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| Master’s Thesis  Local Trading of Renewable Energies via a Blockchain Platform - A Requirement Analysis |
| **Submitted to** Chair of Energy Economy and Application Technology  TUM Department of Electrical and Computer Engineering  Technical University of Munich  Prof. Dr.-Ing. Ulrich Wagner  **Written by** Laura-Maria Baur  **Advisor** Michel Zadé |

**Abstract**

Due to the established energy transition targets in Germany, there is an increasing share of renewable energy sources, accompanied by the appearance of new energy consumers, who are taking an active part in the energy market as so-called prosumers.

The energy produced by the prosumers is fed into the market or consumed for their own needs. If prosumers feed energy in the market, they are supported by feed-in tariffs governed by the Renewable Energy Act. When associated subsidies expire, the question of new marketing solutions arises. Blockchain technology offers the opportunity to automatically and transparently sell decentralized energy from small-scale plants in a local energy market.

In order to successfully implement such a peer-to-peer market, a number of requirements need to be identified first. Two surveys were developed within the scope of this Master’s thesis to collect information from experts, prosumers and consumers about their expectations of such a system. Subsequently, the results of the surveys were analyzed and evaluated, both qualitatively and quantitatively. This led to a catalogue of requirements relating to regulation, social issues, the economy, technology and ecology. The catalogue contains a classification as well as a prioritization of assessed requirements. In addition to a user-friendly application, transparency, financial benefits, an information exchange and support for end users, are necessary to successfully implement a local energy market using Blockchain. The defined requirements resulted in recommendations for practical application. It is suggested that such a peer-to-peer market should first be tested on small scale to investigate possible technical problems and compliance with existing regulatory frameworks such as the General Data Protection Regulation. Furthermore, it is advisable to merge with already operating research institutes and start-ups of this field. In this way a successful implementation is possible and a feasible solution for direct marketing of decentralized renewable energies is offered.

**Abstract**

Aufgrund der angestrebten Ziele zur Energiewende in Deutschland steigt der Anteil der erneuerbaren Energien, begleitet vom Auftreten neuer Energieverbraucher, die sich als sogenannte Prosumenten aktiv am Energiemarkt beteiligen.

Die von Prosumenten produzierte Energie wird dann am Markt eingespeist oder für den eigenen Bedarf verbraucht. Dabei werden sie durch eine Einspeisevergütungen nach dem Erneuerbare-Energien-Gesetz unterstützt. Nach dem Auslaufen der damit verbundenen Fördermittel stellt sich die Frage nach neuen Vermarktungslösungen. Die Blockchain-Technologie bietet die Möglichkeit, dezentrale Energie aus Kleinanlagen automatisch und transparent auf einem lokalen Energiemarkt zu verkaufen.

Um einen solchen Peer-to-Peer-Markt erfolgreich zu implementieren, müssen zunächst jedoch eine Reihe von Anforderungen identifiziert werden. Zu diesem Zweck wurden im Rahmen dieser Masterarbeit zwei Umfragen entwickelt, um bei Experten, Prosumenten und Konsumenten Informationen über ihre Erwartungen an ein solches System zu sammeln. Anschließend wurden die Ergebnisse der Umfragen qualitativ und quantitativ analysiert und ausgewertet. Daraus entstand ein Anforderungskatalog, bezogen auf Regulatorik, Sozialem, der Wirtschaft, Technologie und Ökologie. Der Katalog enthält eine Klassifizierung sowie eine Priorisierung der bewerteten Anforderungen. Neben einer benutzerfreundlichen Anwendung sind auch Transparenz, finanzielle Vorteile, Informationsaustausch und Unterstützung der Endverbraucher notwendig, um einen lokalen Energiemarkt über die Blockchain erfolgreich umzusetzen. Aus den definierten Anforderungen ergaben sich auch Empfehlungen für die praktische Anwendung der Technologie. Es wird vorgeschlagen, dass ein solcher Peer-to-Peer-Markt zunächst in kleinem Maßstab getestet werden sollte, um mögliche technische Probleme und die Einhaltung bestehender Rechtsrahmen wie der allgemeinen Datenschutzgrundverordnung zu untersuchen. Darüber hinaus ist es ratsam, sich mit bereits in diesem Bereich tätigen Forschungseinrichtungen und Start-ups zusammenzuschließen. Auf diese Weise ist eine erfolgreiche Umsetzung möglich und bietet eine praktikable Lösung für die Direktvermarktung von dezentralen erneuerbaren Energien.

Declaration

I,

Baur

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hereby declare that the attached thesis,

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was written independently by me without the use of any sources or aids beyond those cited, and all passages and ideas taken from other sources are indicated in the text and given the corresponding citation.

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I agree to the further use of my work and its results (including programs produced and methods used) for research and instructional purposes.

I have not previously submitted this thesis for academic credit.

Place, Date, Signature

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# Introduction

As energy consumption rises with a growing population, there is an increasing pressure on the global energy market to develop. There is an interest in climate protection goals, such as preventing a further rise in temperature or the development of new energy systems and processes. (1 pp. 12–13)

In the last decades, the energy sector has changed due to various processes on both, market and supply side. With the introduction of the Renewable Energy Act (‘Erneuerbare-Energien-Gesetz’ - EEG), decentralized renewable energies have gained power in the electricity market, which only few large power plants held in former times (1 p. 12). In 2012, half of renewable energies in Germany were generated by civil energy plants, where a distinction is made between individual owners, citizen's energy associations and supra-regional contributions of civic energy (1 p. 42).

Since decentralized energy resources play an increasing role in the energy sector, it is necessary to develop and deploy new technologies. Blockchain (BC) technology could be used in the energy sector to facilitate communication and data management between different stakeholders, and to control volatility of renewable energy generation. (2)

With an expiry of subsidies by the EEG, it is expected that electricity generators from small-scale plants will look for new marketing concepts. Integrating BC technology, energy trade can be implemented using the peer-to-peer approach and to enable direct energy marketing on a local area (2 p. 22).

This Master’s thesis explores regulatory, social, economic, technological and environmental requirements needed for a successful implementation. Stakeholders' requirements are identified for the application of a local peer-to-peer market for regionally produced renewable energy using the BC technology.

This leads to the following research question:

*Which regulatory, social, economic, technological and ecological requirements exist for stakeholders to implement BC solutions in a local energy market?*

To answer this question, the following structure for this Master’s thesis has been developed: Section 2, examines existing literature on the topics of regulatory framework for small-scale renewable energy systems, different marketing concepts, peer-to-peer networks, the BC technology as well as the execution of a requirements analysis. This literature review presents current state of knowledge and creates understanding as well as a basis for further investigation of the topic. Section 3 provides a description of the methodical procedure – an expert survey and a prosumer and consumer survey. The section defines the chosen method and describes involved stakeholders. In addition, assumptions from stakeholder descriptions are made, which serve as the basis for the two surveys. Furthermore, different possibilities of the following survey data analysis are presented. Section 4 presents survey results using quantitative and qualitative methods. The section is divided into two parts: descriptive and inferential statistics for prosumers’ and consumers’ survey results, and descriptive statistics and textual analysis for experts’ survey results. Section 5 deals with the interpretation of the survey results and an evaluation of the survey composition and the used methodical approach. This is followed by section 6, the requirements specification. Section 7 offers a conclusion of the findings and key results, addressing answers to the research question. Furthermore, an outlook for further study is given.

# Literature Review

In the following, different topics are focused based on various literature. These include the current regulatory framework of small-scale renewable energy plants in Germany, different marketing concepts for these, the peer-to-peer network, BC technology and the process of a requirements analysis.

Small-scale renewable energy plants are described as plants with the power of less than 100 kW. According to the Federal Ministry for Economic Affairs and Energy, a small plant is described as having an output of less than 100 kilowatts (kW) (3). Also in the EEG, the critical value for feed-in tariff is set at 100 kW (4 p. 15).

## Regulatory Framework for Small-Scale Renewable Energy Systems

With the introduction of the Electricity Feeding Act 1991 in Germany, first political steps were taken to create incentives for the generation of renewable energy. It was the first regulation to request public electricity suppliers to accept and remunerate electrical energy from regenerative sources. Landfill gas, sewage gas or gas from biomass, hydropower, wind and solar power were among these renewable electricity resources.(5)

Thus, a basis to promote green electricity was created. The following regulation – the EEG in 2000 – aims towards an increase of investments in renewable energies. The concrete goal is to raise the share of renewable energies up to 80% by 2050 leaving 20% for fossil fuels. Intermediary steps include goals of at least 40% by 2025 and 55% by 2035. Hence, the EEG shall bring a transformation to the whole energy market system. (4 p. 6)

In 2017, 410 Terawatt hours (TWh) of renewable energy were generated, leading to a proportion of 36,2% of the whole energy market in Germany. Most of it was produced by biomass. (6)

To achieve these goals, financial support for producers from sustainable energy sources is provided. The produced renewable electricity is fed into the power grid. Subsequently, electricity network operators will reward this with a constant feed-in remuneration for 20 years. This shall help to refinance these climate-friendly facilities and thus provide financial security for electricity producers and suppliers. (4)

After producers have fed their electricity into the grid, it is sold on the stock exchange. If sale revenues fall below the paid price for energy producers, the difference is compensated by the EEG surcharge. Consumers pay the EEG surcharge through the price for electricity. It can be described as the difference of output (by the network operators) minus the input (the market price at the stock exchange). The lower the input; the higher the EEG surcharge will be.(7)

**Figure 2-1** shows the compilation of the electricity price in percent for private households with an annual consumption between 2500 and 5000 kilowatt-hours (kWh) in 2017. After the net grid charge, the EEG surcharge forms the second largest portion of the electricity price and thus enormously affects it. (8 p. 1)

Figure 2‑1: Composition of the electricity price for private households according to the Federal Ministry (2018) (8 p. 1)

However, special arrangements cause that companies with high electricity demand (more than one gigawatt hour (GWh) per year) receive reductions in the EEG surcharge. Thus, the German State aims to preserve the economy. This leads to an unequal distribution of costs, as costs for feed-in tariffs have to be redistributed and will be charged to enterprises with small to medium energy consumption as well as private households.(4 p. 51)

Furthermore, as can be seen from **figure 2-2**, the EEG surcharge was increasing in the years from 2003 until 2018.

Figure 2‑2: EEG surcharge evolution for private households according to Statista (2018) (9)

The increase in the EEG surcharge can be explained by the following (7):

* The electricity price on the stock exchange is increasing. Therefore, the difference between the electricity price and the fixed remuneration rises and so does the EEG surcharge.
* If a rising number of renewable energy plants go into operation, a higher amount of renewable electricity is produced. Feed-in tariffs are paid to more producers, which has to be compensated with a higher EEG surcharge.

Yet, the application of the EEG can record positive developments. **Table 2-1** shows the development of gross electricity generation in GWh by renewable resources from 2009 to 2017. The gross electricity generation can herby be described as total generated electricity within an area including the self-consumption of power plants (10). In 8 years, the amount of produced renewable energy has more than doubled.

Table 2‑1: Historical development of renewable energies from 2000 until 2017 according to ‘Bundesministerium für Wirtschaft und Energie’ (2019) (11 p. 6)

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** |
| **GWh** | 105,18 | 124,04 | 143,04 | 152,34 | 162,53 | 188,80 | 189,67 | 216,34 | 225,69 |

But what happens after the expiration of the EEG? Which opportunities do small electricity producers have to profitably sell their electricity?

## Marketing Solutions for Small-Scale Renewable Energy Plants

As already mentioned, feed-in tariffs by the EEG end after 20 years. As of January 1, 2021, new circumstances will come up for first plant operators who started to benefit from the feed-in tariffs starting in 2000. As a result, the question for renewable energy plant owners arises whether their plant is still economically practical, and they stay in the renewable energy market or whether future costs will be too high, leading to a withdrawal from the market. The feed-in tariffs therefore play a central role in the expansion of renewable energies and represent an important aspect of investment security in renewable energies. Nevertheless an entitlement to grid connection and priority acceptance of the electricity generated in a renewable energy plant exists (4 p. 10). Several options exist for plant operators to benefit from their renewable energy plants:

1. Self-consumption
2. Direct marketing via the plant operator or a third party (4 pp. 14–15)

### Self-Consumption

Self-consumption describes consumption of electricity by operators, who generated electricity with a corresponding system. Self-consumption of electricity from renewable energies became attractive due to legal framework conditions. These created an incentive to invest in a generation plant for renewable electricity and to switch from the public energy supply to cheaper self-produced electricity. An installation of a small-scale system nearby the consumer offers an alternative to electricity from the public grid. Consumers use their small-scale plant’s electricity and save costs for the network usage. Special regulations have the effect that some operators with self-consumption must pay no or a reduced EEG surcharge. (12 pp. 146–148)

As the EEG surcharge increased significantly in the last years (as already shown in figure 2-2), this creates an additional incentive for self-consumption

Furthermore, self-consumption is economically attractive in terms of electricity tax costs. According to §26, 28 of the electricity tax law, self-consumption is exempt from tax payments under certain conditions. (13 p. 3302)

### Direct Marketing

Recently the term of sharing economy became popular among various sectors. A plant operator can channel the electricity through a public network and sell it directly to an interested buyer.

Especially information and technology systems have supported the development into this new market concept. Nevertheless, not only new technologies and systems also users’ mindset towards consumption has changed. Greater awareness for sustainability is a key factor of modern society.(14 pp. 2047–2048)

First steps towards direct marketing already started with the market premium in the EEG. The fundamental idea behind this is, that plant operators of small-scale systems can choose between fixed feed-in tariffs or selling their electricity directly to the market with a market premium. (4 pp. 14–16)

This created an incentive to trade energy via direct marketing. The market premium counterbalances differences between market prices and feed-in tariffs (15).

The market premium therefore describes the difference between an offered value (cent per kWh) minus the value sold on the market. In case that the value on the market is higher than the offered value, no market premium is paid. (4 p. 80)

Besides direct marketing with a market premium, the principle of non-promoted direct marketing exists (4 p. 15). In this case, plant operators must ensure the economic efficiency solely by their achieved electricity sales price. This option is rather unattractive for operators of small-scale systems. (16)

### Further Marketing Concepts for Small-Scale Renewable Energy Systems

Due to the development of smart technologies, the energy market of today could run the risk of becoming a niche market in future. In addition to new technologies, several other factors play a role in the development of the energy market. Political changes like the EEG, a shift in the energy industry towards an orientation to the volatile generation of energy, a diverse competition on the energy market including decentralized energy generation, advanced technologies and societal change regarding demography and consumer behavior. As one wants to remain established in the energy market, it is necessary to face new challenges. These relate to developments in the area of energy generation, transport, storage and marketing concepts. (17 pp. 643–649)

To realize long-term availability of energy, owners of small-scale renewable energy plants act as consumers but can also develop into prosumers (2 p. 11). As there is a trend towards energy from renewable resources, and these vary in their availability, it is necessary to develop business models with a flexible energy management (17 pp. 705–715).

New marketing concepts might be interesting for owner of small-scale plants in the renewable energy sector. Examples will be demonstrated in the following.

#### Virtual Power Plants

A virtual power plant is a system that bundles decentralized units in the power grid to one consortium (18). Every decentralized producer, storing or consuming actor in the electricity market can become part of a virtual power plant. A common control system coordinates the association and markets the needed amount of electricity to the end user.(19)

The volatile availability of renewable energies can be circumvented, as in this way, unplanned deviations of individual feeders can be compensated. However, to guarantee enough electricity for the consumer, plant operators must implement controlling and monitoring elements. Monitoring elements are then connected to a central control system so that power consumption and generation can be managed. Storing systems are integrated to make sure that fluctuations in energy supply can be offset.(18)

The case study project "Kombikraftwerk 1 and 2" by the Fraunhofer Institute for Energy Economics and Energy System Technology examined challenges that come along with a virtual power plant. Energy producers using bioenergy, hydropower, or geothermal energy as well as storage systems were virtually linked throughout Germany. The project, which has already started in 2007, has shown that a sustainable way of generating electricity exists, as stable power supply has been guaranteed during the project. When regarding the economic point of view, high investment costs can in future be exceeded by saving costs for fossil resources. (20)

#### Energy Associations

Regarding the development towards sustainable energy markets and decentralized energy generation, the establishment of energy associations is increasing. These citizen’s associations follow the goal to produce energy independently, regionally and with their own renewable energy plants. (21 pp. 153–155)

Energy associations can choose between different legal forms, which influences the characteristics of participation rights individual members have (22 pp. 11–16).

Thus, small-decentralized units arise with the goal to realize an entirely independent power and heat supply. The energy self-sufficient village Feldheim in Brandenburg uses battery storage systems, biogas plants, wind and solar parks and thus supplies their individually connected households with electricity and heat from renewable energy systems via their own distribution systems. (23)

## Definition and Architecture of a Peer-to-Peer Network

A new direct marketing concept, which seems to be an interesting way for decentralized and independent supply of power and electricity, will be explained in the following. It is known as the peer-to-peer system.

### Properties of Peer-to-Peer Systems

The main goal of a peer-to-peer market is to connect vendors and purchasers. Familiar known examples are Airbnb, eBay or Uber. Private providers can offer their products or services within shortest time on theses platforms. To structure the often very heterogeneous offer and match it with specific requirements of consumers, it is necessary to fulfil a matching process. One possibility would be filtering options that allow buyers to prioritize products or services and be able to easily find the favored one. This also shows that in a peer-to-peer system not only [one-to-one relationship](https://www.linguee.de/englisch-deutsch/uebersetzung/one-to-one+relationship.html)s, but also one-to-several relationships might exist, as a consumer could choose between several private energy suppliers. To figure out the appropriate price for an offered product / service, there are different mechanisms. Auctions, for example, offer the possibility of eliciting private information from buyers. With this form of interactive pricing, sellers can achieve the maximum achievable price on the market. To carry out a transaction between buyer and seller, a certain form of trust is needed. Pre-checks, prominence or regulations can accomplish this. Platform providers could implement a certification process that enables only trustful parties to interact on a peer-to-peer network. Reputation is likely to be feasible by means of review or feedback from former or current customers. (24 pp. 616–622)

Whereas in Europe for example, clear rules on treatment of personal data have been implemented (especially with the introduction of the General Data Protection Regulation (GDPR), which should ensure protection of personal data within the European Union (25 p. 32)), in the peer-to-peer area this data is used to maintain the market.

