blockchain is the basis for this system, which is often mistakenly placed in one and the same category. While Bitcoin is merely an example of a specific application, blockchain represents the technology that provides the basis for the application. Digital currencies are just one example of applications that can be implemented using blockchain. The potential of the technology is enormous and the areas of application, in addition to digital currencies, are extremely diverse in theory. A large number of experts are certain that many areas of society can benefit from new innovative blockchain solutions. The applications rely on distributed networks and cryptography and promise transparency, consistency, and security against manipulation. Furthermore, many intermediaries will become obsolete as they are replaced by software solutions.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

1.1 Stadtwerke Leipzig

Since this feasibility study was written in cooperation with the Leipziger Stadtwerke GmbH (LSW) to determine whether they could benefit from the use of blockchain technology, the next part of the analysis will provide a brief introduction of the company, as well as the research project for which the technology was studied as part of this analysis.

Founded in 1992, the **Leipziger Stadtwerke GmbH** is the municipal energy supplier for the city of Leipzig.[1] It provides the city with electricity, natural gas, district heating and other energy services. District heating in particular has played an important role in the company's history as a supplier. Together with Leipziger Verkehrsbetriebe GmbH and Kommunale Wasserwerke Leipzig GmbH, the Stadtwerke is part of the Leipziger Versorgungs- und Verkehrsgesellschaft mbH, which was founded in 1997 and is a wholly owned subsidiary of the City of Leipzig.[2]

The organizational structure of Stadtwerke Leipzig GmbH is divided into two organizational systems. A distinction is made between the classic and the flexible organizational structure, which is intended to achieve a more efficient implementation of goals and adherence to the strategic objectives.[3] These include, but are not limited to, the following items:

- Ensuring security of energy supply with respect to the media of heat, gas, and electricity
- "Transformation of the heating market with the focus on implementing the adopted generation concept in the coming years"[4]
- "Digitization of customer contacts across all channels and segments as well as automation of process flows and interfaces to the customer."[5]

The Stadtwerke currently employs over 650 staff and trainees to implement and further develop these strategic approaches so that the consolidation and expansion of its market share in central Germany can be reinforced and increased in the future.[6] The value-added chain also provides a basis

[1] Cf. Stadtwerke Leipzig GmbH: The Leipzig Group https://www.l.de/gruppe/das-sind-wir/leipziger-gruppe (09.09.2021)

[2] Cf. ibid. (09.09.2021)

[3] Cf. Intranet Leipziger Stadtwerke https://mega.l.de/lsw/pages/4ec44f0251a344c8.htm (10.09.2021)

[4] Stadtwerke Leipzig: Annual Report 2020 https://www.l.de/gruppe/das-sind-wir/kennzahlen-und-berichte, p. 6 (10.09.2021)

[5] ibid.

[6] Cf. ibid, page 2

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

for the implementation, starting with energy production followed by energy trading and energy distribution. The market requirements, which are considered to be internal goals, are managed by the market control department, where they are examined, coordinated, and implemented.

Innovative product and service ideas are analyzed, defined, and evaluated in detail on the basis of a four-stage process from the concept up to implementation.

SPARCS (=**S**ustainable energy **P**ositive & zero c**AR**bon **C**ommunitie**S**) is a five-year European funding program in which projects are carried out in seven European cities, including Leipzig. In total, there are approx. 100 individual projects that are supervised and examined within the framework of SPARCS. They are designed to generate innovations for the intelligent networking of individual buildings, blocks, or districts as energy systems.[7] SPARCS specific target is to reduce CO2 emissions by 64%, increase the use of renewable energies by 65% and achieve an overall energy savings of up to 53%. This involves interdisciplinary research in the fields of ICT infrastructure (information and communication technologies), storage technologies and intelligent building controls in order to implement sustainable and future-proof solutions. [8]

Three pilot project areas were created for the city of Leipzig as part of SPARCS:

1. Energy concept integration in Leipzig's Baumwollspinnerei: In this project, the integration of various renewable energies is being tested together with a decentralized combined heat and power plant. This will examine whether the neighborhood's internal grid can be balanced with the public energy grid. Work is also being carried out on the implementation of a bidirectional energy management system.[9]

2. The virtual power plant: This refers to the combination of decentralized energy producers, storage facilities and users to form virtual communities. It involves the targeted control of energy flows in order to use the available energy in the best possible way.[10]

[7] Cf. Project SPARCS https://www.leipzig.de/wirtschaft-und-wissenschaft/digitale-stadt/projekt-sparcs/ (05.08.2021)

[8] Cf. Lighthouse City Leipzig https://www.l.de/gruppe/wir-fuer-leipzig/investitionen/energie/sparcs (05.08.2021)

[9] Cf. Energy Management of the Future https://www.l.de/gruppe/wir-fuer-leipzig/investitionen/energie/sparcs (06.08.2021)

[10] Cf. Energy Efficiency through Smart IT Solutions https://www.l.de/gruppe/wir-fuer-leipzig/investitionen/energie/sparcs/virtuelles-kraftwerk (06.08.2021)

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

3. Smart solutions in Leipzig-West: The "Leipzig-West" pilot project combines residential buildings, solar thermal plants, and energy storage to form energy-efficient and low-CO2 energy systems.

In addition, work is being carried out on many individual projects of varying scope. This includes the "Leipzig Zero" project, which is developing ideas for reducing greenhouse gas emissions to zero by 2050. The goal is to create direct access to renewable energy plants and electricity contracts from the Stadtwerke Leipzig GmbH. This includes the core elements:

- Investment: customers can participate in the financing of renewable energy plants.
- Visualization: innovative products, such as the "Green socket," which visualizes a person's electricity consumption, are intended to create awareness for one's own energy use.
- Offsetting CO2 emissions: by means of purchasing regional and renewable electricity.

Various electricity contracts make it possible to address individual customer needs and, in addition, to promote the "Zero" emissions project through 2050. These include community contracts, for example, in which the customer purchases his electricity directly from a "Community project." For example, the stadium roof of a sports team could be equipped with solar panels. Ecomix contracts are also planned. These allow customers to cover their electricity needs with a mix of various regional eco-power plants that they put together themselves. The feasibility study for the SPARCS research project and LSW is designed to find a potential application for blockchain technology within this energy management process. Since direct electricity trading on a peer-to-peer (P2P) blockchain platform is the most promising use case for the SPARCS project, it will be explored in more detail.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

1.2 Structure of the analysis

The purpose of this feasibility study is to examine blockchain technology for areas of application in the energy sector with the goal of recommending a course of action to implement its use case at Stadtwerke Leipzig GmbH. To achieve this end, chapters two to four will first examine the theoretical principles of the technology in more detail, in order to provide a general knowledge base for blockchain. During this process, a distinction is made between a general definition, the functioning, and the classification of blockchains. The following two chapters focus on the strengths and weaknesses of the networks. The goal is to compare current limitations and concerns with the advantages and capabilities of the technology that have already been explored. Furthermore, a special analysis of the advantages and disadvantages of the different types of blockchains takes place, so that the blockchains that have already been classified can be evaluated in more detail in a subsequent step. Next, areas of application for the technology are determined and a framework for evaluating whether using a blockchain makes sense for any use case defined. Following the general areas of application, use cases specifically designed for the energy sector are examined with the rationale of providing an overview of what is theoretically possible for the subsequent creation of a specific blockchain application concept for SPARCS. After that, the most viable potential use case for SPARCS is analyzed and described in more detail, followed by a specific business model for implementing a blockchain solution for SPARCS. The conclusion then summarizes the potential and in an outlook, I give recommendation for action.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

2. BLOCKCHAIN DEFINITION

This chapter will look at the general definition of blockchain technology. The theoretical principles of the technology itself, network architectures and the process of a transaction within a blockchain will be explained.

Blockchain refers to a network technology in which a database is distributed and publicly managed and operated. The database is also called a distributed ledger. The word "blockchain" is composed of the English terms "block" and "chain," which is why it can be interpreted as a chain of blocks. The blocks represent information that is cryptographically encoded and assigned a hash value. The hash value is a type of digital fingerprint, which makes each block unique and impossible to falsify (cf. Chapter 3.1: hash values and hash references). It is precisely these hash values that are used to form a chronologically structured chain from individual blocks, since each block stores not only its own hash value but also that of the preceding block. When a new piece of information is fed into the system, a new block is generated and attached to the existing blockchain. A new block is not attached to the existing blockchain until every computer (node) in the network has verified it. With a blockchain, everyone controls everyone else.

The information is stored on all computers in the network. Each network participant maintains a complete copy of the entire blockchain on their computer. For this reason, all transactions can be viewed and traced by every network participant at any time. However, the participants in the blockchain do not have to give up their privacy: they operate behind self-created accounts that protect the identity of users by not disclosing private data. This can be compared to an account number.

For each new node, a full copy of the entire blockchain is transferred to all machines to ensure consistency of data. The information stored in a blockchain cannot be changed retroactively, because when information is changed, the associated hash value would change, which in turn would mean that every other hash of the entire blockchain would have to change, since the blocks have stored not only their own hash but also that of the previous block. Changing one block would cause changes in all subsequent blocks, thus breaking the chain apart.

The main difference between blockchains and traditional databases is the distribution of the network. Different network structures ensure that an ideal network form can be used for each area of application. Different network structures are examined in more detail below.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

2.1 Network architecture

Choosing the architecture of a network is of vital importance when implementing a system. It determines the structure and organization of various components and defines the relationship between the network participants. There are three main types of structure: centralized, decentralized and distributed.[11]

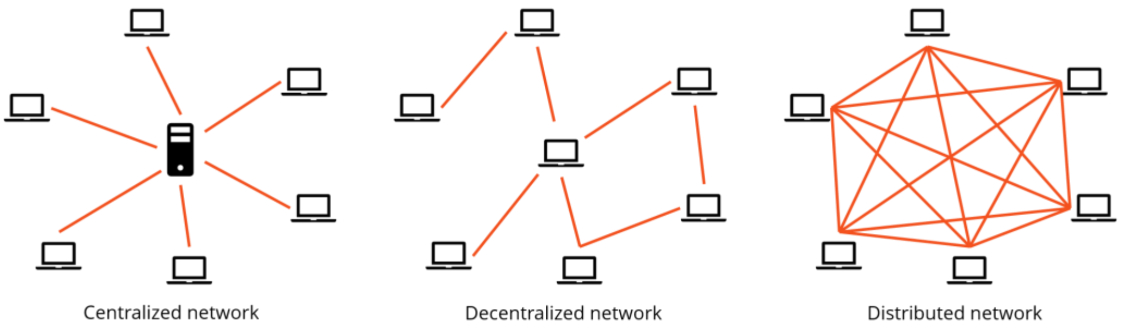

Figure 1: Network architecture (Source: Etherum-base (2021))

Centralized networks are structurally defined by the central authority involved in all communication within the network. Network participants are not directly connected to each other, but only to the central unit. This component regulates the communication of other network participants and controls the entire exchange. The central authority must be trusted by each network participant, otherwise the network cannot function. By contrast, coordination in decentralized networks is organized by the network participants themselves. There is no need for a central authority, which is why this structure is ideal for group interactions. A communication protocol is absolutely necessary for common exchanges since it ensures the integrity (correctness of data) of the system. Weaknesses of decentralized systems arise mainly when files from the network are processed simultaneously by several people and the system must decide which version is to be recognized as the current one. Furthermore, protection against manipulation must be ensured, especially when outside parties who do not trust each other interact. Since this has been relatively difficult to achieve, most of today's Internet was designed as a centralized system (servers as central authorities). If we now look at blockchain technology, a third structure emerges. This differs in structure in that it is neither centralized nor decentralized, but rather distributed. It consists of independent nodes that interact and are synchronized with each other. Each node stores the complete system status in a redundant manner so that

[11] Cf. Mika, Bartek; Goudz, Alexander: Blockchain Technology in the Energy Sector - Blockchain as a Driver of the Energy Transition. Berlin: Springer Vieweg Verlag, 2020. p. 39

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

it is not lost if individual nodes should fail.[12] Blockchain technology is suitable for a wide variety of transactions and always offers advantages when participants who do not trust each other want to build a manipulation-free and coherent network. Due to the permanent storage of each transaction on each network node, data cannot be changed or manipulated afterward.[13]

[12] Cf. ibid. p. 40

[13] Cf. What problem does the blockchain solve? http://haraldpoettinger.com/blockchain-datenstruktur-eintrag/ (18.07.2021)

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

2.2 Transaction sequence

A transaction using blockchain will be presented chronologically in the next section by using a specific example. [14]

Table 1: Transaction sequence

Process step	Process in the Blockchain	Example
1	Trading partners agree to a transaction on an online platform	Frank would like to transfer 50 € to his colleague Richard.
2	Together with transactions created in parallel by other trading partners, the respective transaction is transferred to the blockchain network and summarized in a block.	The transactions... A: "Frank pays Richard 50 €" B: "Carl pays Ronny 26 €" C: "Sandra pays 23.89 € to Franzi" ...are all merged into one block.
3	The information contained in the block is checked for accuracy by the network participants of the blockchain. If everything is permitted, the transactions are confirmed.	The data of all participants is checked: Do all trading partners have an account? Do the accounts have sufficient funds? Can all trading partners be unmistakably associated with their accounts?
4	The block is cryptographed (encoded) and assigned a unique hash value. In addition, the hash value of the previous block is referenced to ensure data integrity.	Frank and Richard's transaction, along with transactions B and C, are summarized under a unique name (hash value).
5	The authorized network participants (nodes) confirm the chronological attachment of the new block to all previous blocks of the blockchain, provided that the generated hash value matches the previous one. The new block is now part of the network and can be viewed by all participants.	If everything is technologically sound, the transaction is officially confirmed, and the money will be transferred from Frank to Richard.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

3. How Blockchain Technology Works

In the next part of the analysis, we will look more closely at the exact sequences of events in a blockchain network. Beginning with a brief review of how it works, the chapter then focuses on the processes of hash value formation, validation, and the completion of a transaction with the addition of a new block.