It is questionable to what extent this data is stored for further use. In addition, it is necessary to introduce principles for the fast-developing internet market to create sufficient regulations before suppliers have grown so big, that an implementation of regulations is almost impossible. The question of regulating peer-to-peer businesses with a legal framework is still under research. Therefore, such processes should attract attention and politicians should start regulation already at an early stage. (24 pp. 629–630)

### Challenges and Opportunities of Peer-to-Peer Systems

In summary it can be said, that peer-to-peer markets involve significant advantages, but also challenges that have to be resolved first. Positive aspects include modern technological processes to match buyers and seller, saving of time and low market entry barriers due to little regulatory challenges and less contractually processes as well as lowering costs for consumers based on auction or flexible prices. The range of peer-to-peer applications is broad and promising, but depends significantly on dealing with technological, economic and legal challenges. It is questionable to what extent peer-to-peer systems can offer high data quality, constant availability, data security and an appropriate cost allocation.

Looking at the current developments of the energy market it is noticeable that regional trade of renewable resources using a peer-to-peer concept can decrease losses of used resources due to long transport distances from power plants to end consumers. (26 p. 485)

Thus, a peer-to-peer approach shapes independence of a monitoring third party, so that the existing energy system can be developed into a more heterogenous one. The energy offer can increase immensely given a proper participation of prosumers. Moreover, economic incentives are created when selling self-generated power. However, it should be mentioned that the generation of electricity from renewable resources is very volatile. (27)

Consequential this Master’s thesis declares the system of peer-to-peer market as one form of direct marketing - yet without a regulatory framework. Consumers might interact as prosumers in case they have surplus energy but are not bound to supply electricity based on contractual arrangements. Thus, it can be described as a flexible, self-determined form of direct marketing.

### Requirements for the Application of a Peer-to-Peer System

To apply the concept of peer-to-peer trading on energy markets several requirements should be fulfilled in order to provide a community of consumers and prosumers with the ability to trade and consume regionally generated renewable energy. Especially operators of small-scale plants can benefit from this marketing concept. (28)

Besides this, also the problem to balance supply and demand can be solved (27 pp. 870–871).

To make sure, that a balanced supply and demand for renewable energy is given, several elements should be provided. Reviewed literature has proposed several key factors shaping a successful application of peer-to-peer trade. These elements will be summarized in the following:

1. **Energy grid**

There must be anl energy grid, which serves as connection between several participants of a peer-to-peer network to deliver and receive energy. (27)

1. **Number of market participants**

Only an adequate number of market participants including prosumers and consumers helps to provide various transactions of locally generated energy and security of energy supply. (27)

1. **Performance measurements for the** **grid**

Controlling elements to ensure quality and reliability of the power supply are necessary to give security to participants of the network. This helps balancing demand and supply in the volatile renewable energy market. (27)

1. **Information system**

In order to make sure that participants of the network receive access to necessary data and performance status, an information technology like BC has to be established (27).

1. **Application system**

An interface is necessary, which encourages participation across the network and enables transaction processes, (28).

1. **Sufficient legal regulations**

Regulations about actors’ responsibilities should be declared in detail regarding the implemented energy system (27). Furthermore the way of collecting and processing data has to be clarified (24, 27).

1. **Price and market mechanism**

A competitive system must be developed structuring the pricing mechanism on the energy market (27). Bidding for example is a reasonable method to agree on a pricing level for energy exchange. But also fixed prices might serve as efficient pricing mechanism. (24)

Peer-to-peer networks offer a possibility for decentralized energy exchange and thus represent a new marketing solution. As mentioned, BC can be used as information system. Technical backgrounds and characteristics of this technology will be presented in the following.

## Blockchain Technology

This section shall provide detailed information concerning the BC Technology - a development with diverse opportunities but also drawbacks for future evolution of the energy market.

### Historical Development

2008, Satoshi Nakamoto revolutionized the system of trade known by this time. During a usual transaction, a third party serves as a medium of trust between party A and party B. This third party might be a bank or a merchant. In this case, entire trust is placed on this one medium. It has the right to verify the whole transaction process. Instead of putting all trust to one medium an option exists to split trust to all parties of a network like a peer-to-peer mechanism. Two parties can exchange information and trade directly with each other without the necessity of a reliable third party. Nakamoto introduced this in a way ‘based on cryptographic proof instead of trust’ (29 p. 1). This electronic system was announced with introduction of the well-known cryptocurrency Bitcoin and was the first system to work with a fully functional consensus mechanism. (29)

### Fundamental Functionality

Regional trade is usually controlled by a central institution. In terms of financial systems this central institution is known as a bank which serves as a reliable third party. (29 p. 1)

This third party conducts a solution for the double-spending problem, which occurs when transferring money in digital currency. Thereby the ability exists to spend money twice using counterfeiting. Meaning an individual token could be used up for two times. But in a centralized system, the bank could prove if the token has already been used. (30)

To overcome the inclusion of a central party, BC technology serves as an alternative to safeguard against data manipulation (29). It can be compared with a conventional cash ledger. Therefore, the so-called BC technology is better described as distributed ledger technology with a decentralized database (31).

It is available through a variety of central process units (CPU’s) in a network (29).

Every node (a computer using a distributed ledger client software) of the network is on the same hierarchical level and connected with each other. **Figure 2-3** illustrates how the different networks (centralized, decentralized or BC) are structured. (32 p. 9)

In the BC network data entries are updated chronologically and summarized in a block. A consensus mechanism shared across the network confirms all block entries using a proof concept, which will be explained subsequently. Those blocks build a chain in order to stipulate preliminary transactions and thereby prevent corruption. New data entries of a BC can be created, however old entries can neither be changed nor deleted. With this system, records can be stored, verified by each peer of the network and therefore high security standards can be expected. (31)

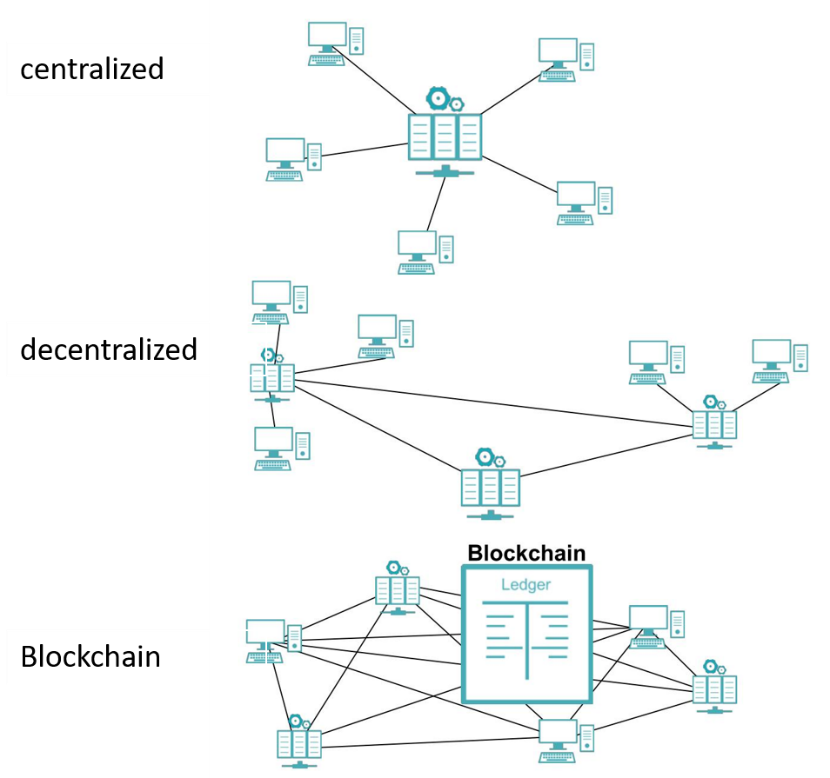
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Figure 2‑3: Centralized, decentralized and Blockchain system (32 p. 9)

### Architecture of a Block

In general, a block can be compared to the page of a ledger. It consists of an identification number, a timestamp, the hash values for every transaction for the previous block and the current block, as well as a nonce value and the difficulty, which represents the required computing capacity to build a block. In addition, a data field for transaction data is available. (32 p. 31)

To make a BC become an actual chain, blocks are subsequently linked with each other. As a block holds several transactions, a representation of all transaction in a block must be found. For this, a ‘solution’ is sought, which represents all data entries in one specific code. (32 pp. 32–35)

Furthermore, it is almost impossible to include manipulated transactions since each block contains the hash value of its predecessor. In order to perform a manipulation of individual transactions, the entire chain would have to be recalculated. (32 p. 20)

### Network and Types of Nodes

The BC network connects various nodes from different locations and thus enables simultaneous storage of data. One distinguishes between full nodes, archival nodes and light nodes. Full nodes can validate blocks and thus interact as miners by summarizing and validating transactions. Without those the whole network could not be kept running. Furthermore, they can conduct transactions. Besides owning the right of performing transactions, archive nodes have information about the whole transaction history. Light nodes act as ‘silent spectator’ and have no rights except the assertion of transactions. (32 p. 19)

### The Private and Public Key Principle

In a distributed ledger network, full transparency is given as every node is permanently able to track each transaction that is carried out. As no financial middle man is involved, a pseudonym is formed using a public key. This public key is the only hint about a node’s identity. (32 p. 12)

Access to a public key account is given by a private key which is created from a combination of numbers. The private key is used for the calculation of the public key. A calculation in the opposite direction is not possible. Therefore, the authentication process in this case is based on asymmetric encryption as shown in **figure 2-4**. (32 p. 22)

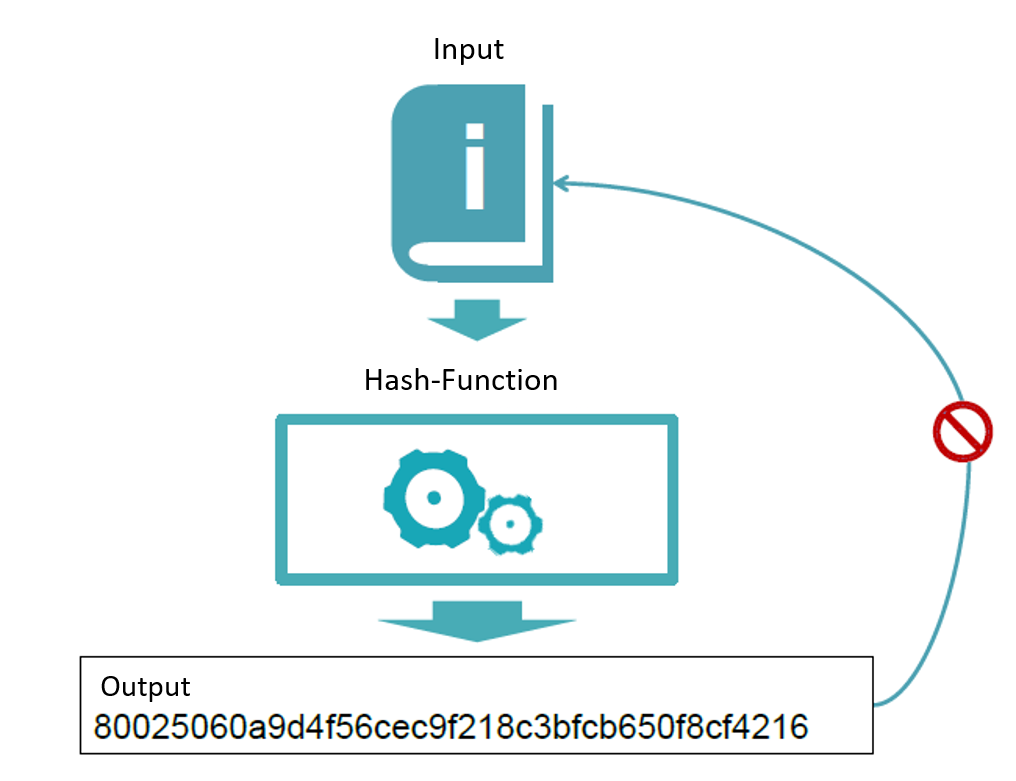
**

Figure 2‑4: Hashing process according to Kaulartz (2016) (32 p. 18)

### Consensus Mechanism

The consensus mechanism is ensuring that the entire network mutually agrees on the contents of the ledger. Information which is added to the ledger is valid and the network is in consensus. This guarantees that the following block represents the most current transactions on the network. Furthermore, it prevents double-spending and invalid content from being attached to the BC. (32 p. 33)

A selection of different consensus mechanisms will be explained in the following.

### Proof-of-Work

To verify a block, one miner gets the right to verify transactions of a block. As a result, the proof-of-work (PoW) system can be introduced. The concept stands for a way of solving a riddle (finding the relevant hash function) by an operator via CPU power. Correlating with higher computing power, the solution of a problem can be allocated faster. The aim is to be the first one to find the hash function. This hash function has to be found by guessing - using the available CPU power. The miner who solved the task first, publishes the new block for validation in the network of the BC. Afterwards the validation takes place through other participants in the BC. After successful validation, the block is added to the BC and thus the BC is updated. Incentive to put effort in finding the correct hash function for a subsequent block is provided by reward in form of a fixed remuneration and transaction costs that are granted to the miner (Bitcoin when considering Nakamoto’s approach). (29 pp. 3–4)

### Proof-of-Stake

In contrary to PoW, validators in the Proof-of-Stake (PoS) consensus act less proactive. Instead of CPU effort, validators invest money in the network and are therefore stakeholders. Afterwards a decision algorithm randomly determines the validator who is allowed to verify a block. Relating to this, a stakeholder who spent more money on the network than the others, has higher chances to be chosen for the verification process. Manipulation attempts of blocks are penalized with the collection of the deposited money resources. (32 p. 39)

### Proof-of-Authority

In the Proof-of-Authority (PoA) mechanism only previously selected nodes confirm blocks. These nodes correspond to real individuals. Thus, this type of BC pertains to a permissioned version, since only few of the entire network have validation rights. (32 p. 42)

Conditions to become an authority are set as following (33):

* A real identity, which can be validated by a lawyer.
* A difficult process to acquire the status of an authority, so that reputation is gained.
* Equal rights for the consortium of authorities.

This consensus mechanism is less energy consuming, as intensive mining processes are skipped, and blocks are validated within fixed times. However, the BC principle of decentralization is lost to some extent. (32 p. 42)

Numerous other consensus mechanisms exist but will not be further discussed.

### Transaction Process

In summary, a transaction process can be described as following according to Nakamoto (2008) (29 p. 3):

1. The transaction history is shared with every node of a network.
2. Every node summarizes transactions within a block.
3. The consensus mechanism to validate a block is carried out.
4. As soon as a correct solution for the block is found, it will be communicated to the other participants of the network.
5. The hash function is accepted if every included transaction of the ‘old’ block is valid.
6. The hash function will be used for the new block

To enable the full bandwidth of functionalities of a BC, essential requirements must be provided. These can be summarized as follows:

1. **Consistency**

Consistency is provided if all nodes permanently have access to the same data (34 p. 6).

1. **Availability**

The system is available if responses are given to every request (35 p. 53).

1. **Partition** **Tolerance**

It is ensured that the system continues working and producing correct results even if a node fails (35 p. 53).

However, only two out of three conditions can be met due to the CAP theorem (36 p. 23).

### Smart Contracts

Another application field of BC is smart contracts. These facilitate the possibility of incorporating programming codes into the system and thus allowing conditional actions to be performed. Smart contract oracles can interact with external data outside the BC and therefore are especially suited to integrate conventional contracts. This enables independent elaboration without third parties such as notaries but still ensures legal assurance. This largely eliminates paperwork and administration costs. (32 pp. 45–46)

### Characteristics of Blockchain Technology

Using BC technology might include various characteristics in both directions: positive and negative. Main features will therefore be explained in the following:

1. **Scalability**

With every transaction, BC adds one more block to its chain of transactions. Thus, data storage increases as the history of all former blocks is represented in the new block. Additionally, with more users joining the network, also more transactions must be verified, leading miners to do a prioritization of transactions that will be verified first. Hence, waiting times increase. Therefore, BCs are restricted in their size and frequency. (37 p. 15)

1. **Energy** **Consumption**

The generation of new hash codes is associated with enormous energy consumption. The longer or older the BC the more energy is consumed. With the inclusion of applications like smart contracts, even more CPU power is needed. Especially the compute-intensive solving of a mathematical puzzle in the PoW consensus mechanism raises the question of the sustainability concept of this technology. (32 pp. 54–55)

1. **Usability**

Not every private user is able to interact with BC. A lack of knowledge in this case prevents users to take part at or to contribute to the system. (32 p. 79)

1. **Irreversibility and Security Concerns**

In a BC system, an indefinitely stored transaction log of each participant is created. Thus, an entry, which has already been verified, can no longer be changed. In case of erroneously executed transactions, there is no return to the original starting situation. The existing situation is irreversible unless one owns more than 50% of the existing CPU power within a network. (38 pp. 4–5)

The GDPR is another important factor raising the concern of irreversibility, since past transactions and thus data is reflected in every block. Although data is not directly attributable by name, but stored in many places, it is readable for all involved parties. It is not possible to remove complete datasets from the BC. Thus, compliance with this law is not possible. (32 p. 55)

1. **Decentralization**

A BC spreads its data all over a network of nodes. There is no need for a central server, which maintains the whole system. (32)

1. **Trust**

In everyday business processes, an intermediary usually assumes the role of a medium of trust, while in a BC system trust is built by transparency. Individuals instead of a third party will confirm digital information and therefore trust is put on the technology. (32 p. 12)

1. **Transparency**

Each transaction of a public address executed via the BC network is accessible to every participant in the network. The technology can allow an immutable tracking of anything executed across the network. As validation of transactions has to be done, every activity can be retraced. Nevertheless with the private key principle, privacy can coexist also with this high level of transparency. (32 p. 12)

1. **Data Security**

Date transactions occur encrypted and with the use of pseudonyms on a BC, which provides a high level of security (32 p. 12).

1. **Speed and Effectiveness**

BC offers huge potential in the throughput of data, which helps to increase speed (32 p. 12).

But it should be mentioned, that with growing size of blocks transactions are handled with increasing time (37 p. 3).

1. **Process Automatization**

With smart contracts, transaction processes can be automatized. As a result, both time and financial losses can be saved or reduced. Thus, business processes can be carried out. (32 p. 12)

1. **Micro-Transactions**

BC technology provides the possibility to process micro-transactions. As a result, even very low value transactions can be processed, both financially or based on data exchange. (39 p. 25)

1. **Tamper-Proof**

As already mentioned, BC technology prevents double spending. Therefore, data manipulation is almost impossible. Thus, ownership relationships can be securely enshrined. (29 p. 8)

## Requirements Analysis

To ensure the success of a local, decentral energy market using BC, it is necessary to perform efficient and extensive planning. A requirement analysis therefore provides a necessary basis to prevent various problems. Different groups of people often have conflicting project requirements. This is due to the uneven level of knowledge as well as different working areas. Therefore, understanding and communication problems arise. Furthermore, effects of the desired system are often difficult to predict and undergo a process of change over time. The complexity of a task also increases the degree of difficulty of a target description. (40 pp. 5–6)

Thus, a requirements analysis assists the act to reach a goal by serving as a description tool. (40 p. 14)

In terms of process engineering, a requirement analysis can be differentiated into four sub processes as can be seen in **figure 2-5**. It should be mentioned that the last step ‘Development of action recommendations’ was added to this procedure model due to the research question of this Master’s thesis.

Figure 2‑5: Process steps of a requirement analysis following Partsch (2010) (40 p. 39)

### Determining Requirements

Determining is possible by using different methods. In this step, the people involved in a project are consulted and requirements are clarified. This can be done using following methods. (40 pp. 40–41)

1. Inquiry techniques e.g. interviews or questionnaires/surveys
2. Observations e.g. workflow reports
3. Document focusing techniques
4. Creativity techniques e.g. brainstorming or mind mapping. (40 p. 40)

#### Inquiry Techniques

Both, written and oral surveys can be carried out as inquiry technique. A written survey will be provided in the form of a questionnaire online or in paper form and can then be completed by respondents. An oral interview takes place in person or via a telephone interview. The personal interview takes up most of the time, whereas telephone interviews or online surveys can save at least travel time and costs. In a personal interview, the interviewer sends queries and might give explanation to certain facts that have to be answered. Critical to consider with surveys (especially personal ones) is the interview bias. The atmosphere, the way a question is posed, as well as subjectivity of questioner and respondent can lead to biased answers. But especially in face-to-face conversations, a relationship can be established and thus a higher degree of answer completeness can be expected than in an online questionnaire. Even early termination of the survey can be excluded, that in turn cannot be guaranteed in an online survey. To draw representative conclusions from a questionnaire, it is important to pay attention to a logical question sequence, one-dimensionality and to include no suggestiveness. (41 pp. 51–56)

An online questionnaire is not only time-saving and therefore also cost-effective, it can similarly be distributed to a wide range of people. To use a questionnaire as a scientific instrument, it must be subject to a certain structure to produce meaningful results. But not only formally, also in terms of content, the questionnaire must be designed in such a way that it can be applied to the group of interviewed people. This means that each question must be formulated in a way that is comprehensible. (42 pp. 53–54)

Usually a questionnaire contains an introductory passage or questions which guide the interviewee to the topic of matter. The main section contains relevant questions for research and are often thematically structured. There can also be an outline according to the importance of questions. More relevant questions are positioned at the beginning whereas less relevant questions are asked at the end. The conclusion includes a short acknowledgement for participation. (42 pp. 55–58)

#### Observations

The scientific observation represents a planned, systematic collection, control and interpretation of data for a defined research purpose based on visual or acoustic perception of an occasion. (43 p. 1)

Such an observation can be performed hidden or in a clearly revealed manner for the person, who is observed. Through observation the detection of subjects one is unaware of is possible. However, in case of an open observation the observed persons might act differently to their usual behavior. Motives, intentions and attitudes of persons cannot directly be experienced through observations. Furthermore, observations lead to intensive work effort since personal involvement is required by this method. (44 pp. 67–97)

#### Stocktaking

Stocktaking as document-centric technique uses data of already existing systems. As it shows the status of a system, the whole functionality according to the used system can be identified. Thereby objective statements can be met. In addition, recording existing data is cost-effective. Disadvantages include a difficult understanding of data, process flows and legitimacy for future development. Therefore, a combination of stocktaking with other techniques is more conceivable. (45 p. 14)

#### Creativity Techniques

The concept of Brainstorming, which was derived from A.F. Osborn in 1957, is sought to find creative solutions based on the principle of free association (46). It is particularly suitable for problem types of simple complexity, as quantity is put before quality. (47)

#### Online Survey Tools

To execute an online questionnaire there are numerous options. A selection of these can be found below.

**Table 2-2** shows a short comparison of four different tools, including their key features that include pricing, export option, survey distribution possibilities and evaluation tools.

Table 2‑2: Comparison of online survey tools

|  |  |
| --- | --- |
| **Name** | **Description** |
| maQ – make a Questionnaire | * Free of charge * Export to Microsoft Excel or SPSS for evaluation * Link to online survey can be sent by mail * No evaluation tools * Rather simple design.(48) |
| LimeSurvey | * Different survey packages from free of charge to 29€ monthly up to 849€ yearly * Data export to SPSS or Microsoft Excel * Link to online survey can be sent via mail or LimeSurvey * Statistics with graphical evaluation and export function.(49) |
| SurveyMonkey | * Different survey packages from 36€ to 99€ per month * Data export to SPSS or Microsoft Excel * Text analysis and statistical significance depending on service package.(50) |
| LamaPoll | * Free trial version for students * Different survey packages from 49€ to 499€ monthly (51 p. 1) * Export to Excel, OpenOffice, SQLite and CSV * Export to SPSS depending on service package * Invitations by importing an address book from Outlook, Thunderbird, Excel, CSV. (52 pp. 1–5) |

#### Survey Evaluation

For the analysis of online surveys two different methods can be used. On the one hand quantitative analyses can be carried out. On the other hand, the method of a qualitative analysis is possible, which can be transformed into quantitative techniques. These two approaches mainly differ in the concept of measurability based on values or expressions of certain characteristics. (42 pp. 118–121)

#### Quantitative Analysis

Quantitative analysis focuses on measurement in numerical values and thus leads to an interpretation based on statistical procedures. In this way quantitative research attempts to identify complex facts using mathematical-statistical methods. (42 pp. 121–129)

#### Descriptive Statistics

At the beginning of a quantitative evaluation, descriptive statistical methods are used. Absolute and relative frequencies in percentage are presented in [frequency table](https://www.linguee.de/englisch-deutsch/uebersetzung/frequency+table.html)s. In this way, an overview of the characteristics of each variable can be obtained. This is done for nominally scaled data series. Ordinally scaled data can determine the median which divides data sample in half. For interval data the arithmetic mean, or the standard deviation can be calculated. The arithmetic mean is defined as the average value of an expression over the total number of expressions. Whereas the standard deviation calculates the dispersion of values around the arithmetic mean. (42 pp. 121–124)

#### Inferential Statistics – Hypothesis Testing

Descriptive statistics can be followed by inferential statistics, which focus on testing the truth content of previously formulated hypotheses using a random sample. This should reflect the total population. Thus, it is examined whether results are based on a scientific legality. Testing these hypotheses uses probability statements only. This means that hypotheses can never be confirmed or rejected for certain. This is only the case for a specific probability. Therefore, a significant level alpha is given, which determines the error probability. (42 pp. 124–125)

Two different error types are possible when conducting inferential statistics. On the one hand one could mistakenly reject the null hypothesis, although that it is true (type one error or alpha error), while on the other hand, the hypothesis can be wrongly not rejected (type two error or beta error). (53 p. 448)

At the beginning of each hypothesis test, a null hypothesis H0 and a rival hypothesis H1, which contradicts the null hypothesis, are established. The significant level alpha is determined. Afterwards data is collected, and a summarizing test variable is calculated based on this data. The rejection range is determined and finally the null hypothesis is rejected or not. (54 p. 371)

To conduct a test scientifically correct, the sample must be randomly selected and not be biased (55 p. 248).

In addition, it must be assumed that a test is always performed according to a methodical approach. This means, that a test fulfils the same framework conditions for each data set of the sample. A different level of significance must not be selected for person A than for person B, just to confirm or reject a hypothesis. (56 pp. 214–215)

Hypotheses can have different properties. Non-directional hypotheses assume a difference between the compared values, which can be directed upwards and downwards. Directional hypotheses assume a difference between the examined values in a certain direction, i.e. either upwards or downwards. Specific hypotheses give information about the expected difference of the examination, while unspecified do not record a certain minimum or maximum value. (55 pp. 247–248)

To test a hypothesis, there is a large number of different tests. Depending on the research question and the data, different testing options are possible (55 p. 248). The most common ones are described below.

* A z-test assumes a normal data distribution. It tests whether the arithmetic mean from the sample corresponds to the population mean. In addition, characteristic values such as the standard deviation and the standard error are applied. (55 pp. 254–257)
* Similar to the z-test, the standard error and the standard deviation are also used to calculate the t-value in a one-sample t-test. This is also used to compare the mean value of the sample with the basic population. However, the t-test can also be used for small samples, whereby a t-distribution is assumed instead of a normal distribution. (55 pp. 257–259)
* Unlike these tests a binomial distribution can be used for discrete data. The binomial test is used to test hypotheses regarding characteristics with two expressions, i.e. are dichotomous. An example would be ‘yes’ or ‘no’. The cumulated probability can be used to make statements about the probability which of the two expressions occurs. Thus the null hypothesis can be rejected or not. (55 pp. 248–251)

As soon as the binomial distribution probability is calculated, it is compared with the significant level alpha. If the probability is smaller than alpha, the null hypothesis can be rejected according to equation (1). (57 p. 121)

|  |  |
| --- | --- |
|  | (1) |

#### Inferential Statistics - Regression Analysis

Besides testing hypotheses, regression analyses can be used. These have the goal to describe the influence of one or more variables on another variable. A distinction is made between the ordinary linear regression and the multiple linear regression. In case of an ordinary linear regression, the influence of one independent variable X on the dependent variable Y is determined. In addition, statements can be made about the direction (negative or positive) of influence and about the factor by which the influence becomes noticeable as soon as the X variable changes. Using the method of least squares, a regression line is drawn up, which mathematically represents the relationship between X and Y. It tries to find a straight line for which the distance to the single variables of the data set is smallest. (58 pp. 192–209)

In equation 2, this relationship is represented mathematically.

|  |  |
| --- | --- |
|  | (2) |

In equation 2, b0 describes the Y-intercept. It defines the value Y when the X variable is zero. B1 expresses the factor or regression coefficient by which the Y variable changes as soon as the X variable is increased by one. The regression line described by equation 2 is only an estimate based on sample data. In addition, an ordinary linear regression is defined here, since only one single X variable is used to describe the Y variable. (58 pp. 196–199)

A multiple linear regression adds further independent X variables, to explain their combined influence on the dependent Y variable (58 p. 210). Equation 3 demonstrates n-many X variables that are used to calculate the Y variable:

|  |  |
| --- | --- |
|  | (3) |

In order to determine how much explanatory content is determined by the estimated regression line, one can consult the coefficient of determination R2. It therefore states how much of the Y variable can be explained by the X variables. Since a higher R² can be obtained by involving several variables, one can additionally calculate the adjusted coefficient of determination R²adj. This adjusted coefficient of determination calculates this distortion error and thus reflects a credible certainty measure. (58 pp. 210–212)

#### Qualitative Content Analysis

In his general content analytical process model Mayring (2014) describes that all activities of a qualitative content analysis are systematically structured and have to be carried out according to a certain program sequence. A qualitative content analysis follows three basic methods, all of them based on the development of a category system. These categories are derived either inductively or deductively. (59 pp. 63–64)

In the following these techniques will be further explained.

Reduction

The aim of this analysis concept is to reduce the textual content so that crucial parts are preserved. With this, a manageable corpus is created, which represents an outline of the whole content. (59 pp. 64–65)

For reduction there exist two different forms, on the one hand summarizing and on the other hand inductive category formation as can also be seen in **figure 2-6**.

To conduct a summary, first paraphrasing is carried out, whereby unimportant text components are removed. Afterwards the text is adapted to a standardized style and shortened further. This is followed by repeated generalization through text shortening, text combination and reformulation to a chosen level of abstraction until key sentences as categories remain. (59 pp. 66–68)

The inductive category formation on the other hand establishes categories while reading through the text. The categories are formed by certain text passages and will be checked after about a half of the text resources have been read. The categories are then revised so that solid material is shaped for evaluation on the basis of frequency tables. (59 pp. 79–80)

Explication

The object of this analysis is to explain incomprehensible text parts, such as interview passages or unusual expressions with the help of supplementary text material. (59 p. 64).

For an explication one differentiates into a narrow contextual analysis und a broad contextual analysis. Whereas narrow contextual analysis directly refers to text passages and tries to explain these, broad contextual analysis adds extra text material. This might include background information on the author or the literature itself. (59 pp. 89–90)

Structuring

The last analysis concept collects certain aspects from the text passage in order to create an average profile of the provided material. This is done by screening the text using previously defined classification criteria. (59 p. 64)

As can be seen in figure 2-6 it is also subdivided into two different methods – nominal or ordinal deductive category assignment. Ordinal categories are in a grouping or an order like grades in school, while nominal categories have no grouping nor an order e.g. colors. (59 p. 98)

As mentioned above the three basic concepts: **reduction**, **explication** or **structuring** for qualitative evaluation can be further differentiated. Mixed forms are also possible as figure 2-6 shows. Depending on the given text and existing theoretical concepts, a special analysis method can be applied. Figure 2-6 gives an overview on the different analysis types.

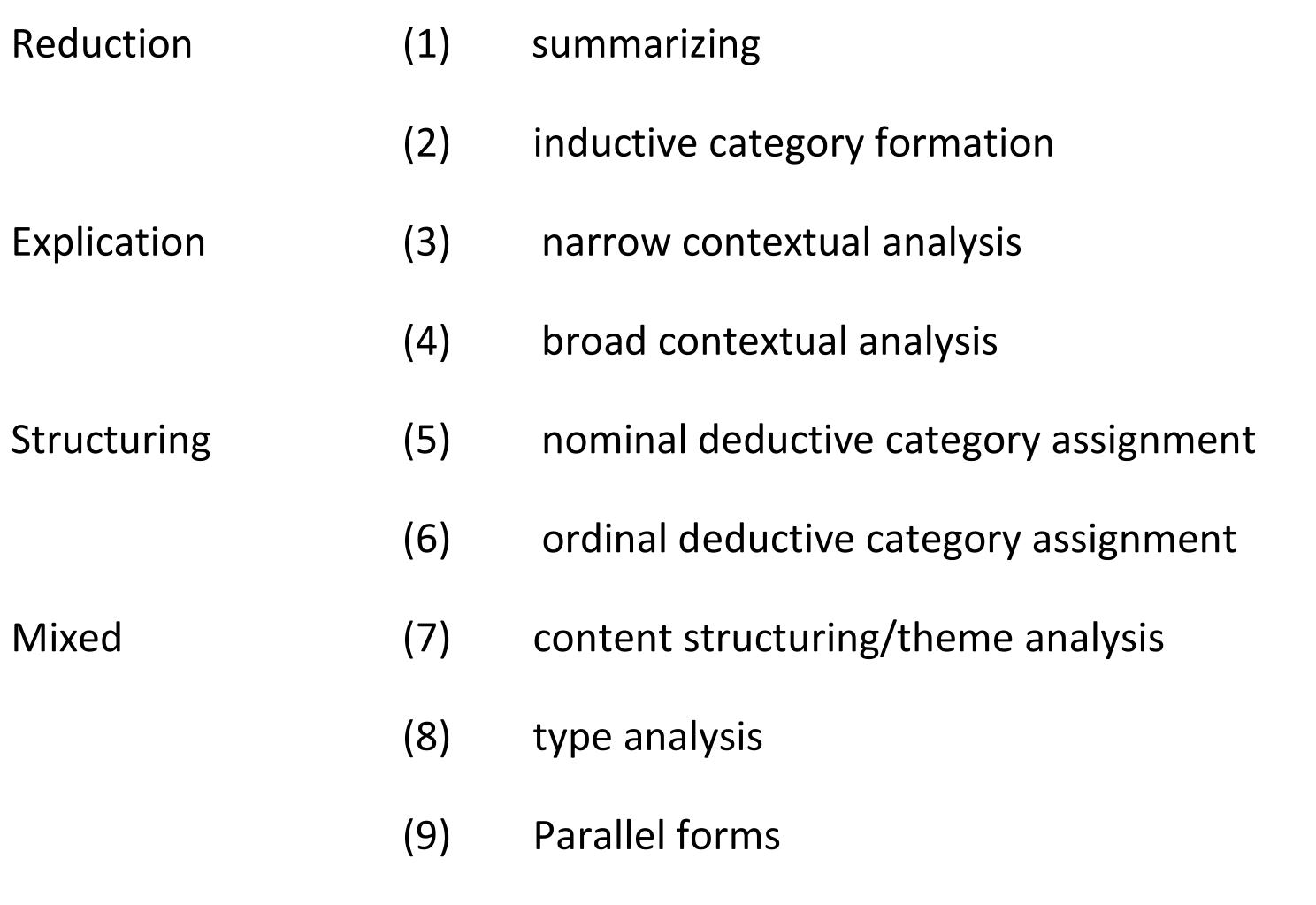
**

Figure 2‑6: Forms of qualitative content analysis according to Mayring (2014) (59 p. 65)

Inductive Category Formation

Whether the method of summary, explication or structuring should be conducted for a qualitative content analysis depends on the material.

By using the inductive category formation (which can also be seen as point (2) in figure 2-6), it is possible to create a summary of the content on basis of non-theoretical category formation. Thus, only essential information is summarized from the text. In addition, not all steps of the summary need to be exercised, which can save a significant amount of time. In contrast to a summary, irrelevant material can be neglected and does not have to be added to the category construct. The analysis is not distorted by theoretical concepts, which would examine the text according to certain criteria only. (59 p. 79)

The concept inductive category formation is based on 8 main steps, which can also be seen in **figure 2-7**.