How a blockchain works can be understood using five consecutive processes (cf. Chapter 2.2: Flow of a transaction). In the first step, a transaction must be initiated by a network participant. In the second step, the transaction is transferred to the network and distributed. After that, the transaction is checked for validity by the nodes and validated using consensus building. In the next step, all valid requests are encoded and linked to the blockchain (via hash value). In the final step, the transaction is completed by attaching the block to the existing chain and the nodes storing a copy of the new, expanded blockchain.[15] For a more detailed understanding of how it works, individual process steps and building blocks of blockchain technology are analyzed and explained in more detail below.

3.1 Hash values and hash references

These terms are used mainly in the fields of mathematics and computer science. The English verb "to hash" means to "chop up" something. Hash functions allow large input values to be encoded and stored into smaller target values, called hash values.[16] These are clash resistant because there are no different input values that output the same target value. The same input values (input) result in the same hash values (output). This property makes hash values verifiable, since known encryption parameters generate a predictable value that always remains the same as long as the input does not change. If the input changes, regardless of the extent of the change, a completely new and unpredictable output is created.[17]

Another level of the cryptographic chain is hash references. These combine the hash value with the storage locations of the data records. Their task is to check whether the referenced data (the reference target) has changed since it was created. If there is a change in the reference target, this data will no longer be retrieved with the intended reference value. The hash reference is corrupted or invalid at this point. Hash references are used to check for changes in data that should remain unchanged. These

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[14] Cf. BDEW Bundesverband der Energie- und Wasserwirtschaft e.V, Berlin: "bdew Energie. Wasser, Leben." Study: BLOCKCHAIN IN THE ENERGY SECTOR, p. 12

[15] Cf. Neugebauer, Reimund: Digitization: Key Economic and Social Technology. Munich: Springer, 2018, p. 313

[16] Cf. Mika and Goudz 2020, p. 42

[17] Cf. ibid.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

are used in specific use cases of the blockchain to ensure that the data cannot be manipulated. They link data (blocks) within the blockchain since hash references are assigned to the data and each block also contains the hash value of the previous block. The formation of the hash values, as well as that of the corresponding references, represents a fundamental principle of the blockchain. Without it, such a network cannot function. Each blockchain begins with the first data element, which cannot receive a reference to a previous data record, since there is none before it. If new data is supplemented or added to the network, it will subsequently carry the hash reference, which points to the previous data record. This principle is maintained continuously.[18]

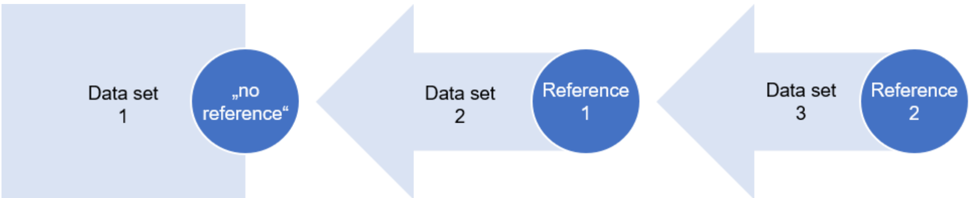

Figure 2: Hash references with corresponding data records
(Source: Internal representation)

The most recently created, i.e. the most recent reference enables access to all data in the chain, since the stored reference automatically saves all references up to the first data record in the opposite order of sequence in which they were added. The list header is always the reference that belongs to the data record that was last added. In the figure, this is represented by "Reference 2" because it belongs to the most recent record and refers to the previous record, which in turn refers to the first record.[19]

[18] Cf. Dreschner, Daniel: Blockchain Principles: An Introduction to the Basic Concepts in 25 Steps. Frechen: Mitp, 2017, p. 104-110

[19] Cf. ibid. S. 104f.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

3.2 Validation

Validation basically means to check something for its validity. The blockchain technology provides a network structure in which transactions can be carried out without a verifying intermediary. These are distributed P2P networks in which the validation of transactions cannot be handled by any centralized authority.[20] The validation must be carried out by the nodes of the respective blockchain; this is achieved by means of consensus building. A consensus mechanism is the basis for establishing agreement between the network participants.[27] The main concern here is to ensure that all protocol rules are adhered to so that every transaction can be processed reliably. Each blockchain is based on a consensus that determines the conditions under which a new block will be approved and appended. This creates an error-free and reliable linking of blocks in the network. A consensus is required for each newly initiated transaction.[27] The consensus approves the transaction. For every change and transaction in the blockchain, a consensus is required that ensures the permissibility of the change. Because there are different versions of the network, a fixed consensus mechanism cannot be used for every application. The selection of a method is based primarily on the trust among the network participants. The common methods will be analyzed and described in more detail below:[21]

- **Proof of Work** (POW)[22]: This concept is mainly used for well-known blockchains such as "Bitcoin" or "Etherum." The validating nodes provide proof of work by supplying a portion of their computational power to complete or solve certain tasks. This is called mining and entitles them to validation if they have reached the correct solution. In addition, they are paid for their work. Trust is present since miners would not benefit from false or manipulated data feeds that violate blockchain guidelines. They would have provided the computing power for free but not made any money for the work performed. A critical aspect of this method is the resources required to provide proof of work, i.e. to solve the puzzles or tasks. In order to be compensated for the work performed, the computers require a considerable amount of energy, which means that large blockchains quickly reach the energy demand of entire cities.

- **Proof of Stake** (POS)[23]: This validation method appeals to all those blockchain participants who attach great importance to the continuity of the network. It also applies primarily to

[20] Cf. Drescher 2017, p. 152

[21] Cf. Mika and Goudz 2020, p. 44 f.

[22] Cf. "bdew Energie. Wasser, Leben." Study: BLOCKCHAIN IN THE ENERGY SECTOR, p. 19

[23] Cf. ibid.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

participants who would lose part of their assets if the network were to be disconnected. Therefore, great importance is attached to the accuracy of each transaction. Since losing assets is not in the interest of investors, they can be trusted. This method is more resource-efficient because less computational effort is required to validate the blocks.

- **Proof of Authority** (POA)[24]: In this method, specific network participants are selected who have the central authority of validation. They are trusted by the rest of the blockchain participants because, for various reasons, they have no interest in disrupting the network.

In summary, trust in the POW validation process is generated by the work performed, in the POS process through the stakes held by the validators and in the POA mechanism by the specific selection of trustworthy people who have no interest in the failure of the blockchain.

3.3 New blocks

The core element of the technology is the expansion of the blockchain by adding more and more new blocks. Except for the first block in the chain, called the "Genesis" block, each subsequent block references the previous transaction using the hash values generated for each block. In addition to storing its own hash value, the previous hash value is also stored and compared, which means that the integrity of the entire chain can be checked. Changing a hash value would lead to problems in the entire blockchain, since the hash values would no longer correspond to their preceding values (cf. Chapter 3.1: Hash values and hash references). This protects against manipulation, since a complete copy of the entire blockchain is stored redundantly with each network participant.[25]

[24] Cf. ibid.

[25] Cf. Mika and Goudz 2020, p. 47 f.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

4. Classification of Blockchains

Blockchain technology offers a wide range of potential applications for a variety of interests. It is therefore important to classify the networks in order to organize the right solution for each use case. The following chapter divides blockchains into three different types.

Blockchain technology offers many different methods of implementation. There is no easy answer; depending on the application, the specific characteristics of the form of use may differ. The term "blockchain" basically refers only to the system of decentralized data management with cryptographic linking. They can be broken down further with regard to the right of use and the right of validation. Depending on the application, it must be determined which type of blockchain offers the most advantages. Sub-dividing based access rights is the simplest form of categorization. A basic distinction is made between "Public blockchains" (permissionless) and "Private blockchains" (permissioned). Since these two types still do not cover the full range of possible applications, so-called "Consortium blockchains" (shared permissions), which represent a hybrid solution, are also used.[26]

4.1 Public blockchains

The best-known blockchains, such as the Bitcoin blockchain used for digital currency exchange, operate "permissionless", i.e. they are publicly accessible. Therefore, anyone can participate in the blockchain. The POW functions primarily as a consensus mechanism (cf. Chapter 3.2: Validation).[27] They offer a very high level of security, since the large number of participants represents a major barrier against attempts to manipulate.[28] Getting started with public blockchains is also comparatively easy, since there is no need to build and operate your own network. This is countered by limitations in terms of operating speed due to unlimited access for participants. Furthermore, there may be difficulties in establishing a regulatory framework, for example, if there is discord among network participants concerning update issues. Public blockchains are not privately financed for a specific benefit. Transaction fees, which are paid by the participants, usually ensure that the network is properly maintained.[29]

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[26] Cf. ibid. p. 49f.

[27] Cf. ibid. p. 50

[28] Cf. "bdew Energie. Wasser, Leben." Study: BLOCKCHAIN IN THE ENERGY SECTOR, p. 20

[29] Cf. "bdew Energie. Wasser, Leben." Study: BLOCKCHAIN IN THE ENERGY SECTOR, p. 20f.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

4.2 Private blockchains

In contrast to public blockchains, which are accessible to everyone, private blockchains are only designed for selected target groups and private individuals. A central authority has the power to decide which participants are admitted to the network. This means that there is usually a high level of trust between the network participants, since they have been granted shared access by the operator. It also results in fast and efficient transactions. The POA consensus mechanism is primarily used here (cf. Chapter 3.2: Validation). Since the private blockchain network consists of a just a small number of selected participants, the risk of external manipulation must be considered, since only a relatively small number of nodes have to be attacked in order to manipulate the network. However, blockchains in private sectors have the ability to "cut themselves off" in fixed periodic cycles and start a new block. This can be useful, for example, for annual balance sheets when all transactions of a particular year have been completed and a new fiscal year begins. The previous year's blockchain, and with it all of the year's stored transactions, can be archived while a new blockchain with the same members begins a new cycle. Private blockchains are mostly beneficial for internal company processes where a large amount of internal data must be managed and stored in a short period of time.[30]

4.3 Consortium blockchains

This form represents a compromise between private and public blockchains. Although they are limited by a consortium with respect to the number of participants and approved applications, they provide a crucial level of security for users, since approval is not completely guaranteed with direct verification required instead. The consortium blockchain could strike the balance between total openness and strict limitations, ensuring that security and freedom are both present and indispensable. The decision-making power in this blockchain form is held by a consortium, which in principle neither works within a private environment nor works in the interest of the public.[31]

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[30] Cf. ibid.

[31] Cf. ibid.

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5. STRENGTHS OF BLOCKCHAIN TECHNOLOGY

This chapter describes the capabilities of the technology and provides a concise summary of its advantages and strengths. After first addressing the general strengths of the technology, the subsections deal with the respective benefits of the different types of blockchain.

Compared to conventional databases, the blockchain offers a wide range of added value for network participants. Every transaction is securely documented. It is stored on the computers of all network participants and cannot be changed afterward. The data stored is accurate, transparent, and consistent. Data security is comparatively high, since decentralized distribution virtually rules out the possibility of data being compromised. More than half of all network participants would be needed to carry out manipulation. The traceability of transactions is also ensured, since the complete history of the blockchain is maintained by each participant. Specific advantages are described and outlined once again below:[32]

- Disintermediation: The most common everyday example of this strength is the digital transfer of money. Whereas no intermediary is needed for analog monetary exchanges, since a physical banknote changes hands, which means that there can be no disagreement about the value and "authenticity" of the transaction after the fact, this is significantly more difficult with digital transactions, because no physical object is exchanged. In order for the exchange to work, a third party is required, or a bank in this specific example. The bank is trusted by all parties and can therefore fulfill its central mediation task. However, liability is not only assumed by third parties when exchanging money: digital processes also require intermediaries if the stakeholders do not know and/or trust each other. With the introduction of blockchain technology, unknown parties between whom there is no trust can now, for the first time, securely and directly execute digital transactions without the need for an intermediary. These are substituted by consensus mechanisms.[33] Trust is generated by all nodes in the network that check and confirm each transaction for accuracy. It is easy to explain how the system works by using the example of a digital money transfer. Instead of a bank checking the accuracy of the sender's and recipient's data and confirming that a transfer is allowed, as is the case with conventional transfers, each network node performs this task automatically. The system checks whether the sender and recipient actually exist, that each has an account (wallet), whether the desired amount can be transferred, and whether all rules for digital payment transactions are observed. If there are no objections to the transaction, the money is transferred, and the transaction is stored as information in the blockchain among all network participants.[34] In general, however, it should be considered that the substitution of intermediaries is only useful if there is no trust among the mediating authorities.[35]
- Data integrity: The structural design of a blockchain with cryptographic links of each block ensures a high level of data integrity. By connecting each individual block to its previous one using the calculated hash values, it is ensured that changing a block or an item of information implies changing all subsequent blocks, since changing a block, results in a new hash value being calculated, which in turn means that new hash references would have to be calculated

[32] Cf. Mika and Goudz 2020 p. 51-54

[33] Cf. "bdew Energie. Wasser, Leben." Study: BLOCKCHAIN IN THE ENERGY SECTOR, p. 23

[34] Cf. Mika and Goudz 2020, p. 52

[35] Cf. Ecktsein, Andreas; Liebetrau, Axel; Funk-Münchmeyer, Anja: Insurance & Innovation 2018: Ideas and Concepts for Success from the Experts in the Field. Karlsruhe: VVW, 2018, p. 70

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

for all subsequent blocks as well. The time and costs involved escalate as the size of the blockchain increases. This ensures that the transaction history is reliable and virtually unchangeable. The elimination of intermediaries, which otherwise guarantee data integrity, makes this feature extremely important.[36]

- Security: Along with the data integrity described above, which the blockchain technology offers, the blockchain can be classified as a secure and trustworthy storage medium for sensitive data with regard to the authenticity and integrity of data. The decentralization of data processing, as well as the redundant storage of transactions on each node in the network, offers the additional security advantage that no loss of data is inevitable in the event that individual network participants fail. Furthermore, there is no central server whose failure can lead to problems. Correspondingly, there is also no central point of vulnerability for hacker attacks; more than 50% of the network participants would have to be attacked simultaneously to validate or manipulate information.[37]
- Transparency: Blockchain technology is the embodiment of transparency, since every single transaction is verified and stored by network participants. This means that every change can be tracked with precision and also checked at a later point in time. At the same time, there is no need to sacrifice data protection, because the stakeholders operate behind pseudonyms, often a number or an identification code, similar to an account number. The prevailing level of transparency is essential for the intermediation-free verification of data and transactions; it creates a system in which foreign network participants can assume mutual control themselves. [38] [39]
- Automation: Blockchain technology offers the potential to transform a variety of manual tasks into digitized and automated processes and interactions.[40] The integration of smart-contracts in particular, which will be discussed in more detail later, offers a wide range of automation options. They also ensure greater contract security since subsequent changes to conditions or deviations in terms are practically impossible.[41]
- Cost reduction: This advantage results from strengths of the blockchain that have already been discussed. Automation and disintermediation help reduce ongoing costs for users.[42] Positive and sustainable economic benefits could be achieved using blockchain, especially in use cases with many transactions in which third parties receive high fees.[43]
- Anonymity: This point is especially important for blockchains used publicly. As already mentioned in the "Transparency" section, each network participant is represented by a cryptographically encoded sequence of numbers. Although the individual activities, accesses and transactions can be traced transparently, it is almost impossible to decipher the real identity of the blockchain participant.[44]

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[36] Cf. Mika and Goudz 2020, p. 52

[37] Cf. ibid. p. 52f.

[38] Cf. ibid. p. 53

[39] Cf. "bdew Energie. Wasser, Leben." Study: BLOCKCHAIN IN THE ENERGY SECTOR, p. 25

[40] Cf. Drescher 2017, p. 252

[41] Cf. Mika and Goudz 2020, p. 53

[42] Cf. Drescher 2017, p. 253

[43] Cf. Mika and Goudz 2020, p. 54

[44] Cf. ibid.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

5.1 Advantages of public blockchains

- Participation as an unknown in the network possible
- Anonymity is guaranteed (or pseudonymity)
- Unrestricted access for any interested party
- Waiving of central authorities for validation
- High level of security
- Opportunities for rapid development with a large number of participants[45]

5.2 Advantages of private blockchains

- Operators have control over access rights
- Operator can control the blockchain
- Comparatively high transaction speeds
- Scalability of blockchain size
- Lower resource requirements thanks to the POA consensus mechanism
- Regular data archiving and "Restart" of the blockchain possible
- No transaction fee required for participants
- Responsibilities for the operation and functionality of the network can be defined
- Operator can set rules for blockchain operation
- Transactions can be corrected in case of error[46]

5.3 Advantages of consortium blockchains

- Different transaction speeds between public and private blockchains
- Specialization in specific application areas (e.g. energy market) possible
- Operator has control over the rules for operating the blockchain[47]

[45] Cf. "bdew Energie. Wasser, Leben." Study: BLOCKCHAIN IN THE ENERGY SECTOR, p. 21f.

[46] Cf. ibid. p. 22

[47] Cf. ibid.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

6. Weaknesses of Blockchain Technology

Following the strengths of the technology, the weaknesses of the technology will now be discussed.

The functionality and structural design of blockchain technology not only offer advantages, but also some disadvantages and weaknesses in practical application. These vary in significance depending on the area of application. Specific weaknesses include:

- *Scalability*: The lack of scalability is one of the biggest weaknesses of this technology. Scalability, in the context of blockchain technology, is the ability of the network to handle growth. The lack of scalability often causes problems, especially with public blockchains, since they are still not mature enough to process large volumes of transactions.[48] With an increasing number of participants and rising transaction volumes, the system can be overloaded if too much information is fed in.[49]

- *Irreversibility:* One of the strengths of blockchain technology is undoubtedly data integrity, since it guarantees that data cannot be changed or manipulated retroactively. In some cases, however, this can also lead to problems, especially when erroneous transactions have been executed that can no longer be reversed.[50] This problem also affects smart-contracts, since incorrectly programmed contracts cannot be changed and corrected. Therefore, each transaction must be thoroughly thought through and checked.[51]

- *Data protection:* Blockchains offer a high level of transparency for all participants, which is essential for intermediary-free transaction processing. However, data protection suffers because every transaction, as well as the entire transaction history, is stored on all nodes. Furthermore, the previously explained irreversibility of the data is in legal conflict with, for example, the right of the data subject to correct or delete data and the "Right to be forgotten" regulated under Article 17 - EU-DSGVO.[52]

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[48] Cf. Mika and Goudz 2020, p. 54 f.

[49] Cf. Scalability: Blockchain can handle the daily volume of the stock market https://de.cointelegraph.com/news/scalability-study-dlt-can-support-daily-trading-volume-of-us-equity-market (19.07.2021)

[50] Cf. Trust and Transparency- Blockchain Technology as a Digital Trust Catalyst https://www.iit-berlin.de/iit-docs/e45b924f7133405ab3f53cb0fb70331f_2018_06_01_iit-perspektive_Nr_39.pdf, p. 11f. (15.08.2021)

[51] Cf. What are smart-contracts? Definition and Explanations https://blockchainwelt.de/smart-contracts-vertrag-blockchain/ (15.08.2021)

[52] Cf. Mika and Goudz 2020, p. 56

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

- *Legal framework:* Since blockchain technology makes interaction with intermediaries, who are often regulated by the state and subordinate to legal requirements, obsolete, there may be legal gray areas in various applications. Controlling a blockchain often proves to be virtually impossible. Therefore, the misuse of the technology to create a legal vacuum is conceivable.[53] This is already being practiced to some extent, since cryptocurrencies, which are based on blockchain technology, are the most commonly used means of payment for illegal activities on the Internet.[54] Because of the direct currency exchange without a bank, the persons behind the transaction cannot be easily identified. The transaction can be seen, but not who is on either end of the transaction. Establishing a legal framework is further complicated by the fact that blockchains can be used across national borders. Therefore, those involved in the transaction can be in different jurisdictions, which can also cause problems if there are deviations in the regulatory environment.[55]

6.1 Weaknesses of public blockchains

- The POW consensus mechanism is resource intensive
- A high number of participants with corresponding storage capacity is required
- Relatively low transaction speed
- No correction options for erroneous transactions
- No complete anonymity, since users operate behind pseudonyms to which all transactions made by them can be assigned
- From a legal point of view, there is no "Responsible person" who is liable for operation and functionality
- Dependence on own access data -> if this is lost, the entire wallet including contracts, assets, and certifications will be lost[56]

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[53] Cf. ibid. p. 56f.

[54] Cf. Bitcoin & Cybercrime: These Cryptocurrencies Dominate the Darknet https://www.digitalshadows.com/de/blog-and-research/bitcoin-und-cyberkriminalitaet/ (20.08.2021)

[55] Cf. Blockchain Technology - Framework for the Use of Blockchains https://www.bafin.de/DE/Aufsicht/FinTech/Blockchain/blockchain_node.html#doc9224766bodyText5 (20.08.2021)

[56] Cf. "bdew Energie. Wasser, Leben." Study: BLOCKCHAIN IN THE ENERGY SECTOR, p. 21f.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

6.2 Weaknesses of private blockchains

- Access restrictions, no public benefit
- Anonymity is often not guaranteed (depending on the specific arrangement)
- Reversibility of transactions undermines security and data consistency (depending on the specific arrangement)
- Less protection against attempts at manipulation
- Possible operator access fees[57]

6.3 Weaknesses of consortium blockchains

- Innovations and further developments must be approved by the consortium
- The network structure limits the flexibility of the potential applications
- Comparatively little protection against manipulation attempts
- Possible operator access fees[58]

[57] Cf. ibid. p. 22

[58] Cf. ibid. S. 22f.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

7. Blockchain Technology Areas of Application

This part of the analysis will provide an overview of the technology's areas of application. After briefly listing general areas of application, two specific examples of existing applications will then be provided. The chapter concludes with factors that assist in deciding whether the implementation of blockchain will add sufficient added value for any given use case.

7.1 Blockchain technology in general

Blockchain technology can be used in areas such as monetary transactions, food production, logistics, government entities, and the healthcare industry - in other words, wherever sensitive data must be managed and stored anonymously, in a way that cannot be manipulated and without the intervention of a "third party" intermediary.[59] Since the technology is relatively new, many potential applications are only theoretical models which still need to be explored in more detail. The use of the technology for digital financial transactions, on the other hand, has already proven itself and is used by several million people every day. The areas of application for the energy sector will be explored in a subsequent section of this analysis.