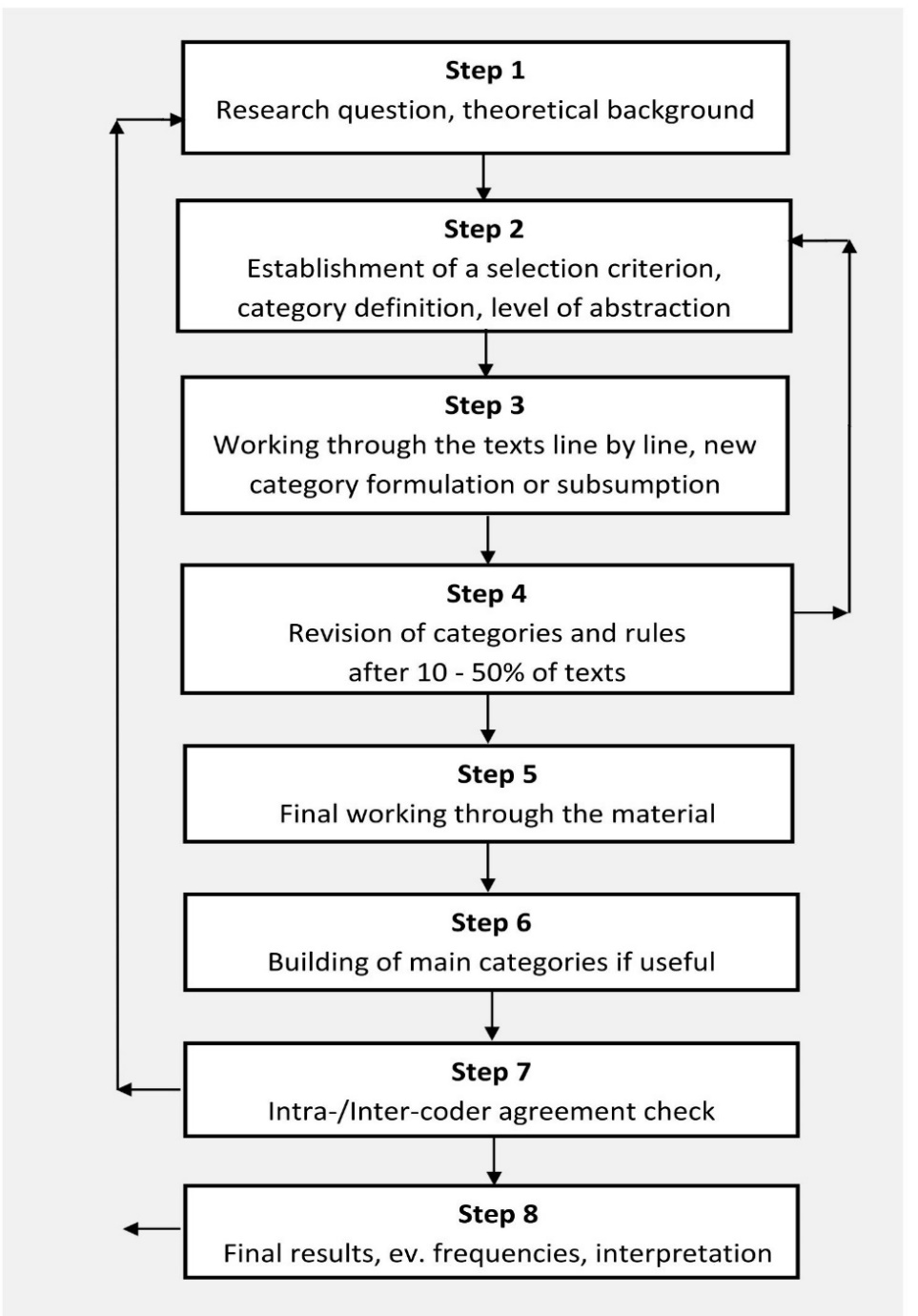
**

Figure 2‑7: Process of Inductive Category Formation (59 p. 80)

First, the research question is introduced based on a literature-guided review. As a second step, a criterion is established after which a text excerpt such as a word or phrase parts are added to or build a certain category also described as coding unit. At the same time, it is defined how abstract or how explicit the individual categories are set up. Afterwards the text (recording unit) is read line by line and components that match the previously defined criteria are added to categories. If a category does not yet exist, a new one is created. This step is performed until up to 50% of the total text material has been looked at and nearly no new categories are added. Then the created categories are checked for their meaningfulness and whether they are conducive to the research question. Finally, the whole coding process can be done a second time and results from the first round are compared with those. Finally, quantitative methods were used to demonstrate measurability of the results found. (59 pp. 82–84)

### Documentation

It is insufficient to pass on requirements orally or per mail to project participants, as otherwise components of the requirements are lost or passed on in a misleading manner. This can ultimately lead to failure of the entire project. Therefore, requirements must be documented in a structured way that is accessible to every stakeholder. (60 p. 87)

Written **documentation** of different requirements with subdivided partial aspects is done by recording those in a central requirement document. There are two possible options (61 p. 2):

1. **Tender Specification**

It describes all demands of a contractor to the order, which has been determined by a client. It involves a brief description with a fixed structure of basic requirements from the client and a description of what and with which goal something has to be done. Thus, the basis for the performance specification is created. (61 p. 2)

1. **Performance Specification**

Requirements, which have been described in the tender specification, are now combined with technical demands. Meaning that solutions to achieve requirements are defined. (61 p. 3)

In order to achieve the goal of an informative and well-structured document, the tender specification should include subsequent sections following ‘Verein Deutscher Ingenieure’ (2001) (61 p. 4):

1. Project outline
2. Report of the initial situation
3. Tasks for the target condition
4. Interface description
5. Different requirements in categories

When requirements are set out in a specification, it is of great necessity not to leave any room for interpretation. In addition, it is important to mention that requirements are strictly different from solutions. A requirement is fixed, while solutions are adaptable. (60 pp. 90–91)

#### Composition of a Single Requirement

A single set of requirements can be created based on following pattern (60 pp. 92–93):

Figure 2‑8: Composition of individual requirements according to Ebert (2012) (60 p. 92)

With the help of this sentence template, requirements can be formulated in as much detail as possible but still clearly understandable. Only one requirement is listed at a time and several requirements are not combined in one sentence. This can prevent incomprehensibility or misinterpretation in the elaboration process. The priority of an individual requirement can also be defined using different conditions (must, shall and can). (60 pp. 92–94)

Each requirement should be assigned a number, which serves as a unique identification key. In addition, a requirement title is assigned, which is intended to briefly and concisely reflect the core statement of the requirement. This is followed by an explanation of the request. In addition, there is a prioritization, as well as a classification of assessable requirements (functional, non-functional), which will be explained in the following. (62)

#### Classification of Requirements

To complete the documentation of specifications, also a classification of requirements should be done. The requirements are classified based on functional and non-functional requirements. Functional requirements refer to what is done, or which functions should be enabled. Thus, relevant inputs for the system, required processing steps and, outputs are described. Consequently, the behavior of the system itself is described. (40 p. 27)

Workflows can also be recorded as functional requirements. In addition, test cases can be described as functional requirements. Their parameters are suitable for validation and verification. (60 pp. 31–32)

Non-functional requirements, on the other hand, relate to how the system should perform its services (40 pp. 27–28).These requirements complement functional requirements and therefore only make sense in conjunction with them. Examples include reliability and availability. However, these requirements are problematic in their implementation and testability. (60 pp. 32–33)

Constraints can be described in addition to the requirements mentioned above. These count as restrictions of a system’s solution. Possible constraints can be of technical, organizational or normative nature, such as system interfaces, business processes or laws. (60 p. 34)

#### Prioritization of Requirements

In addition, a prioritization of individual requirements should take place. This is necessary in order to take both: technical and management-oriented decisions. It supports drawing up a time schedule. (60 p. 157)

Requirements can be prioritized based on various criteria. They can be prioritized according to their importance or stability. Importance expresses how essential a requirement is. Stability, by contrast, expresses how many changes are expected for a requirement due to fluctuations in the given environment. (62 pp. 6–7)

The prioritization of a request is one of the most important steps of a project. A product is only accepted by the customer if it has as many features as possible that meet the previously established requirements. Since a product can rarely meet all requirements in detail, it is of great importance to first implement the most important requirements. Only in this way a timeframe can be adhered to. Less important requirements can be introduced subsequently. (60 p. 157)

### Evaluation of Requirements

**Evaluation of the requirements** is performed by checking for fulfilment of different criteria, which is necessary in order to mediate between various stakeholders and to ‘translate’ single aspects. (40 p. 51)

Therefore, it is more important that individual criteria are met. These include following features (62 pp. 3–8):

1. unique (only one possible interpretation exists)
2. complete (explicit identification of open issues)
3. consistent (no contradictions using consistent terminology)
4. correct (only reasonable requirements)
5. verifiable (using a measuring method)
6. weighted (prioritized)
7. modifiable (clear structure, no redundancy)
8. comprehensible (record source of requirements)

### Development of Action Recommendations

One of the las steps is the development of practical **recommendations** for action. These should help to facilitate the implementation of the investigated process. QUELLE

# Survey Design – Methodology

BC technology is not only interesting for cryptocurrency, as it has the potential to change the energy industry. Due to an expiry of the EEG surcharge, small-scale plant operators might be interested in new, direct marketing channels. To apply these direct marketing options, the BC technology could be used. Therefore, this Master’s thesis is based on inquiries to determine which requirements for a BC system must be implemented in order to engage local renewable energy trading between prosumers and consumers.

## Goal of Stakeholder Inquiries

To find requirements, stakeholder inquiries in form of online questionnaires were used. For this purpose, two stakeholder groups were asked, consisting of group 1 the experts and group 2, prosumers and consumers. Time and cost for this inquiry method are within a reasonable range, as interviewees can be contacted simultaneously across any distance. The time span of this Master’s thesis is not sufficient for conducting interviews for all stakeholder groups. In addition, this method allows a larger number of respondents to be reached, which increases the sample size and thus provides a better picture of the overall population. Also, transcription is not necessary and there is no risk that data will be incorrectly recorded by manual input. The stocktaking method cannot be used in this case because no data or experience reports are available. Observations do not highlight the necessary background, as personal opinions are not captured. For the use of a creative technique, the issue is too complex and an entry to the topic does not give necessary background information.

To provide a basic framework for the online surveys, short stakeholders’ descriptions are provided.

## Stakeholders

Stakeholders are among the most important resources of a project. It is necessary to carefully think about who stakeholders are and which influences and interests they have. This way all relevant requirements can be found (63 pp. 34–36).

Regarding the choice of respondents, it has to be considered to question people with a certain amount of background knowledge on the mentioned topic in order to reflect representative results. A description of stakeholders is given below, to support the theory why a certain group of people is experienced in the field of research. Respondents have been divided into two stakeholder groups and their description include professional backgrounds, but also future or current points of contact with the BC technology.

### Stakeholder Group 1 – Consumers and Prosumers

Stakeholder group 1 includes consumers and prosumers, whose backgrounds will be presented in the following. These were partly investigated literarily, but also determined by brainstorming, as suggested by Hruschka (2019) (63 pp. 36–37).

#### Consumers

Consumers can be individuals, households or a group of people who have the same consumption goal and thus want to minimize their costs. (64)

Therefore, it can be assumed that, consumers choose energy sources for heat or electricity supply that maximize their benefits. In addition, consumers are interested in a stable energy supply. They want to be able to freely decide when and how much electricity to use and not to be restricted in their consumption. It can be assumed that consumers prefer to agree to an automatic energy supply process. Micro transactions for each individual appliance take time and should therefore be bundled and run automatically. This saves consumers’ time and effort. In addition, consumers are used to receiving an annual bill for their electricity consumption. BC technology gives consumers more decision-making power over their contracts. Through direct contracts, BC allows lower transaction costs and forms a decentral coordination of supply and demand as described in section [2.5](#_Blockchain_Technology).

Not every consumer has the necessary background knowledge to deal with BC technology. Many people associate the term of BC only with cryptocurrency or, more precisely, Bitcoin. The potential and challenges behind it are hardly known. Therefore, information should be provided, and the potential of BC should be illustrated based on case studies. To offer every consumer the same access to BC, user-friendly software or application should be available.

Consumers are also interested in secure data administration. They do not want their private information to be freely available to everyone. In addition, they have the right, that their data can be removed from a system according to the GDPR.

To interact as a natural person and to be able to perform transactions, consumers must have a minimum age of 18 years. Between 7 and 18 years, children and young people have limited legal capacity, which means they are not allowed to enter into transactions without the consent of their legal representatives. (65 p. 37)

This also affects the conclusion of a contract with an electricity supplier. Therefore, it is questionable if BC technology is able to comply with this law.

It is important for consumers to get a certain amount of transparency that allows them to see where the electricity is coming from and how it is priced compared to other electricity providers. This is something that BC could provide within real time. Also, insufficient technical functionality, or problem management in the event of fraud are fears that consumers might have towards a BC.

#### Prosumers

Consumers, who interact as operators and sellers for small-scale plants in the renewable energy sector, or producers, who act as consumers can be described as prosumers. (66)

Households that are no longer just interacting as consumers, but also produce electricity and consume it themselves if needed, have intrinsic and/or extrinsic motivations behind this. Besides the profitable energy investment or the idea of an environmentally friendly energy generation, external factors play a role. An independent self-supply with renewable energy or a stable financial income rank among those motivation factors. (67 p. 1)

As plant operators, they bear the function of power generation and have to deliver diverse technical and business skills. In accordance with the German Energy Industry Act prosumers are required to ensure technical safety during the construction and operation of energy plants (68 pp. 91–92).

Due to the EEG, prosumers were able to sell their electricity with a price guarantee for 20 years. This caused a significant increase in the market presence of prosumers. With the expiry of the feed-in remuneration, prosumers are responsible for the marketing of their renewably produced energy and might worry about a stable financial income. They can sell their energy directly or by services of a third party. However, achieved sell prices might decrease if participation on the renewable energy market is increasing. In addition, it is relevant to keep facilities on the latest technological status. Hence, future development of electricity prices includes uncertainties, which have to be carried by prosumers. It is unclear whether prosumers want to afford such expenses or if they are able to do so with their resources and expertise.

However, BC technology could help prosumers to take part in a peer-to-peer network. Market entry barriers could be reduced, and market participation might be more difficult to prevent. Thus, more prosumers will be able to participate in the energy market, enabling a heterogeneous offer on the market. Even if this still involves some regulatory challenges. It is questionable if the use of a BC will affect trade regulations and if prosumers have to apply for something like an energy supplier license.

### Stakeholder Group 2 – Experts

Stakeholder group 2 consists of experts from different areas. Experts are well-informed people with specific knowledge concerning their individual field of experience. They represent certain organizations or departments and have internal expertise, which helps to set up encompassing requirements (63 pp. 35–36).

Therefore, following stakeholder descriptions for the group of experts has been set up based on literature and brainstorming.

#### Distribution System Operators

DSOs run electricity networks for the distribution to end consumers. They maintain power grids on levels in low- and medium-voltage range for regional power supply. (69 p. 56)

Due to their conversion from vertically integrated energy suppliers to regulated energy carriers with network service function, they appear as legally unbundled entities. (70 p. 171)

DSOs must take over real-time control of systems and thus ensure an uninterruptible and efficient power supply. Thereby the implementation of intelligent measuring systems is a key factor.(70 pp. 121–122) Difficulties may arise for them in energy supply due to flexible or volatile feed-in of electricity from renewable resources. Smart meters could therefore be used to provide DSOs with information about consumption, production, and storage conditions. Combined with the BC technology this information could be shared with any participant of the network within shortest time and therefore help to balance supply and demand in the energy market precisely. The increase in the decentralized energy supply will lead to high costs due to an increasing network expansion (70 p. 39). But DSOs achieve their highest profits by using networks to their full capacity and invest as little as possible in new construction and maintenance. Since all applications for a connection to the grid must be treated without discrimination, an anonymization of the application procedure is required (70 p. 156). BC technology could also be used in this case to provide a transparent but pseudonymized overview of all applications.

In future, DSOs could take over the organization of automated energy trading between end customers. With the introduction of a peer-to-peer market system, new business models for distribution system operators arise. Service offerings and trading platforms outside of the network level are becoming important. In regards of the field of production, they might market their knowledge to new players like prosumers. In addition, planning, installation and maintenance of small-scale systems or operation of accounting systems could become an interesting business sector. (71 pp. 33–40)

#### Blockchain Technology Experts

BC experts see potential in the use of this technology for the energy sector. A decentralized transactional system, collaborative secure documentation of data, and an independent energy supply system are a few technical possibilities. Experts in the field might expect high development potential and a market with options for them to expand their current business areas. However, to realize an application of BC technology in the energy sector, confidence in security and reliability are crucial. Therefore, data manipulation should be prevented by using limited access networks or a consensus mechanism with high security standards. Yet there is no ‘German’ BC, which is accepted and used by all participants in the energy system. Therefore, technology experts have to demonstrate, that a secure application is possible and that an integration into an accepted legal and regulatory framework is feasible. Hereby compliance with GDPR is important. This raises the question of if a society is willing to trust a decentralized technology rather than established institutions. Traditional databases are in competition with the BC technology to map decentralized transactions. Furthermore, scalability and referring limitation in size and frequency of the BC network have to be developed. Therefore, technology experts will have to convince when setting up a BC in the market.

#### Electricity Suppliers

Electricity suppliers take care of provision a plant operator’s electricity. They take decisions on resale on the electricity market.(72) With the inclusion of BC technology, concerns arise regarding a loss of market power for electricity suppliers. Decentralized power generators sell electricity directly to an end user. The processing of the payment can also be done by the BC. In this way, a direct transaction without an intermediary (electricity supplier) is possible. This means that electricity is directly exchanged between producer and consumer.

However, the service offered by electricity suppliers is central to a large part of a system operators' ability to use direct marketing. Without them, market integration is rather difficult, as technical and market expertise are essential factors to guarantee successful energy sale. Energy providers could use this knowledge and offer it within service packages to their customers. (71 pp. 35–37)

To remain in the market, energy suppliers must defer their business to the liberalized supply market and deploy new technologies. A transformation process towards a digital energy service provider offering a high variety of products in the energy sector is indispensable. The focus is less on the exhaustion of the energy market with regard to the largest possible sales of electricity but on the offer of service packages for customers. (71 pp. 17–22) BC technology provides electricity suppliers opportunities to develop diverse new business units (71 pp. 70–72).

With the project ‘Tal.Markt’, the local municipal utility of Wuppertal has launched an online platform, where customers can buy their green electricity from local suppliers. The municipal utility uses BC technology to start new business by operating the trading platform and take care of the formalities like billing processes. (73)

In the same way, the energy supplier Innogy steers in the direction of BC technology with its Project BlockCharge by establishing charging processes of electric vehicles through BC-based charging and billing systems, as Burger et al. (2016) points out (2 p. 13).