7.2 Cryptocurrencies

Since blockchain technology is far from being as mature as other databases, there are still very few everyday applications. The use of technology for digital currency transactions using cryptocurrencies, on the other hand, is a proven and functioning system that is readily available to any interested party. Cryptocurrencies, in the context of blockchain technology, are digital currencies that use cryptographic principles to create and manage currencies. Transactions are verified by a decentralized P2P computer network and stored within the same network.60 The systems operate independently of governments or banks, and the network itself ensures data consistency. At the same time, this area of application has been extensively researched and can be used in everyday life. Time and transaction costs can be saved by eliminating the need for intermediaries required in conventional digital currency exchanges. The validation by the blockchain participants ensures a

[59] Cf. Blockchain – 28 Opportunities And Applications of the Distributed Ledger Technology (DLT) https://morethandigital.info/blockchain-moeglichkeiten-und-anwendungen-der-technologie/ (01.08.2021)

[60] Cf. Understanding cryptocurrencies: What does P2P mean & what are the advantages? https://cryptoticker.io/de/p2p/ (05.08.2021)

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

secure and transparent payment system, which enables users to exchange digital currencies with little effort.[61]

7.3 Smart-contracts

Smart-contracts are an application of the blockchain in which conventional contracts are represented in digitized form. The rationale behind this is the same as for conventional contracts: the exchange of services, goods, or money between different parties. In the case of smart-contracts, these are computer protocols that replicate and verify contracts. In simple terms, smart-contracts can be understood as computer programs on a blockchain that execute if-then rules defined by the developer. The developers define conditions and actions in advance, which are then automatically executed. [62]

More specifically, these are software-based contracts in which a wide variety of contractual terms and conditions can be stored. During the contract process, certain linked actions, such as a payout, can be carried out automatically if a corresponding trigger, such as the fulfillment of a contractual condition, is present. Many tasks or activities that were previously performed manually can be automated to save costs and ensure that fraud is prevented. One use may pertain to insurance contracts, for example: the insurance sum could be paid out independently after an insurance claim has been automatically verified. Automated contracts are not a new invention, the concepts have been around for a long time. A beverage dispenser, which automatically dispenses the beverage of choice after the coin is inserted, works on the same principle. Smart-contracts work in a similar manner, but they run on a blockchain, which is the key difference.[63]

[61] Cf. Bitcoin and Co.: Cryptocurrencies Easily Explained https://www.baloise.ch/de/privatkunden/magazin/zahlen-sparen/bitcoin-und-co-kryptowaehrung-einfach-erklaert.html (05.08.2021)

[62] Cf. Goudz, Alexander; Jasarevic, Melisa: Use of blockchain technology in the energy sector - principles, application areas, and concepts. Wiesbaden: Springer Fachmedien, 2020 S.6f.

[63] Cf. "Chain Code." Smart contracts demonstrated with simple code examples https://www.grin.com/document/416782 (04.08.2021)

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

7.4 Factors influencing the use of the technology

The factors that must be considered when determining whether the use of a blockchain makes sense will be examined in some more detail below:

1. Economics: Blockchain technology provides a lot of space for process optimization and automation. This reduces operating costs. Furthermore, in many applications, "third parties" become obsolete, which can also save money, since they usually charge fees for their services. These savings are offset by the costs required to set up and operate the infrastructure in the company. As described earlier, the active use of a blockchain generates large amounts of data that must be stored and processed.[64]

2. Technology: In spite of examples that work flawlessly, blockchain technology is still in the early stages of realizing its potential. The level of development in many areas is still not mature enough to be used in everyday life. Nevertheless, research and pilot projects will open up new areas of application and make the technology ready for practical use in the future. When assessing whether the technology is ready for use in a particular project, the state of development for the respective area of application must be analyzed in detail. While some areas can already benefit from the technology today, there are applications where, for example, legal issues make it difficult to use. Future improvement to the interfaces and the development of initial standards should have a positive effect on the usability and scalability.[65]

3. Regulatory environment: As already mentioned in the Technology section, the regulatory environment is a key factor in determining whether or not to use blockchain. In the energy sector, for example, the use of blockchain is generally possible within the framework of energy law. Since the technology encompasses many different legal aspects, the influencing factors are as diverse as the areas of application themselves. These include data protection law, data security law and energy law.[66]

[64] Cf. dena study: The use of blockchain in the energy system already makes sense today https://www.dena.de/newsroom/meldungen/2019/dena-studie-einsatz-von-blockchain-im-energiesystem-ist-schon-heute-sinnvoll/ (15.07.2021)

[65] Cf. ibid. (15.07.2021)

[66] Cf. ibid. (15.07.2021)

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

8. Blockchain in the Energy Sector

The following use cases of blockchain in the energy sector provide an overview of theoretical models in which the technology could provide solutions to existing problems well into the future.

The breakdown into application groups makes it possible to define more specific use cases for different processes with greater clarity. The results are all based on a study by the "Deutsche Energie-Agentur" (dena).[67] All subsections of Chapter 8, "Blockchain in the Energy Sector," were written using this study as a foundation, and all information was taken from this source. The source is no longer referenced below in order to improve overall readability. As part of the study, an evaluation was performed for each use case according to "Degree of fulfillment of technical requirements," "Economic benefits," and "Regulatory impact." This rating on a scale of 1 to 5, where the higher the number, the greater the suitability, is attached to the description of the use cases unchanged and without comment.

8.1 Asset-management

Asset management deals with the economic management of assets and investments. [68]

Congestion management in distribution networks: The shift in our mobility towards electric drive chains presents some challenges for local electrical grids. These systems are reaching their capacity as the rate of electro-mobility increases, especially when charging processes take place simultaneously. The distribution grid operators must respond; automated grid management is needed. This could use a blockchain as a basis for communication and cooperation between the stakeholders in order to prevent congestion caused by load shifts at the distribution grid level. The technology is used to store projected, adjusted, and in real-time measured load profiles. Furthermore, network-friendly behavior can be recorded and rewarded. Intelligent grid structures and metering systems are essential for the implementation of this use case.

[67] Cf. dena-MULTI-STAKEHOLDER-STUDY Blockchain in the Integrated Energy Transition Process https://www.dena.de/fileadmin/user_upload/dena-Studie_Blockchain_Integrierte_Energiewende_DE4.pdf p. 36-78 (19.07.2021)

[68] Cf. ASSET MANAGEMENT – for EVU https://www.amevu.de/kapitel1.html) (19.07.2021)

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

Assessment:

- Degree of compliance with technical requirements: 3.6
- Economic benefit: 4.2
- Regulatory impact: 3.0

Energy services for buildings and industrial processes: Many different industrial plants require regular maintenance. This affects, for example, building control instruments, air conditioning and heating installations, but also ventilation systems. The maintenance requirements in terms of frequency and type of maintenance and servicing are as varied as the systems themselves. The use case here envisions a blockchain solution for storing maintenance and servicing data. This allows a transparent view of the complete maintenance history with no room for attempts at manipulation. Smart-contracts can still be used to make automated payments after maintenance work has been completed.

Assessment:

- Degree of compliance with technical requirements: 4.3
- Economic benefit: 4.3
- Regulatory impact: 5.0

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

8.2 Data management

Registration of plants in the market master register: According to the German Market Master Data Register Ordinance (MaStRV), all electricity and gas generation plants, as well as electricity storage facilities, must be entered in the market master data register if they are connected to an electricity or gas grid. The size or the quantities of electricity or gas generated are not relevant. Moreover, all plants connected to a high-voltage or extra-high-voltage grid must be entered in this register. In the use case, the blockchain assumes the administration of this register and thereby substitutes traditional databases, which have up until now handled the digital administration. Advantages result from the partly automated registration and administration, as well as from the possibility to provide market master data selectively. The combination with smart meter gateways, which could participate in the blockchain network as a node, provides further security in the authentication of assets.

Assessment:

- Degree of compliance with technical requirements: 2.3
- Economic benefit: 4.5
- Regulatory impact: 2.0

Proof of origin certification: Until now, the supply of electricity and gas has been non-transparent with regard to the actual origin of the energy. Imprecise certificates have thus far been the only retroactive form of proof. A blockchain solution could provide a remedy in that evidence of issuance, trading and collection can be created and viewed. This creates an end-to-end certification, which is equivalent to plant-specific verification. After registration of a plant, an energy purchase agreement is made with the consumer. The quantities generated and consumed are then fed as information from the metering point operators into the blockchain on a smart contract. This creates tokens for the units generated in each plant, which are then transmitted to the consumer. Consequently, that the origin of the energy can be viewed transparently.

Assessment:

- Degree of compliance with technical requirements: 3.8
- Economic benefit: 4.7
- Regulatory impact: 2.0

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8.3 Market communication (electricity)

Settlement of fees and charges: The billing of fees and charges is an energy sector process that involves communication and data exchange between different market players. This application uses smart metering systems (smart meter gateway) to write customer-specific consumption data to a blockchain. Vendors can then create an invoice and the distribution grid or transmission grid operators can determine the amount of fees and charges.

Assessment:

- Degree of compliance with technical requirements: 3.3
- Economic benefit: 2.7
- Regulatory impact: 4.0

Termination and change of vendor: The termination of the electricity contract or switching to another vendor involves active communication between different market players. Process automation proves difficult because many manual process steps are involved, and different market players use differentiated systems to address the concern. Blockchain technology could be used for this purpose since it can streamline the communication process and use smart contracts to standardize it. Both registration and disconnection by the vendor as well as shutdowns by the grid operator can be achieved.

Assessment:

- Degree of compliance with technical requirements: 3.7
- Economic benefit: 3.7
- Regulatory impact: 4.0

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8.4 Electricity trading

Over-the-counter wholesale: This use case utilizes a blockchain-based order book where traders can place bids anonymously. If a buyer is interested, the business partners are mutually disclosed, and the commercial transaction can be carried out without third parties being able to access the data. The blockchain is in effect used to bring together third-party, anonymous market players so that they can engage in commercial activity without making their identities public. The transaction itself, i.e. the delivery, payment, and consumption processes, is not captured by the blockchain. The purchase of electricity from local users can be arranged online.

Assessment:

- Degree of compliance with technical requirements: 3.9
- Economic benefit: 4.2
- Regulatory impact: 4.0

P2P trading between customers of a vendor: In this application, a blockchain solution is used to create a digital trading platform for trading electricity between the customers of an electricity supplier. The electricity supplier is still responsible for the accounting grid management. The trading platform can then be used, for example, by local green electricity providers to offer and sell their services. However, the platform must be operated by the customer's electricity supplier.

Assessment:

- Degree of compliance with technical requirements: 4.1
- Economic benefit: 3.7
- Regulatory impact: 4.0

Although the use of blockchain technology is not absolutely necessary for the direct marketing of electricity generated from renewable sources, the technology is in principle suited for this type of trade. The characteristics of the technology in terms of transparency and speed almost completely rule out the double marketing of a service. In addition, this trading concept automatically incorporates other use cases of the technology, which were also investigated as part of this analysis. These include the "Certification of proof of origin," the "Settlement of fees and charges," and the "Registration of plants in the market master data register." P2P electricity trading using blockchain represents the use case with the greatest potential for SPARCS. For this reason, it will be examined in more detail in the next part of the analysis for subsequent design of a specific blockchain-based business model.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

Trading and allocation of grid capacity: In this use case, the distribution grid operator has the freedom to adjust the grid usage fee based on the current load forecast. Market-based trading within a distribution grid area remains unaffected, only the grid fee component is adjusted to reward grid-friendly behavior. This process, with all interactions between the distribution grid operator and the prosumer, is fed into the blockchain as a data module with smart-contracts processing the payment transactions.

Assessment:

- Degree of compliance with technical requirements: 3.6
- Economic benefit: 3.8
- Regulatory impact: 3.0

Tenant electricity: Tenant electricity is locally generated electricity that is consumed directly in the vicinity of where it is generated without using the public grid, e.g. by apartment tenants if the landlord has installed PV systems.[69] The optimization of local resources (local electricity is consumed to a large extent) should be ensured through a platform based on blockchain technology where customers and the owners of the tenant electricity property can interact. The renewable energy generation system may be owned by the electricity supplier or the property owner, for example. In addition to the power generation plant, third-party tenants receiving deliveries must also be considered in the metering concept. This makes billing between the parties involved (tenant, electricity supplier, plant owner, grid operator and metering point operator) relatively complex. In the use case, in-house and/or external transactions can be easily expanded.

Assessment:

- Degree of compliance with technical requirements: 4.0
- Economic benefit: 2.7
- Regulatory impact: 4.0

[69] Cf. THIS IS HOW THE TENANT ELECTRICITY MODEL WORKS https://www.wegatech.de/ratgeber/photovoltaik/foerderung-finanzierung/mieterstrommodell/ (15.09.2021)

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

9. Peer-to-Peer Electricity Trading Using Blockchain

In the following chapter, the blockchain use case with the greatest potential for SPARCS is analyzed in more detail.