This shows that the BC technology is already known in the electricity provider industry and they have already conducted studies in cooperation with research institutes and management consultancies.

#### Regulators

In Germany, the ‘Bundesnetzagentur’ mainly handles energy regulation. Tasks include control and approval of grid utilization charges and the creation of access to electricity and gas networks. In this way, sustainable competition and transparency should be ensured. (74)

Based on the report ‘Digitale Transformation in den Netzsektoren’ published in May 2017, it can be seen, that the Bundesnetzagentur has already dealt with the topic of digitization of the energy sector. In addition, the BC technology and the implementation of local energy markets has been mentioned. But, necessary computing power for BC technology and thus related energy needs have also been mentioned. (75 p. 72)

Beyond that, consumer protection plays an important role as it is desirable that BC technologies follow current data protection laws. Consequently, regulatory authorities have to face diverse challenges, which have to be clarified before a transformation of the energy market is enabled.

#### Plant Manufacturers

The expansion of renewable energies in Germany might have positive effects regarding the occupancy rate of plant manufacturers in the regenerative sector. With the expiry of the EEG, this could change again. As financial support will cease, renewable energy business may lose its interest again. It would be entirely up to prosumers to finance maintenance investments for a small-scale plant and no financial security would be given. However, this could be prevented by the introduction of BC technology. Prosumers could use the peer-to-peer system and thereby promote the use of decentralized energy supply systems. This would ensure that the market position for plant operators in this area remains.

#### Meter Operators

Meter operators measure all necessary meter data for billing and net fee calculation. This will then be distributed to electricity suppliers for individual billing, as well as to distribution network operators. (76)

The integration of BC technology will lead to changes for this role. Meter operators no longer have to measure data themselves, but the entire documentation of consumption and transaction data can be taken over by the BC, also in combination with smart metering systems. This can be an automated process and even smallest units of fed or used electricity can be detected. This reduces a meter operator’s workload, which have to install, operate and maintain measuring pointsand their measuring equipment (76 p. 6)*.* The task of reporting measured values will be handed over to consumers

Since 2017, there has been an obligation for certain consumer groups as well as producers with small-scale systems to install smart metering systems. These serve as a safe and standardized technology for energy efficiency or network operation. (77)

For the BC technology to be used together with such intelligent measurement systems, a node must be implemented into a smart meter. This raises the question of how far meter operators are capable of doing this.

#### Scientists

Another relevant expert group is made up of scientists from various fields, such as information technology or the energy industry. This group of people researches latest topics and has access to a wide range of information. The expert group is independent of the energy market and can therefore make objective statements.

## Assumptions for Requirements of a Blockchain System

Based on the stakeholder descriptions, assumptions can be made about requirements which might be necessary for local trading of renewable energy through BC.

**For both stakeholder groups** an assumption set consisting of if-then assumptions with categorical characteristics was created.

* **A 1:** If the BC technology is introduced into a local energy market, it requires financial incentives for all involved stakeholders (e.g. consumers can minimize their costs).
* **A 2:** If the BC technology is introduced into a local energy market, an easy to handle payment system to conduct energy transactions must be integrated into it.
* **A 3:** If the BC technology is introduced into a local energy market, a fixed pricing mechanism should be introduced to deliver best possible financial results for consumers and energy providers.
* **A 4:** If the BC technology is introduced into a local energy market, a stable, efficient and permanently disposable energy supply must be provided by the use of real-time control of energy supply and demand due to the volatility of renewable energy.
* **A 5:** If the BC technology is introduced into a local energy market, the participatory process should be simplified with the help of user-friendly applications, which have to be compatible with the BC network, so that purchase and supply transactions for electricity are bundled and run automatically.
* **A 6:** If the BC technology is introduced into a local energy market, acceptance and understanding of BC technology must be promoted through sample projects and institutional education.
* **A 7:** If the BC technology is introduced into a local energy market, stakeholders’ trust into a decentralized energy market instead of well-established third parties has to be created.
* **A 8:** If the BC technology is introduced into a local energy market, unauthorized access and data manipulation in a peer-to-peer network using BC must be prevented by the use of a private BC network with a PoA consensus mechanism in Germany.
* **A 9:** If the BC technology is introduced into a local energy market, the GDPR and associated protection of data privacy must be fulfilled and can be described as most difficult challenge.
* **A 10:** If the BC technology is introduced into a local energy market, for the introduction of BC technology in the energy industry, there must be regulations and checks whether and how individual stakeholders can participate (e.g. by issuing licenses).
* **A 11:** If the BC technology is introduced into a local energy market, the possibility to include contract changes and certain contract components must be possible by the use of BC technology.
* **A 12:** If the BC technology is introduced into a local energy market, it must help to reduce market entry barriers in the energy market, thus increasing participation in this market and making it more heterogeneous.
* **A 13:** If the BC technology is introduced into a local energy market, its set-up in the energy market has to offer significant technological advantages compared to other technologies.
* **A 14:** If the BC technology is introduced into a local energy market, limitation problems on the amount of transactions the BC network can process referring to its scalability have to be solved.
* **A 15:** If the BC technology is introduced into a local energy market, it must be compatible with or integrated into other devices (e.g. smart meters) in order to use it.
* **A 16:** If the BC technology is introduced into a local energy market, different user interfaces must be provided for different groups of participants. (e.g. end consumers only have access to web interfaces while city utilities should also have access to the database system).
* **A 17:** If the BC technology is introduced into a local energy market, environmental impacts based on high power consumption through hash computation must be reduced or circumvented (e.g. using PoA consensus mechanism).
* **A 18:** If the BC technology is introduced into a local energy market, a high amount of transparency concerning energy sources or pricing mechanism has to be provided for all stakeholders.
* **A 19:** If the BC technology is introduced into a local energy market, through the introduction of a peer-to-peer trade market for renewable energies a larger and more heterogenous participation will take place as market entry barriers will be reduced. As a result, the energy transition can be driven forward.
* **A 20:** If the BC technology is introduced into a local energy market, solutions to the compensation of costs for BC infrastructure must be found, as DSOs will not agree on bearing these costs completely alone.
* **A 21:** If the BC technology is introduced into a local energy market, DSOs, electricity suppliers and meter operators need to develop new business models to survive on the energy market.

As these assumptions served as basis for the questions, they subsequently supported the process of drawing up the questionnaires.

## Survey Design

To collect the necessary data and test the already formulated assumptions, two different online questionnaires were created. One for stakeholder group 1 and one for stakeholder group 2 – these can also be found in the appendix A.1 and A.2

As the research project is conducted in cooperation with the Thüga AG, the survey tool LamaPoll as described in section [2.5.1](#_Online_Survey_Tools) was chosen. This tool is also used by the Thüga AG and offers a large number of useful features. Besides interactive questionnaire elements such as drag and drop modules for sorting elements, there are also various evaluation options available. These support subsequent evaluation and analysis of the answered surveys.

First, the two surveys were transferred to the platform LamaPoll by means of a student access to migrate it to an employee account version later. After a final revision, the surveys were migrated to the online access of Thüga to use its network for further distribution. From the Thüga account the surveys were started. Afterwards the surveys were sent as a link by e-mail to different target groups including the network of Thüga and Technical University of Munich. Furthermore, the survey was also shared on platforms such as Xing and LinkedIn. About two weeks later, a reminder email was sent to all participants who had been contacted so far, to point out the survey and to increase the response rate.

Both questionnaires were set up in a manner similar to that described in section 2.5.1.1. A short introductory text was prepared to inform the participants about the title, objectives and duration of the survey. The respondent could click on a ‘next’ button to access the actual questionnaire. Questions then were displayed on a screen page depending on a specific category. After finishing the questions about the respective category, one could click the ‘next’ button to reach the following question set for the subsequent category. In order to view the status of the questions already answered, the respondent was shown a percentage display. In addition, the questions were sorted according to importance. Technology and usage questions were at the beginning, whereas social issue questions were rather asked at the end of the survey. The purpose of this was that more research-relevant questions would be answered with more motivation and thus possibly contained better input. The final page included an acknowledgement to the respondents for their participation, in order to show appreciation.

Initially, all questions were set as mandatory questions for both surveys, to make sure that respondents answer every question. This means that the participant only got to the next page once he has answered all the questions on the respective page. However, this was changed at least for the expert group after about a week to increase the overall response rate.

### Survey for Stakeholder Group 1 – Consumers and Prosumers

First, the questionnaire was roughly structured. Hereby, questions for prosumers and consumers were listed in a Microsoft Excel table. With this tool it was possible to define answers by means of a dropdown menu and thus present the closed question character of the survey. 28 questions were created including contact and career details as well as BC background. Also, a comparison with the assumptions in section 3.3. was carried out. All questions were differentiated according to several categories including background information, technology, security, usage and economy. Furthermore, two questions came directly from Thüga AG to include their interest of research as well. The closed questions contained yes/no questions, multiple selection options on e.g. BC characteristics, assessment of one's own state of knowledge on BC from 1 (= briefly known) to 4 (= expert) as well as assessment of importance from 1 (=not important), 2 (=less important), 3 (=more important) to 4 (=very important). There was also the option to choose 'no answer' for the assessment questions.

For assessment questions, prosumers and consumers were given an even number of possible answers to exclude the possibility that no tendency would become clear if otherwise only the mean value would be selected. Additionally, a subsequent binary evaluation was possible.

The survey contained predominantly closed questions in order to establish a high degree of comparability between the respondents. Moreover, it cannot be assumed that all persons of stakeholder group 1 have the same level of knowledge and can therefore answer open questions without any indication. Moreover, existing knowledge by the assumptions in section 3.3 can be confirmed or refuted using quantitative methods. The complete survey can be found in appendix A.2.

### Survey for Stakeholder Group 2 – Experts

A set of questions for stakeholder group 2 - the experts - was prepared in a Microsoft Word file. This consisted of 37 questions including different categories, career details as well as the BC background. For better comprehensibility and to cover all aspects of requirements, the questionnaire was also divided into different categories. These categories are made up as follows: technology, ecology, regulation, social and economic aspects. In parallel, the questions were compared with the assumptions in section 3.3 in order to ensure that all of them would be queried on the basis of the questionnaire. Since experts have already dealt with the BC topic, open questions have been integrated into their survey catalogue. This serves to confirm or reject existing assumptions in section 3.3, but also to generate further knowledge on the topic. The complete survey can be found in appendix A.1.

# Survey Results

In the following, the data collected from the two conducted surveys in LamaPoll will be presented. Both, quantitative and qualitative methods have been carried out.

## Descriptive Statistics for Prosumers and Consumers

The survey for stakeholder group 1, consisting of consumers and prosumers, was online for 3.5 weeks from 21st of January 2019 until the 16th of February 2019 via the platform LamaPoll. During this time 152 prosumers and consumers visited the survey, 103 people took part at the survey (completed and not completed) and 88 of them fully completed it. This can also be seen in **table 4-1**.

Table 4‑1: Participation overview of prosumer and consumer survey

|  |  |  |
| --- | --- | --- |
|  | Absolute frequency | Percentage |
| Visitors | 152 | - |
| Participants | 103 | 67,76% |
| Fully completed | 88 | 85,44% |
| Not fully completed | 15 | 14,56% |

The highest participation was not on a weekend but on a day during the week, the 31st of January 2019.

In the following different frequency tables according to the categories proposed in the consumer and prosumer survey will be shown. These tables include the question with answering options, results concerning each question in absolute numbers and in percentage. In few questions the percentage per option is given, as respondents had the choice to select several answers per question. In this way it can be seen how often a single answering option has been selected.

### Survey Part: Background Information - Prosumers and Consumers

As shown in **figure 4-1**, more than four fifth from 97 participants, who answered the first question, indicated that they were consumers. Merely 13.40% confirmed to be prosumers and produce their own electricity.

Figure 4‑1: Participation proportion of prosumers and consumers in the survey

From 97 people who answered the second question, more than half didn’t know where their energy comes from. This can also be seen in **table 4-2**.

Table 4‑2: Prosumers' and consumers' knowledge about energy sources

|  |  |  |
| --- | --- | --- |
| **Do you know which energy sources you receive your electricity from?** | **Absolute frequency** | **Percentage** |
| Yes | 46 | 47,42% |
| No | 51 | 52,58% |

From these 46 prosumers and consumers, who knew where their energy comes from, 4 people said that they would receive electricity from conventional energy sources, 16 from regenerative energy sources and 26 from a combination of conventional and renewable energy sources.

From 97 respondents, 72,16% claimed that they had neither knowledge nor points of contact with the topic BC. Accordingly, on a scale from 1 (= briefly known) to 4 (= expert), 68,09% briefly known BC, while 2,13% said they were experts in this field. 19,15% opted for the value 2 and 10,64% for the value 3 on the presented scale.

### Survey Part: Technology - Prosumers and Consumers

In the second part of the survey, questions about technological aspects of BC applied to a local energy market where raised. Results are outlined in **table 4-3**, which includes the question with answering possibilities as well as absolute frequency of answers and its percentage.

Table 4‑3: Survey results for prosumers and consumers - Technology

|  |  |  |
| --- | --- | --- |
| Would you switch from the current electricity market system (consumers receive their electricity through an electricity supplier) to the peer-to-peer system using a BC (consumers buy electricity directly from regional producers)? | Absolute frequency | Percentage |
| Yes | 79 | 84,95% |
| No | 14 | 15,05% |
| **In your opinion, which form of BC (private or public) makes more sense for regional distribution of renewable energies?** | **Absolute frequency** | **Percentage** |
| Public | 54 | 58,06% |
| Private | 39 | 41,94% |
| **Do you need further experience / instructions before you participate in such a peer-to-peer system via BC?** | **Absolute frequency** | **Percentage** |
| Yes | 81 | 87,10% |
| No | 12 | 12,90% |
| **If yes: Which forms of experience / instructions do you need?**  **(several options possible)** | **Absolute frequency** | **Percentage per option** |
| Public training | 34 | 23,78% |
| Information brochures | 63 | 44,06% |
| Webcasts / Online trainings | 36 | 25,17% |
| Others (please specify) | 10 | 6,99% |
| **How important is it to you that when introducing BC technology, training courses are offered by service providers or regulators on this topic?** | **Absolute frequency** | **Percentage** |
| 1. Not important | 5 | 5,49% |
| 1. Less important | 18 | 19,78% |
| 1. More important | 35 | 38,46% |
| 1. Very important | 33 | 36,26% |

The survey shows that more than 80% would participate in a peer-to-peer market with a BC application. In this respect, the majority would also be interested to receive an exchange of experience and instructions. Information brochures are of highest interest. But also webcasts or public trainings are interesting interventions for prosumers and consumers. In addition, 10 respondents considered other measures like a contact person or consultant (which might also offer a home visit), experience reports from third parties, a service hotline or independent media reports. More than half also found that training courses by service providers or regulators are more important or very important. As a further technical aspect, almost 60% of those questioned, stated, that they consider a public BC to be more appropriate.

### Survey Part: Usage - Prosumers and Consumers

In the survey section on usage, estimation questions regarding compatibility with other systems, supply security and other properties of BC technology were asked and summarized in **table 4-4**.

Table 4‑4: Survey results for prosumers and consumers - Usage

|  |  |  |
| --- | --- | --- |
| How important is it to you that user-friendly applications (e.g. mobile apps for your smartphone) are available for participation in a local energy market via BC? | Absolute frequency | Percentage |
| 1. Not important | 5 | 5,49% |
| 1. Less important | 18 | 19,78% |
| 1. More important | 35 | 38,46% |
| 1. Very important | 33 | 36,26% |
| **How important is it to you that the availability of electricity exists automatically and without active control by you?** | **Absolute frequency** | **Percentage** |
| 1. Not important | 3 | 3,30% |
| 1. Less important | 2 | 2,20% |
| 1. More important | 26 | 28,57% |
| 1. Very important | 60 | 65,93% |
| **How important is it to you that a local energy market ensures permanent security of supply?** | **Absolute frequency** | **Percentage** |
| 1. Not important | 0 | 0,00% |
| 1. Less important | 1 | 1,10% |
| 1. More important | 25 | 27,47% |
| 1. Very important | 65 | 71,43% |
| **Do you have a smart device for measuring your electricity consumption?** |  |  |
| Yes | 13 | 14,13% |
| No | 79 | 85,87% |
| **If yes - How important is it to you that your smart device is compatible with BC technology?** | **Absolute frequency** | **Percentage** |
| 1. Not important | 0 | 0,00% |
| 1. Less important | 1 | 8,33% |
| 1. More important | 7 | 58,33% |
| 1. Very important | 4 | 33,33% |
| **How important is it to you that the BC technology uses as little energy as possible?** | **Absolute frequency** | **Percentage** |
| 1. Not important | 2 | 2,27% |
| 1. Less important | 6 | 6,82% |
| 1. More important | 32 | 36,36% |
| 1. Very important | 48 | 54,55% |
| **Which characteristics should BC technology bring to a local energy market? (several option possible)** | **Absolute frequency** | **Percentage per option** |
| High scalability: Functionality of an application despite size or volume changes | 17 | 6,32% |
| Low energy consumption | 49 | 18,22% |
| Easy handling | 74 | 27,51% |
| Irreversibility of data entries | 3 | 1,12% |
| Decentralization: Data is not stored in a central system but decentralized to various nodes. | 11 | 4,09% |
| Transparency: Transactions are visible to all network participants | 25 | 9,29% |
| Data protection | 25 | 9,29% |
| Speed and efficiency of data processing | 13 | 4,83% |
| Automation of processes | 19 | 7,06% |
| Execution of microtransactions: Exchange of transaction objects with very low value at low transaction costs | 5 | 1,86% |
| Counterfeit protection: Tamper-proof documentation of ownership relationships | 28 | 10,41% |

68 out of 91 respondents to the question on mobile application for a user-friendly application feel that this is more or very important. Security of supply and an automatic energy process also seem to be very important for 65% or more. Only 13 out of 92 people have a smart device in their household. But almost 92% of those who have a smart device, find it more or very important that it is compatible with BC technology. Low energy consumption of the BC is also very important for more than half of the respondents. If one considers other characteristics also, an easy operability with about 74 votes comes first.

### Survey Part: Security - Prosumers and Consumers

In the following, data on the topic of security are described. For this purpose, the participants were asked four questions, which also required their assessment regarding importance.

Table 4‑5: Survey results for prosumers and consumers - Security

|  |  |  |
| --- | --- | --- |
| How important is it to you that all processes of an energy network take place exclusively in Germany? | Absolute frequency | Percentage |
| 1. Not important | 17 | 19,32% |
| 1. Less important | 23 | 26,14% |
| 1. More important | 25 | 28,41% |
| 1. Very important | 23 | 26,14% |
| **How important is it to you that unauthorized attacks and manipulations on a decentralized, BC-based energy network are prevented?** | **Absolute frequency** | **Percentage** |
| 1. Not important | 1 | 1,12% |
| 1. Less important | 1 | 1,12% |
| 1. More important | 8 | 8,99% |
| 1. Very important | 79 | 88,76% |
| **How important is it to you that the use of BC technology in the energy industry complies with existing regulations on the protection of personal data?** | **Absolute frequency** | **Percentage** |
| 1. Not important | 1 | 1,12% |
| 1. Less important | 8 | 8,99% |
| 1. More important | 15 | 16,85% |
| 1. Very important | 65 | 73,03% |
| **How important do you consider the availability of transparency in a BC network on the local energy market to be?** | **Absolute frequency** | **Percentage** |
| 1. Not important | 3 | 3,41% |
| 1. Less important | 4 | 4,55% |
| 1. More important | 51 | 57,95% |
| 1. Very important | 30 | 34,09% |

Prosumers and consumers agree on the topic of data security. According to the frequency **table 4-5**, the majority states, that it is very important that data protection rules are adhered to and that hacker attacks on a BC-based energy network must be prevented. Nevertheless, transparency plays an important role for more than 50% of participants in such a network. There is disagreement on the issue of whether processes of a BC-based energy network should take place exclusively in Germany. The scale received an almost identical response rate for each response option, which varies between 19 and 28%.

### Survey Part: Economy - Prosumers and Consumers

In the last part of the survey, mainly economic aspects are examined. The results of the consumer survey can be seen in **table 4-6**.

Table 4‑6: Survey results for prosumers and consumers - Economy

|  |  |  |
| --- | --- | --- |
| Would you switch from the current electricity market system to the peer-to-peer system using BC if this would bring financial benefits? | Absolute frequency | Percentage |
| Yes | 82 | 91,11% |
| No | 8 | 8,89% |
| **Is your willingness to pay higher, if you know the vendor of the regeneratively produced electricity, or if it comes from the local environment?** | **Absolute frequency** | **Percentage** |
| Yes | 57 | 63,33% |
| No | 33 | 36,67% |
| **Which pricing mechanism would you prefer to determine electricity prices, if BC technology is applied to the energy market?** | **Absolute frequency** | **Percentage per option** |
| Auction prices: Real prices passed on in a defined market area. | 27 | 27,27% |
| Fixed prices determined in advance: Flat-rate fees for electricity purchases. | 60 | 60,61% |
| Exchange prices: Price determination through trading on the electricity exchange. | 9 | 9,09% |
| Others (please specify) | 3 | 3,03% |
| **How important is it to you that a local energy market using BC technology has a simple payment system?** | **Absolute frequency** | **Percentage** |
| 1. Not important | 4 | 4,60% |
| 1. Less important | 4 | 4,60% |
| 1. More important | 28 | 32,18% |
| 1. Very important | 51 | 58,62% |
| **Which form of electricity payment would you prefer?** | **Absolute frequency** | **percentage per option** |
| Crypto currency | 7 | 4,86% |
| PayPal | 42 | 29,17% |
| Bank transfer | 46 | 31,94% |
| Payment on invoice | 46 | 31,94% |
| Others (please specify) | 3 | 2,08% |

More than 90% of the survey participants would support BC in a peer-to-peer system, given that financial benefits are higher. Moreover, the majority would even pay more for their electricity if the producer comes from the surrounding area or the producer is even known. Most people don't just want to know who the electricity producer is, they also want to know how the electricity price is made up with almost 58% of participants and whether a green electricity certificate can be shown, also with around 58% of participants, which can also be seen in **figure 4-2**.

Figure 4‑2: Prosumers' and consumers' willingness to pay for renewable energy

For the respondents listed under ‘Other’ following results exist: One respondent stated that the electricity price in Germany is generally too high and therefore there is no willingness to pay more at all. Another stated ecological value as incentive to pay more money for electricity. Nearly 70% of the participants expressed their support for the fact that renewable electricity would be associated with ecological added value to a green electricity product, support for the Energy transition with 70,18% and regional value added with 71,93% in almost equal proportions. **Figure 4-3** shows these results graphically.

Figure 4‑3: Added value for prosumers and consumers from local, regenerative produced electricity

According to table 4-6 more than 60%, consumers and prosumers voted in favor of a pricing mechanism based on fixed prices determined in advance, thus flat-rate fees for electricity purchases. Ranked on second place are auction prices with around 27.3%. For the majority of participants, it is also very important that a simple payment system exists. There is no extraordinary difference between PayPal, a bank transfer and payment on invoice with around 30% each. “Others” include debiting and a traceable collective debit, e.g. at the end of the month.

## Inferential Statistics for Prosumers and Consumers

In the context of inferential statistics, two methods were used to evaluate the prosumer and consumer survey. On the one hand, a left-sided binomial test was carried out, and on the other, a multiple as well as an ordinary linear regression. Results and procedure are described below.

### Lower-Tailed Binomial Test

Since the data of the consumers and prosumer surveys are distributed discreetly, a binomial test was carried out. On the basis of these questions directional hypotheses could be tested. On the one hand there were ‘yes’ or ‘no’ questions, but also questions concerning the assessment of importance. For questions about the assessment, the results were divided into ‘high importance’ (=more important and very important) and ‘not important’ (=less important and not important), to receive values with a dichotomous characteristic. The survey results were prepared and tested using Microsoft Excel. To perform the test, the function BINOM.DISTwas used. The individual components of this Microsoft Excel function are described as follows:

* number\_s: number of successes in a series of tests (e.g. the number of people who answered a question with ‘yes’)
* trials: total number of trials (e.g. the number of people who answered a question)
* probability\_s: the probability of success for each attempt (e.g. 75%, 80% or 85%)
* cumulative: probability function for the probability that there will be cumulated number of successes (corresponds to the value 'true') or the probability for an exact number of successes (corresponds to the value 'false')

With this formula the binomial distribution probability will be calculated and can be compared with the significance level.

In science, significance levels between 1%, 5% or 10% have predominantly become established. But the choice of the significant level depends on how critical it is to erroneously reject a hypothesis. The lower the risk, the lower the level of significance should be. It should also be considered that with a lower level of significance, the type two error also increases in size. This means that the null hypothesis is not rejected even though it is wrong. Therefore it is probably also the question on which one puts the focus.. (58 pp. 128–129)

Hilger (2007) also uses a significant level of 5% in most examples, which has become established in medical science research. (57 pp. 121–123)

Therefore, a significance level of 5% was chosen for the binomial test in this Master’s thesis. Since type one and type two error influence each other, also type two error should not be kept too high. Consequently, a significance level of 10% was not chosen. In addition, it was decided to set the probability to three different cases in order to see whether there were differences in the rejection or retention of certain hypotheses. In all test cases, limits of 75%, 80% and 85% were set. Values greater than 50% were chosen to clearly show that the majority of participants had a certain tendency. In addition, it is already clear from the frequency tables that with the majority of questions, a clear tendency towards one or the other direction prevails. Only the question which characteristics the BC should have and that there was a tendency to high scalability, it was assumed that probabilities of 20%, 25% or 30% could be reached, as eleven different options were possible to choose. Nevertheless, it was possible to make a multiple selection, which made it possible to choose scalability besides others.

This test was conducted for 16 questions leading to directed hypotheses of the prosumer and consumer survey on each of three different thresholds. Complete results can be found in **table 4-7**. The table includes the question from the survey, the null hypothesis denoted with H0 and the rival hypothesis denoted with H1, as well as the result. This result shows if H0 could be rejected or not. Despite the selection of three different thresholds from 75% to 85%, only one hypothesis, which was focusing the importance of training courses offered by service providers or regulators, was rejected in the last case. The result, which shows that the null hypothesis for the probability for importance of training courses of greater than or equal to 85% can be rejected, can also be found in table 4-7. In all other cases, there were no changes in the result despite modified thresholds. The test results in table 4-7 show that four null hypotheses H0 can be rejected. These include that a private BC should be implemented, that all processes of an energy network should take place exclusively in Germany, that a fixed pricing mechanism would be preferred to determine electricity prices and that BC should bring high scalability as a characteristic.

Table 4‑7: Lower-tailed binomial hypothesis test results with different threshold levels

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Question** | **H0** | **H1** | **Result (rejecting / not rejecting H0)** | |
| In your opinion, which form of BC (private or public) makes more sense for regional distribution of renewable energies? | Private BC P ≥ 75% | P < 75% | rejecting | |
| Private BC P ≥ 80% | P < 80% | rejecting | |
| Private BC P ≥ 85% | P < 85% | rejecting | |
| Do you need further experience / instructions before you participate in such a peer-to-peer system via BC? | Yes P ≥ 75% | P < 75% | not rejecting | |
| Yes P ≥ 80% | P < 80% | not rejecting | |
| Yes P ≥ 85% | P < 85% | not rejecting | |
| How important is it to you that when introducing BC technology, training courses are offered by service providers or regulators on this topic? | High Importance P ≥ 75% | P < 75% | not rejecting | |
| High Importance P ≥ 80% | P < 80% | not rejecting | |
| High Importance P ≥ 85% | P < 85% | rejecting | |
| How important is it to you that user-friendly applications (e.g. mobile apps for your smartphone) are available for participation in a local energy market via BC? | High Importance P ≥ 75% | P < 75% | not rejecting | |
| High Importance P ≥ 80% | P < 80% | not rejecting | |
| High Importance P ≥ 85% | P < 85% | not rejecting | |
| How important is it to you that the availability of electricity exists automatically and without active control by you? | High Importance P ≥ 75% | P < 75% | not rejecting | |
| High Importance P ≥ 80% | P < 80% | not rejecting | |
| High Importance P ≥ 85% | P < 85% | not rejecting | |
| How important is it to you that a local energy market ensures permanent security of supply? | High Importance P ≥ 75% | P < 75% | not rejecting | |
| High Importance P ≥ 80% | P < 80% | not rejecting | |
| High Importance P ≥ 85% | P < 85% | not rejecting | |
| If yes - How important is it to you that your smart device is compatible with BC technology? | High Importance P ≥ 75% | P < 75% | not rejecting | |
| High Importance P ≥ 80% | P < 80% | not rejecting | |
| High Importance P ≥ 85% | P < 85% | not rejecting | |
| How important is it to you that the BC technology uses as little energy as possible? | High Importance P ≥ 75% | P < 75% | not rejecting | |
| High Importance P ≥ 80% | P < 80% | not rejecting | |
| High Importance P ≥ 85% | P < 85% | not rejecting | |
| How important is it to you that all processes of an energy network take place exclusively in Germany? | High Importance P ≥ 75% | P < 75% | rejecting | |
| High Importance P ≥ 80% | P < 80% | rejecting | |
| High Importance P ≥ 85% | P < 85% | rejecting | |
| How important is it to you that unauthorized attacks and manipulations on a decentralized, BC-based energy network are prevented? | High Importance P ≥ 75% | P < 75% | not rejecting | |
| High Importance P ≥ 80% | P < 80% | not rejecting | |
| High Importance P ≥ 85% | P < 85% | not rejecting | |
| How important is it to you that the use of BC technology in the energy industry complies with existing regulations on the protection of personal data? | High Importance P ≥ 75% | P < 75% | not rejecting | |
| High Importance P ≥ 80% | P < 80% | not rejecting | |
| High Importance P ≥ 85% | P < 85% | not rejecting | |
| How important do you consider the availability of transparency in a BC network on the local energy market to be? | High Importance P ≥ 75% | P < 75% | not rejecting | |
| High Importance P ≥ 80% | P < 80% | not rejecting | |
| High Importance P ≥ 85% | P < 85% | not rejecting | |
| Would you switch from the current electricity market system to the peer-to-peer system using BC if this would bring financial benefits? | Yes P ≥ 75% | P < 75% | not rejecting | |
| Yes P ≥ 80% | P < 80% | not rejecting | |
| Yes P ≥ 85% | P < 85% | not rejecting | |
| Which pricing mechanism would you prefer to determine electricity prices, if BC technology is applied to the energy market? | Fixed pricing P ≥ 75% | P < 75% | rejecting | |
| Fixed pricing P ≥ 80% | P < 80% | rejecting | |
| Fixed pricing P ≥ 85% | P < 85% | rejecting | |
| How important is it to you that a local energy market using BC technology has a simple payment system? | High Importance P ≥ 75% | P < 75% | not rejecting | |
| High Importance P ≥ 80% | P < 80% | not rejecting | |
| High Importance P ≥ 85% | P < 85% | not rejecting | |
| Which characteristics should BC technology bring to a local energy market? | Scalability P ≥ 20% | P < 20% | rejecting |
| Scalability P ≥ 25% | P < 25% | rejecting |
| Scalability P ≥ 30% | P < 30% | rejecting |

### Multiple Linear Regression

Equally to the binomial hypothesis tests, that have already been carried out, Microsoft Excel was also used for the multiple linear regression. In the course of this, raw data of the survey were initially adjusted.

The X and Y variables are defined as following:

* Y: If someone would switch to a peer-to-peer market using BC
* X: criteria that might influence the Y variable e.g. the importance of permanent security of supply

The complete definition of X and Y variables is shown in **table A 1 in appendix A.3**.

In order to indicate the correlation between a switch from the current electricity market system to the peer-to-peer system using a BC, this has been recorded as Y variable. To explain the Y variable, the X variables were selected which are relevant for the research question. Since in Microsoft Excel a maximum of 16 independent variables can be used, the above described were chosen to explain the relation between those and someone who would switch to a peer-to-peer system via BC technology. For questions with only two possible answers, ‘yes’ or ‘no’, the value 1 or -1 was assigned. Questions that asked for an assessment of importance were rated with values between -1, -0.5, 0.5 and 1. (-1 for people who indicated a question with ‘no importance’ up to 1 for ‘very important’). The same was done for the question of one's own knowledge assessment of BC technology. If participants did not give any answer, the empty cell has always been replaced with the value 0. Afterwards a regression using data analysis in Microsoft Excel was carried out. The raw data from the conducted survey were used for the variables described in table A 1 as Y and X variables.

Table 4‑8: Regression statistics from multiple linear regression

|  |  |
| --- | --- |
| **Regression Statistics** | |
| R Square | 0,2929 |
| Adjusted R Square | 0,1440 |
| Observations | 93 |

As can be seen in **table 4-8**, the regressions statistics for 93 observation show a coefficient of determination of 29,29%. But when considering the adjusted coefficient of determination, it indicates only a half as large coefficient of determination with 14,40%.

If a significance level of 5% is determined, equally to the binomial hypothesis testing, the null hypothesis can be rejected. Since the ANOVA f statistics reach a value of 0,0264 and thus is below the claimed alpha, the regression carried out indicates a certain explanatory content.

Table 4‑9: Results from multiple linear regression

|  |  |  |  |
| --- | --- | --- | --- |
| **Variables** | **Coefficients** | **Standard Error** | **P-Value** |
| Intercept | -0,0467 | 0,3298 | 0,8879 |
| X1 | -0,3835 | 0,1377 | 0,0068 |
| X2 | -0,1770 | 0,1314 | 0,1820 |
| X3 | 0,2370 | 0,1226 | 0,0570 |
| X4 | 0,2417 | 0,1477 | 0,1059 |
| X5 | 0,0064 | 0,1762 | 0,9710 |
| X6 | 0,1490 | 0,2798 | 0,5961 |
| X7 | 0,1089 | 0,1655 | 0,5128 |
| X8 | -0,2145 | 0,4884 | 0,6618 |
| X9 | -0,0437 | 0,2101 | 0,8359 |
| X10 | -0,0978 | 0,1084 | 0,3695 |
| X11 | 0,4369 | 0,2602 | 0,0972 |
| X12 | -0,1698 | 0,1855 | 0,3628 |
| X13 | 0,0043 | 0,2062 | 0,9834 |
| X14 | 0,1730 | 0,1473 | 0,2437 |
| X15 | 0,1331 | 0,0897 | 0,1422 |
| X16 | -0,0455 | 0,1799 | 0,8011 |

The coefficients in **table 4-9** show that there are negative as well as positive correlations between the variable Y, i.e. whether one would change to a peer-to-peer system using BC, and the X variables. The Y-intercept is located at -0,047. The X1 coefficient shows that a change to peer-to-peer with BC would rather happen with less knowledge concerning BC technology. This is recognizable by the negative sign to the factor 0,3835. A strong positive correlation can be denoted with the X11 variable. It can be assumed that the more important the prevention of unauthorized attacks and manipulations on a decentralized, BC-based energy network is, the more likely one would agree to a change from the current energy system to a peer-to-peer system using BC. The standard error in this case is 0,2602 and can be added to or subtracted from the coefficient. By this one will find the interval in which the true coefficient value lies, because the regression is only an estimation. The P-value shows that almost all variables are random. If the P-value is not below the alpha of 5%, the null hypothesis, which states that the value has no influence on the Y variable, cannot be rejected. Thus, all values except X1 have no statistical significance. Only the coefficient for variable X3 is close to being significant with a p-value of 0, 057. It expresses that the more important it is for prosumers and consumers to receive training courses with introducing BC technology, the more likely they would switch to a peer-to-peer system using BC technology.

### Ordinary Linear Regression for Selected Examples

In addition to the multiple linear regression, an ordinary linear regression was performed using X variables from **table 4-10**.