Among all the blockchain technology use cases listed, the use for P2P electricity trading is the one with the most potential. The goal is to enable private individuals and prosumers to trade electricity without the involvement of an energy (supply) company, regardless of the amount of power generated.[70]

The increasing supply of renewable energy to German households is causing a shift from large, centralized energy generation units to many small, decentralized energy generation plants and producers. As a result adjustments are also required in the electricity grid. This could give rise to so-called "microgrids", which according to "I am the future" are defined as "[...] small-scale power grids for the supply of energy, but primarily electricity."[71] . This ensures that in the event of disruptions in nationwide grids, the supply of electricity to customers is guaranteed for a certain period of time. With a high degree of utilization of renewable energies in particular, this can represent a basic added value since the energy sources often depend on many external factors and are not available around the clock. Research on "microgrids" and their potential for implementation is in full swing, and functioning pilot projects already exist.

An example of this is the "Brooklyn Microgrid" created by the company "LO3 Energy" in the New York borough of Brooklyn. Electricity distribution networks enable joint electricity trading among resident neighbors. Households with their own electricity generation using solar panels can sell surplus electricity, or purchase electricity from neighbors if they have a surplus.[72] At the same time, the households are still connected to the main grid to ensure the supply of energy even in times of low yield. New solutions are required for all energy management processes, since this type of trading platform can do without traditional energy supply companies. There are no longer any electricity contracts in the traditional sense; new methods of billing and accounting must be designed. For this purpose, the Ethereum blockchain was used in the "Brooklyn Microgrid" project, which enables users to easily buy and sell electricity. Conventional energy suppliers are no longer needed as intermediaries, since each microgrid participant verifies and stores the purchases and sales, similar to how a blockchain works (cf. Chapter 3: How blockchain technology works). The technology

[70] Cf. Mika and Goudz 2020, p. 61

[71] What exactly is a "Microgrid"? https://www.ich-bin-zukunft.de/faq-items/microgrid/ (10.09.2021)

[72] Cf. Mika and Goudz 2020, p. 74

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

represents a digital cash book, and smart contracts coordinate supply and demand.[73] The "Brooklyn Smartgrid" is being followed by more and more pilot projects, including "District Two" in Austria's capital city of Vienna in 2015. This is an innovative residential area that is used as a research center for new technologies that will shape "Smart cities" in the future. One project is electricity sharing via blockchain.[74]

The theoretical feasibility of this type of trading has been established beyond doubt. A more detailed analysis of the principles for this type of trading concept is provided in the following chapters.

9.1 Principles

Peer-to-peer means trading among equals. Electricity trading between two or more "peers" is, in principle, a smart market concept in which energy trading takes place directly between producers and consumers without having to rely on central intermediaries.[75] In the following, conventional-style electricity trading will be analyzed in order to subsequently highlight how it differs from concepts of P2P trading (cf. Chapter 8.4: Electricity trading).

In 1996, an initial directive was issued for the liberalization of the European internal markets of performance-based energy in the European Union. The EU Internal Market Directive on Electricity 96/92/EC had to be implemented within two years, which was accomplished in Germany in 1998 via the German Energy Act (EnWG). This opened up the electricity market to competition. Regular revisions and amendments keep the guideline current and up-to-date. Liberalization is intended to ensure fair and free trade in performance-related energies. The following requirements exist for this:[76]

- **Free choice of supplier:** All electricity customers are free to choose their own suppliers.[82]
- **Unbundling of generation, grid, distribution/trading:** The liberalized market requires that energy supply companies separate the areas or departments of generation, transmission distribution and trading from an organizational perspective. In contrast to the monopoly

[73] Cf. A micro.electricity grid in Brooklyn demonstrates clean energy supply via blockchain https://reset.org/blog/ein-mikro-stromnetz-brooklyn-demonstriert-die-saubere-energieversorgung-blockchain-05232018) (05.09.2021)

[74] Cf. Electricity sharing via blockchain in Vienna's "District Two." https://reset.org/blog/strom-sharing-blockchain-wiens-viertel-zwei-02222018 (05.09.2021)

[75] Cf. Mika and Goudz. 2020, p. 79

[76] Cf. Konstantin, Panos: Practical manual for the energy sector manual - energy conversion, transport and procurement, transmission grid expansion and nuclear energy phase-out. Berlin: Springer Vieweg, 2017, S.432f.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

market, where supply is usually secured by companies that control and manage all processes from generation to the end consumer, the separation of the individual process steps is intended to ensure the existence of competition.[82]

- **Freedom from discrimination:** All network users are entitled to free, fair, and equal access to the grid. Transmission and distribution grid operators may not differentiate between their own customers and "off-grid" customers from other suppliers. The grid area also represents a natural monopoly in the liberalized market, but this must not affect the treatment of customers. All grid usage fees are transparent and the same for every grid user.[82]
- **Regulatory body:** The Federal Network Agency has been monitoring and designing the framework for a competitive environment since 2005. In the event of violations and anti-competitive behavior, it is entitled to take action against violations and to impose sanctions.[82]
- **System operator:** The system operators work in the technical field and make sure that the grid operates smoothly. This includes tasks in the area of voltage and frequency regulation, as well as compensation for schedule deviations. In the German market, these tasks are performed by four transmission system operators (50Hertz, Amprion, TenneT and TransnetBW).[82]

Many stakeholders interact in different ways in the conventional electricity market. Market participants include:[77]

- **Customers:** Subdivided according to the amount of annual consumption into "Basic supply customers" and major customers. Customers who consume up to 10,000 kWh of annual consumption are defined by the EnWG as basic supply customers. They must be connected to the grid by the basic supplier, i.e. always the supply company that supplies the most household customers in the grid area.[83]
- **Grid operators:** Subdivided according to the voltage level of the grid into "Transmission grid operators" and "Distribution grid operators." Transmission grids are used for the efficient transport of electricity in extra-high voltage grids over distances, which in some cases are long, at high voltages of 380 kV and 220 kV. Other responsibilities of transmission grid operators include voltage and frequency regulation, supply restoration, and compensation for schedule deviations in their control area. The distribution grid carries electricity voltages of up to 110 kV and regulates the supply to end customers and secondary distributors connected to the grid. Their tasks are limited to grid operation only; they do not perform any electricity supplier or trader functions.[83]

[77] Cf. ibid. p. 433f.

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- **Producers:** Perform the task of generating electricity in power plants and small power generation plants. After production, traders and major customers are supplied.[83]
- **Vendors/suppliers:** The vendors are power plant operators or traders. They trade electricity independently (buying and selling). Vendors have accounting grid responsibility with respect to transmission grid operators, which means that they must deliver schedules for power withdrawal or feed-in to the accounting grid coordinators in each control area every quarter of an hour.[83]
- **Energy exchange:** In the liberalized market, electricity is considered a commodity and, like securities, is traded on exchanges, in particular, energy exchanges. The energy exchange is responsible for providing a financially, legally, and technically secure trading venue for authorized trading participants. The Leipzig-based energy exchange "European Energy Exchange AG (EEX)" is the established trading venue in Germany.[83]
- **Other stakeholders:** Other stakeholders in the energy market are, for example, brokers or agents who trade in electricity on behalf of their customers as intermediaries.[83]

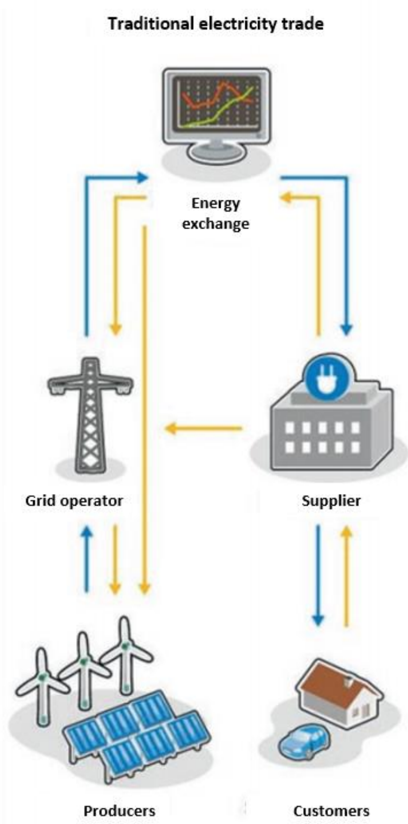

Figure 3: Conventional electricity trading
(Source: Maier 2018, p. 9)

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

9.2 Challenges faced by the conventional energy sector

As previously mentioned, the energy supply is transitioning towards decentralization as renewable energy sources are increasingly used to substitute fossil fuels. Electricity generation is no longer a matter for large corporations with huge power plants; private individuals, citizens' initiatives, local public utility companies and municipalities can also get involved. According to the Federal Environment Agency, renewable energy accounted for 45.4 percent of gross electricity consumption in 2020, an increase of 3.4 percent over the previous year.[78]

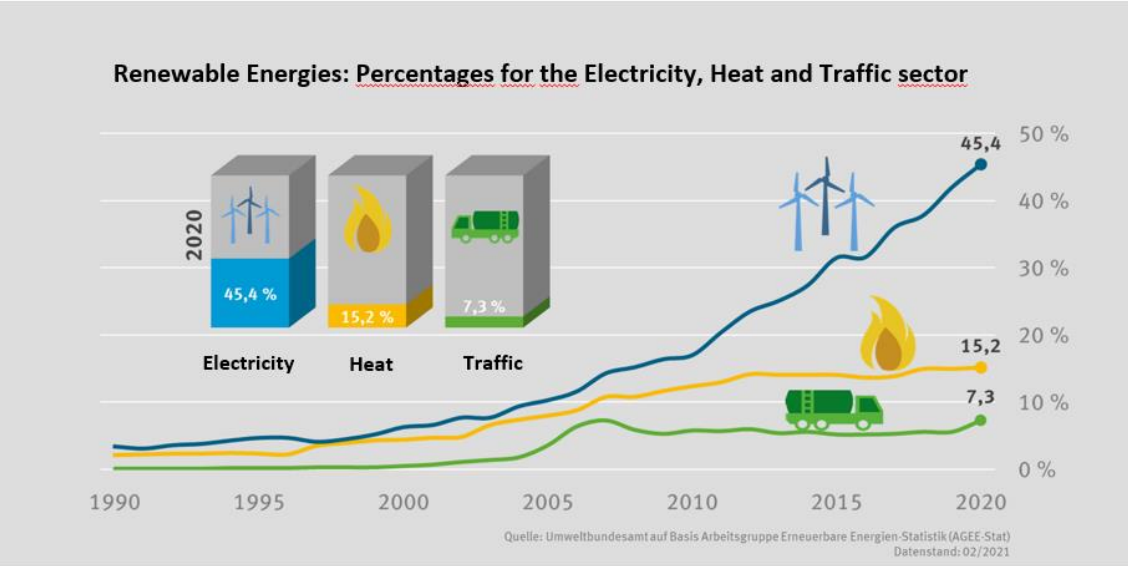

Figure 4: Percentage of renewable energies by sector as of 1990
(Source: https://www.umweltbundesamt.de/themen/klima-energie/erneuerbare-energien/erneuerbare-energien-in-zahlen#uberblick)

Private individuals play a significant role in energy transition and are indispensable as investors in renewable power generation plants. In 2017, private households accounted for nearly one-third (31.5%) of sustainably generated electricity.[79] If this electricity is used simultaneously during generation or at a later point in time by means of a storage medium to cover one's own energy requirements, one speaks of "Prosumers." This means that households or individuals produce their own electricity (PROducer) and then use it themselves (conSUMER). The principle works perfectly for covering one's own needs. However, it becomes problematic when an excess of energy is produced that cannot be used or stored directly. For the producer, the energy is lost. This could be remedied by a local grid for the distribution of surplus electricity, in which resident households can be supplied

[78] Cf. Renewable Energy Statistics https://www.umweltbundesamt.de/themen/klima-energie/erneuerbare-energien/erneuerbare-energien-in-zahlen#ueberblick (28.08.2021)

[79] Cf. Mika and Goudz 2020, p. 81

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

with the sustainable electricity they do not consume themselves. Theoretically, this could be achieved, but in practice the principle is still not being applied in this country, since electricity marketing is handled by aggregators such as grid operators or direct marketers.[80] For producers with small amounts of marketable power, there are many obstacles that make entering the market difficult. The transaction costs are too high in relation to the potential transaction value due to administrative and regulatory obstacles. Electricity trading is not economical enough for prosumers because of legal and bureaucratic obstacles. This is why the move toward smart energy trading is facing a slowdown.[81] In contrast to decentralized energy production, other economic structures continue to operate in a centralized manner.[82] A current trend in the sustainability movement focuses on regionality and procuring products and services from local residents and stakeholders. So far, this has mostly been limited to food, clothing, and everyday items. The energy sector could follow suit in this area and create opportunities for decentralized, regional and sustainable electricity trading. Conditions and business models must be created in which market players with low supply capacities also have fair and equal opportunities for selling their own electricity. Blockchain concepts, for example, could be used for technological management, since they are capable of processing transactions in a secure, transparent, and automated manner. In this way, the trust between the stakeholders is secured via the technology and no participant can unjustifiably enrich themselves at the expense of others. P2P trading could bring about major changes in the energy sector, and blockchain technology could provide the foundation and basis for this transformation.[83] The forms of implementation are multifaceted and are theoretically capable of completely substituting intermediaries and institutions of the conventional energy sector. Even if no practical applications for P2P trading platforms with blockchain as the technological basis are being implemented in the German market at the present time, the pilot projects already mentioned, such as the "Brooklyn Microgrid," show the potential of the concept if ways can be found to compensate for the technical and regulatory restrictions.[84] This means that it will be necessary to define the charges and fees payable for this type of electricity trading, since up to now these have only been stipulated and defined by law for private consumption and tenant electricity models (EEG levy, grid fees, etc.). If the electricity generated by a PV system is sold in the "normal" way under the EEG, the producer is guaranteed a fixed feed-in tariff for a specified period, usually 20 years. After the subsidy has

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[80] Cf. ibid.

[81] Cf. Voshmgir,Shermin: Blockchains, Smart Contracts and the Decentralized Web. Berlin: Technology Foundation Berlin, 2016, S.24

[82] Cf. Why does the Germany energy sector like blockchain? https://bitcoinblog.de/2017/01/13/warum-die-deutsche-energiewirtschaft-auf-blockchain-steht/ (07.09.2021)

[83] Cf. Voshmgir,Shermin: Blockchains, Smart Contracts and the Decentralized Web. Berlin: Technology Foundation Berlin, 2016, S.24

[84] Cf. Sieverding, Udo; Schneidewindt, Holger: Blockchain in the energy sector - brave new (digital) energy world for consumers and prosumers? Bonn: Friedrich-Ebert-Stiftung, 2016, p. 2f.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

expired, there is still a right to grid connection and purchase of the electricity, but an extra contract must then be concluded with an electricity trader, since trading falls into the category of "other direct marketing" according to §21a EEG 2017. Revenues that can be achieved on the electricity market, or the anticipated savings, will most likely not compensate for the costs and trouble of operating a 20-year-old PV system. The blockchain-based P2P trading platform provides a direct remedy to the problem, since the electricity can continue to be marketed between producers and consumers without any problems as long as the PV system is producing profitably.[85]

9.3 Goal of creating a P2P electricity trading concept

In order to strengthen the role of prosumers in the energy sector in general and during energy transition in particular, a concept and a business model must be developed and evaluated in which producers of renewable electricity have the opportunity to market their energy directly without having to go through intermediaries. The electricity must flow directly between the producer and the end consumer. As a foundation for the creation of a business model (cf. Chapter 10: Creation of a Business Model), an assessment of the potential with regard to the technical maturity and suitability of blockchain technology, the regulatory basis, the market potential and the general functionality of the power supply by means of such a P2P platform must be performed, which then itself must be assessed for potential in order to issue a final recommendation for action (cf. Chapter 11: Conclusion and Outlook).[86]

The assessment for potential should answer the following key questions:

- Is blockchain technology suitable for P2P trading?
- Which regulatory obstacles must be overcome?
- Can certain intermediaries be dispensed with?
- Does this result in a profitable business model?
- Which stakeholders connect and how does the communication work?

[85] Cf. Mika and Goudz 2020, p. 82

[86] Cf. ibid. p. 82f.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

9.4 Assessment for potential

In order to explore the added value of blockchain technology for the respective area of application, it is essential to carry out an assessment for potential. Not every use case benefits from the use of the technology, often conventional network technologies and databases offer more added value than blockchain.[87] The use of the technology itself does not generate money. However, new, and innovative business areas can be developed, which justify a close examination of the technology. Similar to the use of the Internet, new access to opportunities, as well as a possible increase in efficiency in various areas, generate added value for users; the technology itself does not bring any benefit.

9.4.1 Assessment for technical feasibility

It has already been proven that blockchain technology is suitable for this type of trading platform. Projects such as the aforementioned "Brooklyn Microgrid", where solar power has already been sold among neighbors via a blockchain-based P2P trading platform, prove that all the technical requirements for a functioning trading platform are in place.

9.4.2 Is it possible to do without intermediaries?

To answer this question, the classical approach to electricity trading with its stakeholders will be described and analyzed first. Then a comparison with blockchain-based trading can be made.

In the first step, the electricity must be produced by an electricity producer. In the field of renewable energies, producers mainly use energy from wind, water, sun (PV), biomass or geothermal energy (geothermal energy). Conventional (fossil) fuels in power plants, on the other hand, can be traced back to coal, natural gas, oil, or uranium. In addition to large-scale industrial facilities and power plants, private individuals are also emerging at the forefront of energy transition since renewable energies offer great potential for self-sufficiency with self-generated electricity. As prosumers, they not only generate their own electricity, but use it directly to meet their own energy needs.[88]

After the electricity has been produced, it is transmitted and distributed from the place of generation to the place of consumption. The infrastructure is provided by the grid operator. This ensures the highest possible grid stability and efficient transport of electricity via high, medium, and low voltage.[94] In addition to the four large transmission grid operators Amprion, 50Hertz, Transnet BW

[87] Cf. "Blockchain technology does not offer advantages per se for every use case" https://www.euwid-energie.de/blockchain-technologie-bietet-nicht-per-se-fuer-jeden-anwendungsfall-vorteile/ (01.09.2021)

[88] Cf. Mika und Goudz, p. 83f.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

and TenneT, which provide the infrastructure for nationwide electricity grids[89], there are over 850 other electricity grid operators throughout Germany.[90]

Electricity suppliers play an essential role as intermediaries and suppliers of electricity to households and businesses. They organize the amount of electricity needed by customers. This usually takes place via special trading centers such as the Leipzig-based European Energy Exchange (EEX). It is the responsibility of the electricity supplier to prepare a daily forecast of customers' electricity consumption and to report this to the grid operator. The preparation of contracts for the billing of energy costs as well as the billing of all other charges and fees is also the responsibility of the electricity supplier. He ensures trouble-free supply and is available as a contact person for questions and problems from the consumer. [91]

The electricity consumer forms the end of the chain, whether a private household or a company. The electricity supplied can be used according to demand; both the base load and normal household electricity consumption can be covered without problem.[92]

If one compares the process of electricity supply, from generation to consumption, according to the classic and blockchain-based model, digital marketing using blockchain makes it possible to replace some intermediaries. Both the tasks of electricity suppliers and the services of electricity traders or the electricity exchange can be replaced by digital technology.[99] In the P2P model, the tasks of the electricity supplier, which are primarily limited to supplying customers with electricity, are performed directly by the electricity producer. Furthermore, there is no need for an electricity exchange since the electricity being sold does not have to be organized by an electricity supplier. It is also handled by the producer, who markets and sells the available electricity directly.[93]

The following diagram represents the process steps in the blockchain-based P2P market in a simplified and chronological manner based on five simple steps:

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[89] Cf. The transmission grid operators: Responsible as experts for security of energy supply https://www.netzentwicklungsplan.de/de/wissen/uebertragungsnetz-betreiber (05.09.2021)

[90] Cf. Number of electricity network operators in Germany from 2010 to 2020 https://de.statista.com/statistik/daten/studie/152937/umfrage/anzahl-der-stromnetzbetreiber-in-deutschland-seit-2006/ (05.09.2021)

[91] Cf. Mika and Goudz, S. 83f.

[92] Cf. ibid. p. 84

[93] Cf. ibid. p. 84

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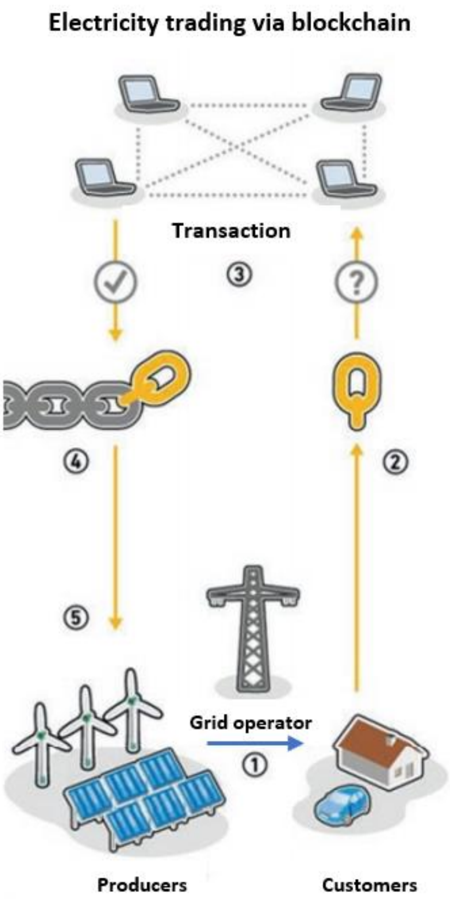

Figure 5: Electricity trading via blockchain
(Source: Maier 2018, p. 9)

1. The direct supply of the consumer via the grid operator with electricity generated from renewable sources[94]
2. Every transaction is cryptographed and transformed into a data block[100]
3. The transaction (the block) is checked and verified on the network[100]
4. The information is added to the blockchain[100]
5. Payment is made using a smart contract[100]

The yellow arrows in the figure represent the flow of money, the blue arrows symbolize the flow of electricity.

[94] Cf. Magnus, Maier: Meta-analysis: Digitization of Energy Transition. Agency for Renewable Energies Registered Association, 2018 p. 9.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

9.4.3 Regulatory obstacles

As part of the dena study "Blockchain in the integrated energy transition process," the auditing firm Deloitte conducted a regulatory assessment, from which the following critical regulatory obstacles and points of consideration emerged:95

- §3 No.18 EnWG: Prosumers who want to share their self-generated electricity with third households and private individuals must be considered as energy supply companies according to the EnWG. This results in duties and responsibilities for the prosumer.101
- §5 EnWG: Vendors are obligated to report supplies to household customers to the regulatory authorities.101
- §41 EnWG: Energy supply contracts must comply with certain standards and minimum requirements.101
- StromNZV § 1 sentence 1: defines the conditions for power feed. The requirements of §§23 ff. EnWG with regard to the contractual provisions for access to the network must be observed.101
- §4 StromNZV: An accounting grid manager who creates load forecasts and informs the network operator about them must be appointed.101

Blockchain technology has the potential to support a trading platform on which private individuals can sell their own renewable electricity. The implementation of such P2P trading is complicated by various regulatory and bureaucratic obstacles.[96] Even if fulfilling the obligations and complying with all regulations is basically possible, they still represent a significant obstacle that, realistically speaking, many prosumers do not want to face. Classification as an energy supply company may deter many potential P2P traders because the obligations it imposes are burdensome for prosumers who want to participate in the P2P marketplace.[102] Therefore, potential participants may refrain from selling their own electricity. To prevent this, there are concepts for blockchain-based P2P markets, where a service company is interposed, which manages and fulfills the regulatory obligations. According to Mika and Goudz, this can be, for example, an energy supply company, which is "responsible for accounting grid management, procurement of replacement and surplus quantities, forecasts, as well as bureaucratic obligations (registration of the prosumer as an EVUs, payment of the EEG levy, electricity tax obligations, etc.), while the participants can trade freely among themselves within the accounting grid." (2020, p. 86).

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[95] Cf. dena-MULTI-STAKEHOLDER-STUDY Blockchain in the integrated energy transition process https://www.dena.de/fileadmin/user_upload/dena-Studie_Blockchain_Integrierte_Energiewende_DE4.pdf S. 206ff. (20.08.2021)

[96] Cf. Mika and Goudz 2020, p. 86

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

This would take a lot of work off the hands of prosumers and provide a viable alternative for self-management in the marketplace with all of its regulatory demands. Since this model, rationally speaking, offers a more realistic chance of implementation, a model with service intermediaries will be sought when creating a concept for blockchain-based P2P trading.