Table 4‑10: Results from ordinary linear regression

|  |  |  |  |
| --- | --- | --- | --- |
| **Variables** | **Coefficients** | **Standard Error** | **P-Value** |
| X1 | -0,2771 | 0,1344 | 0,0420 |
| X2 | 0,0185 | 0,1118 | 0,8688 |
| X3 | 0,2434 | 0,1162 | 0,0390 |
| X4 | 0,3516 | 0,1165 | 0,0033 |
| X5 | 0,0412 | 0,1667 | 0,8055 |
| X6 | 0,0236 | 0,2597 | 0,9278 |
| X7 | 0,0914 | 0,1072 | 0,3958 |
| X8 | 0,2024 | 0,3083 | 0,5133 |
| X9 | 0,1705 | 0,1529 | 0,2676 |
| X10 | -0,0368 | 0,1007 | 0,7159 |
| X11 | 0,4191 | 0,2153 | 0,0547 |
| X12 | -0,0298 | 0,1515 | 0,8447 |
| X13 | 0,2175 | 0,1629 | 0,1850 |
| X14 | 0,2661 | 0,1266 | 0,0383 |
| X15 | 0,2055 | 0,0760 | 0,0082 |
| X16 | 0,0690 | 0,1428 | 0,6303 |

As can be seen from table 4-10, the variable X1, X3, X4, X14 and X15 are statistically significant as all p-values are below the assumed significant level of 5%. Thus, it can be stated that with a lower level of knowledge, a higher importance of training with the introduction of BC technology and user-friendly applications, a change for prosumers and consumers to the peer-to-peer system via BC takes place. In addition, there is a positive correlation between the switch to the peer-to-peer system and a higher willingness to pay for the electricity, if one knows the electricity producer or if it comes from the local environment. The coefficient of variable X14 also shows that a prosumer or consumer would rather switch to the peer-to-peer system by means of a BC if financial advantages were to be gained.

## Descriptive Statistics for Experts

The survey for stakeholder group 2, consisting various experts, was online for 5 weeks and almost 3 days from 21st of January 2019 until the 28th of February 2019 via the online survey tool LamaPoll. The experts’ survey was put online 1,5 weeks longer than the prosumer and consumer survey, as little feedback could be obtained initially. Through a longer survey period additional participant had the chance to contribute. During this time 117 people visited the survey, 66 people took part at the survey (completed and not completed) and 23 of them fully completed it while 43 terminated the survey answering not every question. This can also be seen in **table 4-11**.

Table 4‑11: Participants overview for the experts’ survey

|  |  |  |
| --- | --- | --- |
|  | Absolute frequency | Percentage |
| Visitors | 117 | - |
| Participants | 66 | 56,41% |
| Fully completed | 23 | 34,85% |
| Not fully completed | 43 | 65,15% |

The highest activity was on two consecutive Wednesdays, February 6th and February 13th, 2019 with 13 visitors. On February 6th,11 of them participated at the survey and 4 of them finished the survey. Since not all questions correspond to the closed question character, only some results of the survey are presented in frequency tables in the following. Remaining questions are presented in the second part of the data analysis for the experts.

### Survey Part: Background Information - Experts

As shown in **figure 4-4**, most of the participants who answered the first multiple choice question asking about their expert background, claimed to be BC Technology Experts with 45,9%. Right after that scientists followed with about 41%. 29,5% said they were electricity suppliers, and 13% DSOs. Meter operators, plant manufacturers and regulators amounted to less than 10% in each case.

Figure 4‑4: Participation proportion per expert group in the survey

### Survey Part: Technology - Experts

In the technology part of the survey, experts were asked both, open and closed questions. In addition to opportunities and challenges for the BC in a peer-to-peer market, the survey also dealt with questions such as the suitable consensus mechanism or private and public BC. **Table 4-12** shows the result of the second question. Among the 23 participants fifteen decided to use a private BC while eight they rather trust in the use of a public BC. The question about the consensus mechanism was also answered by 23 participants, whereby it became clear that the majority would prefer a PoA mechanism with 73,91%. Around 17,39% decided for the Pow mechanism and only 8,70% for PoS mechanism. The results can also be viewed in table. When asked whether experts perceive data manipulation in a local energy market by means of BC as critical, a tendency is visible. More than 60% argue that they do not regard data manipulation as critical, while around 40% consider it critical.

Table 4‑12: Survey results for experts - Technology

|  |  |  |
| --- | --- | --- |
| **In your opinion, which form of BC (private or public) makes more sense for the regional distribution of renewable energies?** | **Absolute frequency** | **Percentage** |
| Public BC | 8 | 34,78% |
| Private BC | 15 | 65,22% |
| **Which consensus mechanism should be used to validate all blocks in a network of a local energy market?** | **Absolute frequency** | **Percentage** |
| Proof of Work | 4 | 17,39% |
| Proof of Stake | 2 | 8,70% |
| Proof of Authority | 17 | 73,91% |
| **Do you consider data manipulation by using a BC in a local energy market critical?** | **Absolute frequency** | **Percentage** |
| Yes | 9 | 39,13% |
| No | 14 | 60,87% |
| **Can there be mobile applications for the use of BC technology?** | **Absolute frequency** | **Percentage** |
| Yes | 22 | 95,65% |
| No | 1 | 4,35% |

As table 4-12 also shows, it is clear to 22 of the 23 participants that there is a possibility to provide mobile applications when using BC.

### Survey Part: Regulation - Experts

In the survey section, which deals mainly with regulatory issues, there is only one closed question. Its’ results are presented in **table 4-13**. The question is whether it necessary for prosumers to obtain a pre-qualification / license to operate as a provider in a peer-to-peer market or not.

Table 4‑13: Necessity of pre-qualification / license for prosumers

|  |  |  |
| --- | --- | --- |
| Is it necessary for prosumers to obtain a pre-qualification / license to operate as a provider in a peer-to-peer market? | Absolute frequency | Percentage |
| Yes | 10 | 66,67% |
| No | 5 | 33,33% |

This question was only answered by 15 persons, of whom two-thirds consider it necessary to have a prequalification or license as a prosumer if one wants to be provider in a peer-to-peer market.

### Survey Part: Social Issues - Experts

The question category social issues predominantly deals with the topic of how prosumers and consumers can be introduced to BC technology and its use. In addition, the question arises how important it is to experts that secure data processing is guaranteed.

Table 4‑14: Importance of secure data processing using blockchain for experts

|  |  |  |
| --- | --- | --- |
| How important is secure processing of private data using BC to you? | Absolute frequency | Percentage |
| 1. Not important | 2 | 16,67% |
| 1. Less important | 2 | 16,67% |
| 1. More important | 1 | 8,33% |
| 1. Very important | 7 | 58,33% |

As **table 4-14** shows, almost 60% of respondents agree that it is very important that secure data processing is ensured when using BC. 33,34% equally agree that this is not or less important.

### Survey Part: Ecology - Experts

The last part of the survey focused on ecology. The results of two questions are presented in **table 4-15**.

Table 4‑15: Results concerning ecology questions for experts

|  |  |  |
| --- | --- | --- |
| Do you classify the energy consumption of BC technology in the form of a local energy market as critical? | Absolute frequency | Percentage |
| Yes | 7 | 46,67% |
| No | 8 | 53,33% |
| Can the use of BC technology in the local energy market contribute to the energy transition? | **Absolute frequency** | **Percentage** |
| Yes | 14 | 93,33% |
| No | 1 | 6,67% |

When asked whether BC technology includes critical energy consumption, the result is only slightly different. 47% think ‘yes’, while 53% would say ‘no’. The result is clearer when looking at the following question. 14 out of 15 respondents believe that the use of the BC can contribute to the energy transition.

## Inductive Category Formation

For the expert survey, a qualitative content analysis was used since many questions with an open question character have been queried. The data obtained cannot be evaluated using statistical methods in the first place, which is why text analytical methods are used. Thereby new topics and content, that cannot be derived theoretically, can be opened.

A complete structuring content analysis based on an online survey is not possible, as the subject of requirements on BC technology in a local energy market has so far only been little researched. Therefore, it is difficult to derive a category system in advance based on theoretical background. Otherwise this would also be in contradiction with this Master’s thesis itself, as the answer (requirements on a BC) to the research question would already exist. Furthermore, the text material due to the nature of an online survey is kept short and an explication of unclear passages is not relevant. Answers to concrete questions are given and unnecessary possibly unclear text passages are not present. In addition, it is not necessary to collect further background information, as for example the backgrounds of the individual stakeholders have already been described in section 3.2.2. Also, this method is based on differentiating text parts even more, instead of shortening the text like with summary or structuring. In addition, the time-consuming summary process is avoided as described in section 4.4. Consequently, the inductive category formation was used to evaluate the online survey on BC technology in a local energy market. Categories were inductively derived from the answers given by various experts.

Since in section 1 and 2 the theoretical background as well as the tasks of this Master’s thesis were described in detail, it will not be dealt with further here. Content analytical parts are determined in advance as follows:

* Coding unit: Words or phrases per answer
* Context unit: The whole expert survey
* Recording unit: Answers of all 66 participants

The surveys responses were then fully investigated, and categories formed. The categories were given an abbreviation from ‘A’ to ‘U1’ to enable a simplified presentation in the frequency table A 3 in appendix A.5. It was forgone to consult another analyst for category formation, as recommended by Mayring (2014). For time reasons, this could not be implemented. Nevertheless, the categories were revised several times and summarized in table A 2 in appendix A.4.

An excerpt of this can be found in **table 4-16**, which shows 9 different categories. In the same way as for table A 2 in appendix A.4, in table 4-16 the category name can be found in the first column. In the second column the corresponding description is outlined.

Table 4‑16: Excerpt from category description for Inductive Category Formation

|  |  |
| --- | --- |
| Category | Description |
| Category A | BC offers transparency regarding price composition and energy origin |
| Category C | BC offers flexible, (monopoly-)independent, regional and decentralized peer-to-peer trade |
| Category G | BC is complex and must be designed user-friendly for acceptance and trust |
| Category H | BC must be integrated into or compatible with existing processes and systems |
| Category I | BC should provide low energy consumption |
| Category N | BC may not exceed previous costs or must offer cost advantage |
| Category R | BC should have differently accessible user interfaces for different stakeholders depending on complexity and purposes of use |
| Category Q1 | BC has to offer transparency regarding price composition and energy origin |
| Category R1 | Central stakeholders should create awareness for the BC technology and its general functionality only |

Category A, for example, denotes a characteristic of BC which has repeatedly been mentioned by experts. The category refers to transparency in terms of energy origin and price composition. Similarly, Category C represents BC as a flexible, regional and decentralized method for peer-to-peer trade, which simultaneously creates independence from intermediaries or 'monopolies' such as large energy suppliers. Category H describes the demand on the system to be compatible with other systems such as intelligent measuring systems for example. Another request is represented by category I, which claims low energy consumption, when using BC. Categories G and R describe further expectations for a BC. In addition to providing user friendliness, the BC should also have different user interfaces. For example, applications for mobile devices are conceivable for end customers, whereas service providers should be able to work at the back end. Further features that BC should provide for end customers are transparency such as described in category Q1 or cost advantages such as denoted in category N. Furthermore, it should not be forgotten that central stakeholders should inform about BC and its functionality, Whereby, no in-depth technical information but the basic functionality of BC should be conveyed. Category R1 was set up for this purpose.

The evaluation took place per respective expert group in order to show which requirements were most important for which expert group or where differences might lie.

This all was then recorded using a frequency table, which is available in its complete version in appendix A.5. In addition, the table A 3 shows the question involved, the percentage of a specific expert group that named a specific category, how often the category was chosen for a question in absolute numbers, and how often a category was chosen in relative numbers with respect to all answers to the respective question. Five different abbreviations were used for better presentation of experts. The participants were following: Distribution System Operator (DSO), BC Technology Expert (BCT), Energy Supplier (ES), Meter Operator (MO) and Scientist (SC). Furthermore, one person described oneself as 'Other', but did not provide any further explanation in this regard. There have been no responses from regulators or plant manufacturers for evaluation of the inductive category formation, which is why they do not appear in the table.

In the square brackets below the respective expert groups, one can find how many experts from this group participated in the respective question. Since individuals could also select several expert groups when asked about their background, the total sum does not correspond to what one gets if one counts all experts together. individual persons have made a multiple selection and the absolute frequency, does not indicate the number of experts per question, but the total sum of persons per question.

A few examples of the complete frequency table A 3 in appendix A.5 are shown in **table 4-17** below.

Table 4‑17: Excerpt of frequency table for Inductive Category Formation by experts' results

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1. Where do you see technological opportunities regarding the application of BC technology in the form of a local energy market? | DSO  [1] | BCT [12] | ES [4] | MO [1] | SC [9] | Other [0] | Absolute frequency | Relative frequency (n=19) |
| Category C | 100% | 67% | 50% | 0% | 44% | 0% | 11 | 58% |
| Category A | 0% | 25% | 50% | 0% | 44% | 0% | 7 | 37% |
| **2. Where do you see technological challenges regarding the application of BC technology in the form of a local energy market?** | **DSO [2]** | **BCT [13]** | **ES [4]** | **MO [1]** | **SC [9]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=20)** |
| Category G | 100% | 38% | 50% | 0% | 56% | 0% | 7 | 35% |
| Category H | 0% | 8% | 25% | 0% | 0% | 0% | 2 | 10% |
| Category I | 0% | 0% | 0% | 0% | 11% | 0% | 1 | 5% |
| Category N | 0% | 8% | 0% | 0% | 0% | 0% | 1 | 5% |
| **5. How is it possible to make it sufficiently attractive for end-users (consumers) to switch from already established systems (electricity supply by electricity suppliers) to the BC?** | **DSO [2]** | **BCT [13]** | **ES [4]** | **MO [1]** | **SC [9]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=20)** |
| Category N | 100% | 92% | 75% | 0% | 67% | 100% | 16 | 80% |
| Category Q1 | 0% | 23% | 25% | 0% | 44% | 0% | 7 | 35% |
| Category G | 0% | 23% | 50% | 100% | 11% | 100% | 5 | 25% |
| **6. How can the use of the BC system be differentiated for different stakeholder groups?** | **DSO [2]** | **BCT [10]** | **ES [4]** | **MO [1]** | **SC [6]** | **Other [0]** | **Absolute frequency** | **Relative frequency (n=14)** |
| Category R | 100% | 100% | 100% | 100% | 100% | 0% | 14 | 100% |
| Category G | 0% | 0% | 0% | 0% | 17% | 0% | 1 | 7% |
| Category Q1 | 0% | 10% | 0% | 0% | 0% | 0% | 1 | 7% |

Among other characteristics mentioned by categories for question 1 in table 4-17, i.a. categories C and A appeared. Category C, which is characterized by the flexibility, (monopoly-) independence, regionality and decentralized nature of BC, was most frequently used by 11 out of 19 respondents, resulting in a frequency of 58%. BC technology experts in particularly ensured the frequency of this category. Category A received slightly less encouragement from around 37%. Question 2 of table 4-17 was more focused on challenges of a local energy market via BC and received several expectations placed on the system by experts. The highest level was achieved by user-friendliness in category G with 35%. This was followed by integration and compatibility with other systems and processes described in category H, with around 10%. A low energy consumption, category I, and the creation of cost advantages or the avoidance of increased costs by the BC, category N, equally received 5% approval from the experts. Question 5 of table 4-17 examined which characteristics are necessary in order to bring end-users to switch to BC. As already mentioned in question 2, it is apparent that cost advantages play a major role. 80% of experts referred to category N, with scientists and BC technology experts dominating in terms of proportions. User-friendliness with 25%, as previously mentioned, also seems important, as does transparency in terms of price composition and origin of energy with 35%. The importance of different web interfaces for different user groups is clearly shown by the evaluation of question 6 in table 4-17. All 14 experts were in favor of category R. In addition, transparency and user-friendliness were again mentioned, each with 7%.

# Interpretation and Discussion

In the following, the previously established survey results will be interpreted. For this purpose, a distinction will be made between the two stakeholder groups. In addition, an evaluation of the survey approach and the overall methodology will be carried out.

## Prosumers’ and Consumers’ Individual Data Interpretation

Interestingly, most participants were consumers. This might be because the majority of participants are more likely to come from urban living space. As there are often apartments or flat-sharing communities and fewer people own their own property. Hence, fewer have the option to actively participate as prosumers on the energy market. This might also be the reason why less than half of the respondents knew whether their energy came from conventional or renewable resources.

What surprisingly emerges from data analysis in table 4-3 is that more than 80% would switch to a local energy market using BC, although most people are still unaware of BC and its functionality. Therefore, the question arises if the current hype surrounding the BC theme is responsible for this. Resentment about energy suppliers and thus an independent design of the local energy market might also play a role in this case. Contrary to the assumption that most respondents would opt for a private BC, no clear statement could be made at this moment. It is possible that prosumers and consumers have too little knowledge regarding this, since a concrete case of application does not yet exist and therefore an answer was probably simply chosen by chance.

According to descriptive statics and the binomial hypothesis testing, consumers and prosumers insist on the exchange of information and explanations regarding BC technology to switch to it. However, two statements contradict each other here. On the one hand, the most frequently made statement was that information and instructions in form of information brochures are desired, on the other hand, more than 70% confirmed that when BC is introduced, training courses by regulators should be offered. Therefore, it is conceivable for prosumers and consumers to switch to BC by only being informed in paper form, but when it is officially introduced, personal application advice is expected. Perhaps for reasons of time it is rather conceivable for many people to get a clear picture of the situation themselves in advance by means of written information material, instead of undergoing a time-consuming and/or possibly even cost-intensive personal consultation beforehand.

As expected, descriptive and inferential statistics confirmed that characteristics like usability, a high degree of automatization, simple payment systems, permanent security of supply and a low energy consumption are desired by consumers and prosumers when BC is applied to the local energy market. The payment procedure to be used remains open. It seems that the solution itself is irrelevant to the end customer, if it is easy to use. Consumers and prosumers therefore hardly want to deviate from their usual environment and the comfort zone provided by it. This is understandable, as otherwise this would cause additional effort. On the other hand, a certain amount of extra work can hardly be avoided, as a complete reorganization of the energy market will lead to a change of certain habits for individual consumers or prosumers. The fact that more than 60% of respondents have opted for a fixed price mechanism with predetermined flat rate prices also suggests that a high degree of convenience is expected. Scalability seems to be a rather less significant feature. According to above presented results, scalability achieves a comparatively low result with slightly more than 6%. The rejection of the hypothesis in the inferential statistics of prosumers and consumers also advocates this. This can be because the terminology is not plausible enough for many despite explanation in the survey. For a lot of people, the relatively abstract term cannot be determined from practical experience, in contrast to how much power an application requires or how easy to use something is.