9.4.4 Analysis of the stakeholders

Mika and Goudz (2020, p. 87) identified four different stakeholders when creating a depiction representative of the stakeholders in the P2P market:

- Platform operator
- Platform user
- Data supplier
- Data user

The platform operator is responsible for the proper functioning of the blockchain on each platform. His tasks include the development of the trading platform, but also adjustments and enhancements. This can be any company, association, institute, etc. that considers blockchain technology among its field of expertise and can provide an infrastructure for this trade. The platform providers are remunerated, for example, with commissions for maintenance work and support on the blockchain, for data processing or for the development and integration of smart-contracts.[97]

The remuneration of the platform operators by the platform users entitles the users to read and write access to the blockchain trading platform. This allows them to connect the systems of the end customer via the platform and offer specific products. The platform users are mainly public utility companies, electricity suppliers and energy supply companies with direct customer connections.[103] Mika and Goudz (2020) attribute to the users primarily energy related activities, such as "[...] accounting grid management, vendor switching, and regulatory reporting obligations, which they also assume as a service provider for the suppliers of data" (p. 87).

The end customers of the platform user can be defined as data suppliers. These are people and groups of people who want to generate and sell electricity and those who want to buy and use the electricity. The data suppliers are offered a new method of purchasing or selling electricity via the platform. Therefore, the data suppliers are both the producers and the end users.[103] In exchange for the opportunity to use the platform and trade in electricity, users supply data on their generation capacities or electricity consumption. Furthermore, the producers are relieved of a large percentage of regulatory tasks and obligations, since these are fulfilled by the platform user. End consumers

[97] Cf. ibid. p. 87

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

benefit from greater participation in determining which electricity they want to have supplied. It is absolutely essential that secure and calibrated hardware is used to record the generation and consumption data and make it available to the blockchain in digital form.[103]

The data user can access the blockchain to read and analyze the data stored in it.[103] This includes reading rights for "[...] portfolio management, forecasting or benchmarking of assets [...]." (Mika & Goudz 2020, p. 87). The database can also be used to calculate investment projects or to reinforce renewable energy crowd funding projects, since the data stored in the blockchain can provide information about local preferences of consumers and producers, which means that improvements can be implemented for future projects with more precision.[98]

9.4.5 Summary of the market potential

The analysis of the market potential has shown that blockchain technology can definitely act as a driver of energy transition. The technology frequently offers significant added value compared to conventional electricity trading. For example, the roles of electricity suppliers or electricity traders/exchanges can sometimes be completely eliminated. The capabilities of blockchain technology (cf. Chapter 5: Strengths of Blockchain Technology) enable fair and secure trading between producers and consumers.

On the other hand, there are some regulatory obstacles that make it extremely difficult to use the technology for P2P trading in the short term (cf. Chapter 9.4.3: Regulatory obstacles). As a result, many potential buyers are losing interest in the P2P market and producers prefer to use their electricity themselves rather than trade it. A good compromise for this could be service models in which regulatory obligations are met by a platform user. When creating a specific business model, however, only the option with a service intermediary should be considered, since this offers the most realistic chance of implementation on the German market.

[98] Cf. ibid.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

10. Creation of a Business Model

After the principles of the P2P electricity market were analyzed in the previous chapter, a specific SPARCS business model for this use case will now be created in the subsequent chapter based on Chapter 7.5 "Business model" by Mika and Goudz (2020). Here, the public utility companies assume the role of blockchain platform operator and coordinate trading via their distribution grid and the trading platform.

The obstacles which sand in the way of using the technology in the P2P electricity market identified in the "Summary of Market Potential" (cf. Chapter 9.4.5) show that, at this point in time, independent and decentralized P2P electricity trading for producers will not fully function due to a number of conditions in the legal framework (cf. Chapter 9.4.3 Regulatory obstacles). Nevertheless, the advantages of blockchain technology (cf. Chapter 5: Strengths of Blockchain Technology) could be used to generate a trading platform where LSW, as a service provider, can offer its capacities with respect to the fulfillment of energy sector obligations. The regulatory complications for potential, private blockchain trading platform participants are addressed by the public utility companies in this concept. They provide and operate their own online trading platform where market participants can trade electricity among themselves. LSW is responsible for the accounting grid and is subject to all regulatory and energy industry obligations. For producers and consumers, this results in a new opportunity for market interaction since they can easily manage electricity as a commodity. The blockchain technology ensures the secure and accurate administration of the collected data for each system and each transaction. A certificate of origin for the traded electricity automatically generates the type of data storage, since each kilowatt-hour produced and sold can be assigned to the trading partners that have been in contact with each other. Smart-contracts enable the automation of some process steps, e.g. the creation of invoices can be automated and implemented in a secure manner. Producers can publish their offer on the platform as they wish, while consumers have the freedom to select the vendor with the best conditions or the preferred electricity mix, depending on their needs. Although this would not result in independence from energy supply companies for prosumers or other P2P market participants, end customers could benefit from lower prices and greater transparency regarding the origin of electricity, producers from higher revenues, and the environment from better integration and more efficient use of renewable energy.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

10.1 Implementation requirements

In addition to the operation of blockchain technology, to which all network participants are digitally connected via the Internet, a number of requirements for P2P trading via such a platform are mandatory for implementation: The trading participants trade in electricity, which can be physically transmitted over lines designated for this purpose. A physical connection between the stakeholders must exist before an exchange between market participants can take place. This is usually not a problem, since private households are connected to the local distribution grid of LSW, which can be used directly for feed-in and supply. The construction of a "Smart grid" that includes means of communication and intelligent components, is beneficial. The grid would include smart meters, which are systems that accurately record the actual energy consumption and time of use. Smart Meter Gateway (SMGW) provides a communication interface between physical power flows and the digital transaction via the blockchain.[99] A combination of the two systems is a basic requirement for electricity trading using blockchain, since this is the only way to monitor the exact feed-in and withdrawal quantities. The system must be compatible with the blockchain so that the recorded data can be stored directly as information in the blockchain, and smart-contracts can request and fulfill the contractual conditions assigned to them.[105]

Another requirement for P2P trading are producers who can independently generate electricity in the field of renewable energies. These are usually PV systems, which can be installed on the rooftops of houses or other suitable locations.

For this business model it is assumed that both the producer and the end consumer have capacity to store electricity, so as not to "waste" electricity, i.e. not to use it if there is no demand at the time. This allows more flexibility in the market since producers can also fulfill requests when they are not able to generate electricity at the moment.

In order to promote trade between producers and consumers, it is also important that the purchasing terms for the buyer are consistent with the products offered by the producer.

[99] Cf. Mika and Goudz 2020, p. 89

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

10.2 Structure of the system

This section is used to visualize the infrastructure relevant for the business model with all its components and their relationship to each other. The most important element is the trading platform based on blockchain technology. It is operated by the LSW, which also fulfills all regulatory and bureaucratic obligations. The trading platform represents a local marketplace for trading in electricity. Producers and consumers, i.e. all those parties who want to sell or buy electricity, are then connected via this network. Trading partners are physically connected via the local distribution grid. Therefore, nothing stands in the way of the flow of electricity after a successful transaction. Electricity is generated by the producer via renewable methods (usually by means of a PV system), accurate recording of generation and consumption data at specific time intervals from all network participants is enabled by smart meter and SMGW systems. The SMGW is used as the interface between the physical flow of electricity and the digital level since this regulates the communication between measuring instruments and the blockchain system. For implementation, the producer receives an address in the blockchain ledger, an EC wallet.[100] Personal data, the serial numbers of his power generation plants and information on the current capacities in the power storage system are stored here. The combination of smart meter and SMGW system enables plant-specific proof of origin for the electricity sold based on the link between individuals and their generation plants, which is why end consumers can be sure that they are buying and using sustainable electricity from the region.[106] Information about the current storage levels of the generator, displays the level of resources currently available and provides information about electricity capacities that can be purchased at the moment. A suitable unit must be formulated in order to store the level of storage on a blockchain. The storage levels are usually specified in kWh. To simplify data processing on the blockchain, 1 kWh of electricity is stored in the system as 1 EC token (1 kWh = 1 EC token).[106] To enable real-time trading, information about current capacities must be updated at a high frequency. This information should be updated every minute because it is the only way to trade resources that are actually available, and no electricity is sold that has not been generated or has already been sold. On a monetary level, so-called EH tokens, which can later be exchanged for real money, are used for the actual transfer of value. They assign a fixed value to the owner within the trading platform. [106]

In order to participate in electricity trading in the P2P market, each stakeholder, regardless of whether he is a producer or consumer, always requires his own EH wallet.[101] Furthermore, LSW as a

[100] Cf. ibid. p. 90

[101] Cf. ibid.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

trading platform operator needs such an exchange, since it will be implemented as a type of escrow account between the wallets of the trading partners. This method prevents fraudulent actions, because the producers only receive the buyer's money from the intermediary (LSW's escrow account) which is only credited after proof has been provided that the agreed amount of electricity has actually flowed. The blockchain ensures transparent and manipulation-free data storage by storing each transaction all corresponding actions.

The system also includes smart-contracts, which are stored on the blockchain and automatically execute the terms of the contract once all conditions have been met. This means that invoices can be created independently and the payment for the services can be automated and implemented in a reliable manner. In the figure, the "Service provider" position is assumed by LSW.

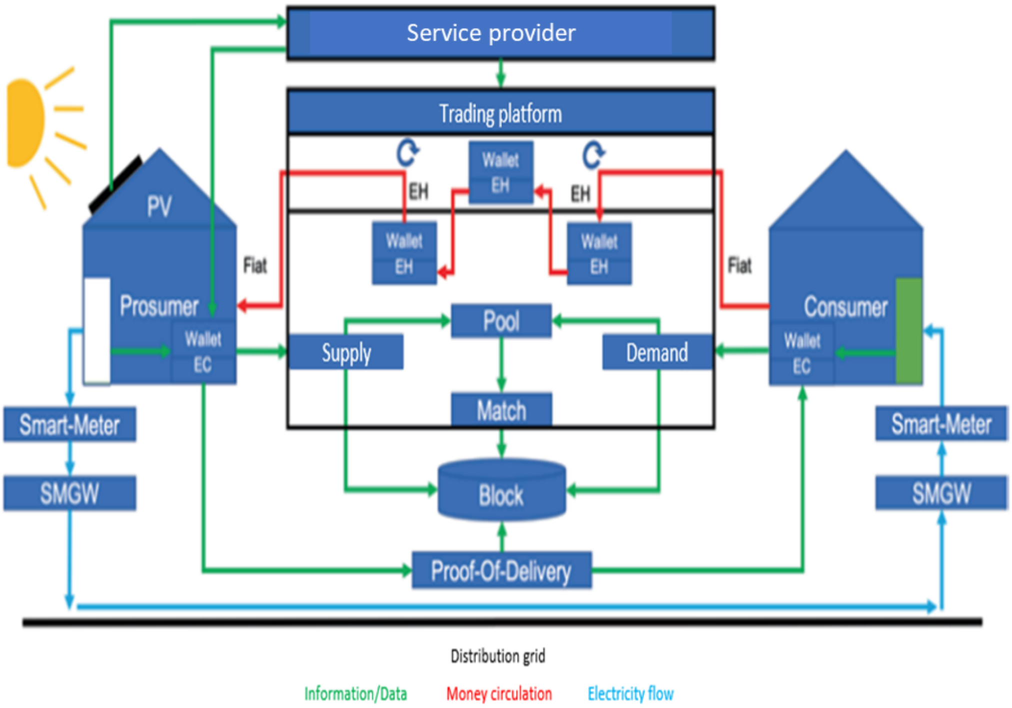

Figure 6: P2P trading infrastructure
(Source: Mika & Goudz 2020, p. 91)

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10.3 Specific mode of operation

In order to describe electricity trading using blockchain in a P2P system, the processes were divided into eight individual and consecutive process steps[102] which are now broken down and analyzed in more detail below. Since the system is currently only available as a theoretical model, there may be deviations in individual process steps during practical implementation. However, this would not pose any problems for the creation of this system.

1. Identification and authentication

This step is indispensable for participation in electricity trading. All stakeholders must register with Stadtwerke Leipzig. They check personal data to ensure there are no misunderstandings about market participants later. This step is also necessary for the distinct classification of a producer and a buyer, so that the respective production and consumption values can be assigned. Proof of origin can only be created if the flowing energy can be clearly assigned to the producers. In the authentication process step, the market participants are assigned accounts (EC wallets) by the LSW, which links their personal data with the generation plants (their serial numbers).[103]

2. Electricity generation

In order to trade a product, it must first be produced or generated. Renewable energy is traded in the case of blockchain-based electricity trading. This requires generation plants, which are primarily limited to PV systems in the context of trade among private individuals. In order to respond to different needs regarding the amount of electricity requested in a flexible manner, the use of electricity storage systems is recommended. This makes it possible to meet requests for electricity on days when no electricity can be generated due to the current weather conditions. Market participants are also equipped with the smart meter and SMGW systems so that each flow of electricity can be transmitted to the blockchain in a transparent manner.[104]

[102] Cf. ibid. p. 91

[103] Cf. ibid. p. 91f.

[104] Cf. ibid. p. 92

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

3. Tokenization

Tokenization represents the process of digitizing real-world objects for digital use. More specifically, a certain amount of the real product is assigned to a certain amount of a digital currency.[105] In the actual application, one kilowatt-hour of electricity is assigned exactly one digital token (1 EC). Therefore, every kilowatt-hour of electricity generated and measured by the smart meter is assigned exactly one EC coin in the blockchain. The number of tokens in the blockchain thus represents the power capacity. EH tokens, which can be purchased by consumers, are used as an equivalent to the EC coin, which enables trading in the first place. In principle, the value of an EH token can be defined arbitrarily. For reasons of value stabilization, however, it is advisable to use a fixed equivalent value as the basis for determining the amount of the value.[111] For example, an EH token could be worth exactly the price of one kilowatt hour of electricity. In order to create an incentive for using the trading platform, it would make sense to keep the electricity price for buyers below the current average electricity price of approx. 27 cents/kWh[106] and the remuneration for producers and sellers above the current feed-in tariff of 7.47 cents/kWh for systems up to 10 KWP and commissioned as of 01.07.2021[107]. To achieve this, cost savings are required, which can be realized by eliminating intermediaries.

4. Sale

The electricity producers can release the existing electricity for sale based on their EC token status and create an offer. The synchronization of all data (including the EC token balance) in almost real time ensures that the "Account balance" actually corresponds to the available amount of electricity, which also reveals the current storage level. The offer is accepted and considered valid if the amount of electricity currently in storage matches. A so-called "Sales TAG" with information on quantity, price and time of the offer creation is generated and assigned to the respective offer. In the event that the producer wants to consume the offered amount of electricity himself before a buyer accepts the offer, he can do so at any time. The offer will then be deactivated until the producer has generated new electricity and capacities are once again sufficient to reactivate the offer.[108]

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[105] Cf. ibid.

[106] Cf. Stadtwerke Leipzig https://strom.preisvergleich.de/info/13420/stadtwerke-leipzig/ (10.09.2021)

[107] Cf. Feed-in Tariff https://www.solaranlage.eu/photovoltaik/wirtschaftlichkeit/einspeiseverguetung (10.09.2021)

[108] Cf. Mika and Goudz 2020, p. 93

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

5. Electricity trading

As already explained in the first step, all market participants must be registered on the trading platform. Electricity trading takes place on the basis of a blockchain system, which is why the exchange of conventional currencies is difficult. For this reason, consumers must first purchase so-called EH tokens from LSW before they can buy electricity. In doing so, the latter may charge a transaction fee, thereby generating profit. If the consumer now wants to buy electricity via the trading platform, he can filter offers according to various categories (origin, price, etc.). If a suitable offer can be made by a supplier that fulfills the needs of the buyer, then smart-contracts will determine whether all the terms and conditions of the contract can be met by both parties. Among other things, the system checks whether the buyer has enough tokens and whether the offer is still available. If all conditions can be met, the completed trade is written to the blockchain with a "Trade TAG."[109]

6. Purchase

The purchase combines the process steps of sale and electricity trading and is the product of demand and supply. The use of smart contracts on the blockchain enables automated and secure payment processing, while taking into account the conditions specified in the offer. The smart contracts ensure consumer protection by only debiting the money (the tokens) from the consumer if the producers have enough electricity capacity in the storage system. The money initially goes to a type of escrow account at LSW, where it is kept until the transaction is concluded. All information from each transaction is stored in the blockchain in the form of a "Purchase TAG".[115]

7. Electricity flow

Once the correct amount of EH tokens has been transferred to the escrow account, the flow of electricity can begin. The agreed amount of electricity flows via the distribution grid from the producer's storage system to the consumer's storage system. After the electrical energy has been transferred, another "Electricity TAG" is written to the blockchain, which contains information about the meter readings of the electricity storage.[110]

8. Conclusion

After the transmission of electricity has been carried out, the EH tokens stored in the escrow account are transferred to the producer via smart-contract. He can then decide for himself whether he wants

[109] Cf. ibid. p. 94

[110] Cf. ibid.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

to convert the amount into actual money, and have it paid out, or whether he wants to keep the tokens in his digital wallet to pay for transactions via the trading platform later himself. If the producer decides to exchange the tokens into the actual currency of his country, a transaction fee must be paid to the platform operator, LSW.[111]

To conclude the transaction, the TAGs of sale, trade, purchase, and electricity flow are combined and written to the blockchain. This ensures traceability and security against manipulation for each network participant.[112]

10.4 Blockchain desing

Specific features of the blockchain will be discussed below. Since there are many different types of blockchains with different characteristics and applications, a more detailed description of the network is very significant (cf. Chapter 4: Classification of Blockchains).

The first thing to consider is the type of blockchain: during implementation, an assessment of the characteristics for the intended use must be carried out for each use case in order to ensure the optimal use of the technology by using the most suitable type of blockchain. A distinction can be made between private, public and consortium systems according to the right of use (cf. Chapter 4: "Classification of Blockchains"). The blockchain has a number of requirements for the use case of P2P trading: energy-efficient transaction validation, compliance with data protection, and high transaction speeds.

High transaction speeds in particular are of great significance, since the system must work at almost real time to prevent duplicate sales from the offers created and to prevent long waiting periods for product delivery to customers. For this reason, the use of a public blockchain can be ruled out because this type of blockchain has limitations with respect to all three requirements for the P2P blockchain (cf. Chapter 6.1: Weaknesses of public blockchains). The consensus mechanism is energy intensive, data protection is comparatively low, and transaction speeds are relatively slow. Private blockchains are better suited at this point, the energy consumption for the consensus mechanism can be minimized compared to public systems, the blockchain runs more

[111] Cf. ibid.

[112] Cf. ibid. p. 95f.

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efficiently and faster (cf. Chapter 5.2: Strengths of private blockchains). However, consortium blockchains also offer advantages for P2P electricity trading (cf. Chapter 5.3: Strengths of consortium blockchains): the validation by the nodes, in contrast to private individuals in private blockchains, is achieved by a consortium of organizations within the network, which in the specific example can be fulfilled directly by the LSW. The consortium specializes directly in the highly regulated energy market, which is why it can react appropriately to potential changes in legislation, for example.

The transaction speed also benefits from this form of network because the access restriction permits lower requirements for the level of encryption of the information. Since this use case involves some specific requirements due to the specific characteristics of the energy industry, the consortium blockchain provides the best basis for a properly functioning network, because it can meet these requirements. The POA consensus mechanism is used to validate the data, since only authorized validators have the decision-making power for reaching a consensus (cf. Chapter 3.2 "Validation"). This is the LSW in this specific use case. The producers and consumers of the electricity are not involved in validating the data and information they provide. This means that they only receive read rights to the blockchain so that they can check and view the data for purposes of transparency but cannot validate blocks in their own interest. The LSW, on the other hand, actively participates in the consensus mechanism, has a validation right, and is therefore authorized to read and write.

Smart contracts are used to implement automated processing and verification of data and processes within a blockchain. These programmed contracts are based on the if-then principle (cf. Chapter 7.3: Smart-contracts). This ensures that contract conditions are met before the next action is performed. This offers enormous advantages for trade, regardless of the trade type, since processing is only authorized if all trading or contractual partners can meet the respective conditions. Similar to a notary, the system checks the trading partners and only accepts the deal if the producer's offer matches the consumer's terms of purchase. The transaction will only be authorized if the computer log has checked the buyer's account balance for sufficient funds and has determined that there is no double sale by the producer. Only after all criteria have been examined will the buyer's EH tokens be automatically transferred to LSW's escrow account, and the electricity released. Another smart-contract later transfers tokens to the producer's wallet after the agreed amount of electricity has flowed to the consumer. Smart

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

contracts create trust between unknown parties because they leave no room (if properly programmed) for fraud or manipulation.

Currently, EWF is working on a platform that could be suitable for such P2P based electricity trading since it provides a consortium blockchain solution and operates according to the POA consensus mechanism. These requirements generally enable energy trading according to the principle introduced.[113]

11. Conclusion and Outlook

The efficient use of every kilowatt-hour is guaranteed without losing unused electricity through interconnection of small utility grids in which unused electricity can be traded among interested parties. Producers benefit from relatively high feed-in tariffs and customers from relatively low electricity prices. In order to provide a trading platform for this exchange, energy supply companies could agree to act as service providers and offer a blockchain solution for trading. They would then benefit from transaction fees. Since it is generally not worthwhile for electricity producers to distribute electricity independently due to many regulatory obstacles, they could benefit from the expertise of the platform providers on the basis of such a platform and leave the regulatory obligations to them. This would save producers a lot of bureaucracy and costs, while they are still able to market the electricity they generate. Initial pilot projects such as the "Brooklyn Microgrid" prove the functionality of such a P2P trading platform and the technical feasibility of blockchain technology. Replacing conventional stakeholders in the energy industry, such as electricity traders or the electricity exchange and electricity suppliers, with the properties of the new market structure results in cost savings that benefit the trading partners. Thanks to the use of smart-contracts, trading is safe for all parties, since the flow of electricity is controlled and stored by the system using smart meters and SMGW, and the money only flows from a type of escrow account to the electricity producer after all conditions have been met.

The question remains, however, to what extent the investment in building such an infrastructure will pay off. Personally, I advise against implementation at SPARCS, since the profitability of the business model currently is not in alignment with the level of investment risk. The legal framework in Germany for such a project should not be underestimated. Since

[113] Cf. ibid. p. 97f.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

blockchain technology and its use cases are still quite new and rarely implemented in practice, there are legal gray areas that pose a risk to implementation. For example, the "Right to be forgotten" offers protection against permanent data storage, which contradicts the basic principles of the blockchain. Since there is no comparable P2P trading platform in this country, it is difficult to assess the risk. In addition, there is still no evidence that it will work on the German market. Developing, organizing, and maintaining an infrastructure for this type of trading involves enormous costs, which are not immediately compensated for by the use of blockchain technology; the mere use of the technology does not generate any profit. In fact, the opposite is true, because using a blockchain from another service provider incurs costs. SPARCS only earns transaction fees from purchases or sales made by platform users. The resulting profit margin is too low when measured against the offsetting costs of maintaining and servicing the infrastructure.

The next generation of digital technology is on the horizon with blockchain technology. Many billions of processes have already been validated and executed in the field of digital currency transactions. In the period from February 2017 to August 2021, over 666.62 million transactions were carried out in the Bitcoin network alone. New use cases are continuously being tested and implemented across many industries. This technology could bring about major changes in various sectors over the long term. The capabilities of the technology regarding security, anonymity, disintermediation, data integrity, and transparency offer very promising use cases that protect consumers. Distributed databases may therefore represent the future of information storage.

Another industry undergoing change is the energy sector. The shift from huge, centralized power plants for energy production to decentralized, smaller generation plants for a sustainable and clean energy supply into the future places new demands on the energy sector. In order to make energy transition efficient and successful, private individuals as well as industry must make a contribution toward achieving that goal. This increases the opportunities for active participation. Over the last ten years, the prices for PV systems have fallen from €3500 to €1450 per kWp of installed power, making the technology more accessible to private individuals. Nevertheless, due to the technical functioning of these generation plants, it will not be possible to provide every private household and every rental property with its own power generation source. Therefore, in the future, smart cities could create intelligent neighborhoods that collectively participate in the energy transition by guaranteeing the efficient use of renewable electricity.

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