Though, it was surprising, that no clear statement could be made about how important it was whether processes of an energy network take place exclusively in Germany. Neither in descriptive nor in inferential statistics. Data processing therefore does not seem to play such a big role, which is probably also connected with the increasing interconnected globe through social media for example. Furthermore, this can also be related to the previously made assumption that a larger proportion of respondents come from urban areas. The rather less conservative approach and the openness in contrast to consumers or prosumers from rural areas might also play a role in data processing. But it is still important that data is protected against hacking attacks and that valid regulations are complied with.

The question if prosumers or consumers would switch to the BC, once cost advantages arise, is almost irrelevant since the majority confirmed that they would switch to BC technology. However, it is evident that now, instead of 85%, around 91% would take this step. Consequently, about 6% more are willing to switch as soon as cost advantages arise as can be seen from section 4.1.. Though, regarding costs, it can also be seen that the majority would pay even more if information on the origin of energy existed and the vendor is known. This can also be stated from the ordinary linear regression. This approach suggests a trend towards regional products, as these often stand for quality and have intrinsic added value for the local region and the environment. Nevertheless, consumers do not seem to have full confidence in a BC product, as more than 50% of them would want to receive a certificate for green electricity, information about the electricity price composition, as well as the energy source and its producer.

## Experts’ Individual Data Interpretation

As shown in figure 4-4, the majority of participants indicated that they were BC technology experts or scientists, suggesting a tendency for most participants to come from the university environment.

In contrast to consumers and prosumers, experts mentioned a tendency towards private BC according to descriptive data. This could be due to more specific knowledge about the use of the BC in a local peer-to-peer market, as well as already gained experience through the actual implementation of a BC. However, there are also more than 30% who prefer the use of a public BC. They probably see the character of a classic BC without restriction on access and participation in contrast to the private BC, that might lose decentralization. This might also be seen by the results from the inductive category formation. Regarding this fact, 4 participants prefer to use a PoW mechanism. The tendency that this is too energy-intensive does not seem relevant at this point. It seems as if with the PoW mechanism the possibility of pure decentralization is seen, which is not lost that with inclusion of authorities or stakeholders.

It was also not to be expected that only a little more than 66% of experts consider secure data processing to be important or very important. Almost a third consider secure data processing to be unimportant, possibly because experts perceive this as a given characteristic by the BC and therefore see no necessity.

Surprisingly, the assessment regarding criticality of BC’s energy demand was evaluated. No clear trend could be drawn as to whether it would be considered critical or not. This may be due to many factors influencing energy demand, starting with network size or consensus mechanism.

When looking at the inductive category formation categories concerning questions about opportunities and challenges of BC technology make clear that BC experts and scientists in particular bring a lot of knowledge with them. Most categories were mentioned by them and show that they combine positive as well as challenging characteristics with BC. It can be assumed that peer-to-peer networks may have already been set up by them and could have been observed based on these characteristics. Interestingly, also energy suppliers have recognized positive characteristics such as transparency offered by BC or the possibility of a flexible, decentralized energy market, although that BC is questioning their role as middleman. This shows that first experiences have already been made at this point and that new opportunities associated with BC are also being perceived. This is important to recognize and assess a possible market niche at an early stage.

As can be seen from question 5 in table A 3 in appendix A.5, transparency with regard to the composition of price, the origin of electricity as well as cost advantages, play an important role for all experts. Only one expert from the area of meter operating does not focus on these characteristics, but rather on the importance of usability, efficiency and automatization. Therefore, the assumption can be made that this expert concentrates on the correct measurement point operation in order to be able to carry out the job according to valid regulations. A BC that supplies incorrect data or is associated with expenditure would also be disadvantageous to operators of measurement points who are responsible for the transmission of measured data.

As expected for question 7 in table A 3 in appendix A.5, all experts perceive BC as a technology that has potential, but still has to be improved. So far, most experts do not seem to have had any concrete experience with the technology but feel the hype and the excitement that are spread about it. This is probably the reason for the emergence of category T in this question.

Astonishingly, for experts, as already with consumers and prosumers, there was no clear tendency towards problems with scalability of BC. Although scalability was predominantly described as unproblematic by answers from BC experts, who probably also bring more technical knowledge concerning BC, there were 44% who consider scalability to be a challenge for BC. There seems to be no exact assumption about this yet, which may be due to a lack of experience in this area.

Answers given within the categories to question 15 and 16 clearly indicate that experts consider the given regulatory framework to be inappropriate for the introduction of BC in a local energy market. Most people consider a reorganization to be necessary for the introduction of BC. This may also indicate that the introduction of BC is recommended as unsuitable, especially for energy suppliers or meter operators, who might like to keep processes as they are at the moment. Unfortunately, there were no answers from DSOs, which may be due to insufficient experience in the regulatory area.

Also, rather negative tendencies with regard to BC can be observed by category E1 within question 19. The answer to the question of digital dependency and additional effort suggests that energy suppliers and DSOs consider a complete implementation of a peer-to-peer market via BC as critical. Furthermore, the currently very strong market position of energy suppliers is represented by occurrence of category F1. The fact that the majority does not see any danger of a disruption of its own business line shows that BC is not seen as a competitor or could even then be taken over by the current energy market authorities.

It was not to be anticipated that, when looking at the question about a guaranteed purchase of energy, around 80% of the energy suppliers in particular would also argue in favor of such a mandatory purchase by the market participants. However, the assumption remains that the state or private market participants would have to pay for this or that additional storage facilities would have to be provided. Energy suppliers themselves would rather not be willing to make themselves available in this case.

There was even one BC technology expert who considered central systems to be more suitable in the local energy market and thus doubted BC. It is possible that the respondent has already discovered negative effects during application or that too many defects were suspected during more detailed research on the subject of BC.

## Evaluation of Survey Composition

The following section serves to record and evaluate possible difficulties during the creation, distribution and evaluation of the two surveys. On this basis, solutions are designed to support future work in this area.

### Consumer and Prosumer Survey

From 152 people who visited the survey for prosumers and consumers, two thirds of them took part at the survey, of which then about 80% answered it completely. Based on this, it can be assumed that for almost a third of interviewees, the topic of BC is rather challenging or unclear. Even though the general functionality of BC in a local energy market has been explained with the introductory text, the topic seems to be quite difficult and intimidating. It is possible that ‘dropouts’ did not feel up to the topic. Furthermore, it can be assumed that the scope of the survey of almost 28 questions was too long for participants right from the start or during answering. Due to a lack of time and/or interest, the survey was not completely answered. Additionally, all questions were mandatory, which meant that if questions were not answered, it was not possible to reach the next block of questions. This could have caused frustration for participants, leading to an early termination. Nevertheless, a representative number of people took part in the survey and completely answered it. Since the survey mainly involved closed questions with provided answering options, the duration of answering single questions was kept to a minimum. It was attempted to ensure that no prior knowledge was necessary to understand the questions. As soon as technical knowledge was asked, short explanations contributed to making questions and possible answers easier to comprehend. Nevertheless, it should be mentioned that some questions might have been answered randomly. Therefore, it should be kept in mind to ask questions more precisely in future. Summarized it can be stated that more than 50 people, as initially stated, took part in this survey. Various distribution channels that went beyond the network of the Technical University Munich may have contributed to this.

### Experts Survey

The experts’ survey mainly consisted of open questions, which should serve to elicit experts' knowledge. However, since experts with different knowledge backgrounds from were questioned, not all questions could be fully answered. About seven different groups of experts were interviewed, which made it difficult to conduct a survey that could be answered equally well by all participants. To receive more specific knowledge from individuals, surveys should therefore be conducted specifically for each group of experts when interviewing them again. Although this was attempted in part by means of different question categories. In addition, it was noted that the expert survey exceeded the time frame for most of the participants. With almost 40 questions at the beginning, participants shortly lost interest to devote to the rest of the survey. Therefore, they cancelled the survey, which can also be seen from the response rate of only 35%. Although an attempt was made to reduce the scope of the survey by only displaying parts, tailored to the background of the respective expert group. Still, this created only a minimal improvement in the response rate

## Evaluation of Methodology

In general, it can be assumed that many stakeholders have been reached through the online survey. However, the question remains, whether it is possible to make qualitative statements. Results show that an online survey is suitable for consumers and prosumers. Since answers are already given and little or no misunderstandings can arise, meaningful results could be achieved. For experts, it is advisable to take on a smaller number of participants (possibly only 10 to 20 persons) and to consult them in a personal interview. This will lead to more substantial results. Besides, misunderstandings can be prevented. In this way, the inductive category formation can be better implemented. With the results of the online survey, the inductive category formation was difficult, as in some cases only 1 to 2 words were used as answers. This leaves room for interpretation and leads to confusion when evaluating. For such short experts’ answers, it would have been advisable to use explication in form of a narrow contextual analysis to add some more background information. An example of this is the answer 'failback mechanisms' given to question 8 in table A 3, appendix A.5. It would have been interesting to obtain additional information on such failback mechanisms and to concretize them.

Additionally, it should be mentioned that even if there were about 20 answers per question on average, the process of the inductive category formation costs a lot of time. Maybe it is conceivable to use a software for category formation for future projects instead of doing it manually. The QCAmap software is proposed by Mayring (2014) (59). Based on the research question this software supports investigation of the text for codes.

Based on that, the question arises how to proceed in future. Would one like to have only a few questions answered as detailed as possible? Or would one like to issue many questions, but with reduced response quality? This is a question of where to set the focus. In this Master’s thesis it was endeavored to create an all-encompassing picture of various stakeholders to uncover requirements in as many areas as possible. Therefore, the procedure of an online survey with questions for various experts was used.

If focus is put on receiving details from individual expert groups, one should probably resort to personal interviews in future. Depending on the time frame, a smaller sample can be interviewed, but an early termination rate can be prevented.

Multiple linear regression and ordinary linear regressions show differences in the significance of individual X variables. Whereas in the multiple regression the X variable of low prior knowledge is significant for a switch to BC technology, in ordinary linear regressions, several X variables can be confirmed. This can be explained by the fact that in a multiple regression a dependency between individual X variables exists. This could influence the X variables in such way that the Y variable can no longer be explained. In case of ordinary regressions, the relationship among individual X variables does not exist and the entire influence of a single X variable on the Y variable can be considered.

When looking at prioritization methods, one can see, that the degree of stability was not included, as there are currently no changing circumstances that have an influence on the requirements.

# Requirements Specification and Evaluation

This section provides an overview of requirements for BC technology in a local energy market. These have been gathered from survey results by stakeholders from section 3.2.

Requirements were established based on survey data evaluations of prosumers and consumers, as well as experts (please see section 3.2.). Therefore, consideration was given to whether a high percentage was achieved by the frequency analyses for prosumers and consumers, whether the null hypothesis was rejected by the hypothesis test and whether variables of the linear regressions achieved a significant p-value. In addition, experts’ survey results were examined. Besides descriptive data, results of the inductive category formation were considered.

21 requirements for a local energy market using BC technology have been established. The requirements are prioritized according to importance.

The first requirement is the most important, while the last requirement describes the least important. As can be seen from the sentence structure of each requirement, the scheme was followed as described in section **2.5.2.1.** (see figure 2-8). In addition, the auxiliary words must, should and could were used to indicate the importance of the requirements.

With introduction of a peer-to-peer market using BC technology:

* 1. The system must offer an **application that is easy for users to handle and to understand**.
  2. The system must provide **transparency** regarding **energy origin** and **price composition**.
  3. The system must offer **financial benefits for all stakeholders**.
  4. **Central** **stakeholders** such as service providers or regulators must **create awareness** for the BC technology and offer **information material** on its general functionality also before an implementation.
  5. The system must provide **secure data processing**.
  6. The system must ensure **permanent security of energy supply** for all network participants.
  7. The system must **comply with existing regulations**.
  8. The system must ensure a **low energy consumption**.
  9. The system must run **automatized, efficient and fast**.
  10. The system must be **compatible with existing processes and systems**.
  11. The system should provide **digital** as well as **conventional** easy-to-use **payment** **methods**.
  12. The system should offer **different user interfaces** for different groups of participants.
  13. The system should contractually **purchase guarantees for prosumers even if there is excess electricity.**
  14. The system should implement a **PoA consensus mechanism**.
  15. The system should be able to **pre-qualify or license providers to operate in the network**.
  16. The system should offer **flexible, (monopoly-)independent, regional and decentralized peer-to-peer trade**.
  17. The system could regard **scalability as a challenge** on which **further** **research** should be done also before an implementation.
  18. The system could involve a **sufficient number of participants** including different **production** **and storage facilities**.
  19. The system could **save selected data (no personal data) on BC only**.
  20. The system could **connect different regional networks**.
  21. The system could integrate **secret stores und private transactions**.

These requirements demonstrate that user-friendly applications, transparency regarding electricity price composition and origin, cost advantages and information exchange are important for a successful implementation of a local energy market on a BC.

A detailed description of the requirements can be found in the tender specification in appendix A.6, where a justification for each requirement and its classification is given. In **table A 5 in appendix A.7** indifferent requirements are summarized. Indifferent requirements specify requirements that did not allow a clear identification of a tendency from the prosumer/consumer survey or the expert survey based on survey data analytics. Therefore, there is a need for further clarification as which form of BC (private or public) should be used, whether data may only be processed at a regional level (in Germany or in a certain city only) and which pricing mechanism should be used.

With introduction of a peer-to-peer market using BC technology:

1. The system could use a **private or public BC**
2. The system could **allow regional data processing only**. E.g. data processing in Germany or the local area only
3. The system could use **fixed pricing mechanism** or **auctioning** for price determination

Following an evaluation of requirements as described in section 2.5.2 takes place. When assessing the requirements for the criteria mentioned, the following is noticeable:

* All requirements are consistent, as the same wording has been used.
* Only reasonable requirements have been included, which is why the criteria of correctness is fulfilled.
* A prioritization has been carried out for every requirement.
* Due to the clear phrase structure following figure 2-8, the requirements are modifiable.
* Comprehensibility is met due to a justification, which can be seen in table A 4 in appendix A.6.
* There are still unanswered questions (e.g. choice of pricing mechanism, regional data processing, public or private form of BC) especially for requirements in table A 5, as there is no clear solution yet.
* Requirements regarding what 'easy', 'efficient and fast'; 'sufficient number of participants' or 'selected data' means, still include some room for interpretation. The actual meaning of these wordings should be clarified as it did not emerge from the survey results in this Master’s thesis.
* The aforementioned point also shows that measurability of the requirements, is not possible due to the fact that there are many qualitative requirements. This means that the fulfillment of requirements cannot be measurably confirmed. For example, it is not possible to determine what efficient means (e.g. that saving of x Euro per month are possible when participating at a local energy market using BC).

# Conclusion and Outlook

This section offers a summary of the overall work and its essential key findings. The research question is answered and practical recommendations for action are given. In addition, open questions and suggestions for further research are described.

## Conclusion

This Master’s thesis determined different aspects of the BC technology and its use for a local energy market. By presenting the theoretical backgrounds to the BC topic as well as on the regulatory framework for renewable energies, the peer-to-peer system and the conduction of a requirement analysis, different aspects have been explored to process two surveys. Stakeholders’ detailed descriptions compiling their current relation to the BC technology as well as their role in the energy market, supported the development of these surveys. By conducting these surveys, analyzing and interpreting their results, the research question has been answered. 21 requirements on the BC system are shown which define regulatory, social, economic, technological and ecological requirements for stakeholders exist to develop BC solutions in a local energy market. These are listed in the requirements specification in section 6.

The results of expert and prosumer / consumer surveys show that consumers and prosumers are essential for a successful implementation of a local energy market. Thus, it is crucial to meet their expectations. A user-friendly operation is a priority and forms the basis for a participation in a peer-to-peer market via BC. Only through the existence of an application that is coherent with the end user, one is able and willing to participate in the market. It must also be possible to find out where the electricity comes from and how prices are composed. This transparency helps to create trust and acceptance. Furthermore, stakeholders are motivated by financial incentives like cost advantages. Without an adequate exchange of information, misunderstandings will arise, and participants will be disappointed with the system. To avoid this, information should be provided already before the implementation phase of a local energy market by central stakeholders like regulators or service providers of a BC platform. Information can be distributed in the form of information brochures. As soon as the platform is being implemented, personal advice in form of workshops should be provided to offer an appropriate exchange of information. As an important member of the energy market, users perceive appreciation in this way.

Overall, this thesis showed that BC has huge potential to master challenges of the future energy market and to support a decentralized energy supply. The results of the two surveys show that from an expert's as well as consumers’ and prosumers’ point of view, BC has many advantages for the energy market. By providing security, flexibility, independence, efficiency and economic improvements, it can contribute to the energy transition. In addition, participants can be actively involved in shaping the energy market by establishing a local peer-to-peer system. Regional energy products contribute to a sustainable improvement of the future energy market. However, for a successful implementation of a peer-to-peer market using BC, challenges must be mastered. In this respect, the focus is on compliance with existing processes and regulatory requirements.

## Outlook

Local peer-to-peer energy markets using BC technology are still in their initial development stages and need to be further evaluated before they can be fully implemented and operationalized.

This includes setting up a small local peer-to-peer network using BC to test the functionality and acceptance among the population. It is highly recommended to approach already operating start-ups or research institutes that have first experiences with such an implementation. The project ‘Quartier Schwemmiweg’ in Walenstadt has already established a local energy market in which around 37 parties participate (78). Such projects help to investigate which form of BC is better suited for practical implementation. Whether a private or a public BC should be used depends on the size of the network or the legal regulations. An application model requires further research and the concrete technical implementation of regulatory requirements. Otherwise, a complete implementation of a local peer-to-peer market is not possible. Thereby, it should be examined how the GDPR can be implemented. Possible scenarios would be the elimination of certain sequences from the BC or a selection of data (without personal data) stored on the BC. The question remains whether data should only be processed on a regional level or transferred abroad.

Also, the choice of a suitable price mechanism can be further explored. It should be found out, if auction prices or fixed prices should be used. The assumption suggests that especially in the energy market an implementation of auction prices is difficult for customers, as this would lead to additional effort. But, there would be the possibility of an active involvement in shaping the energy price. In connection with this, it is also necessary to analyze how prices and the origin of products can be presented in a user-friendly way.

BC is not the only database technology on the market. Thus, a comparative study with other technologies can be carried out to summarize the advantages and disadvantages of different technologies.

To pursue these open research questions, a different research strategy could be chosen. The survey method was appropriate to reach many stakeholders but it slightly lost quality. Interviews are better suited for experts’ inquiries.

# Appendix

## A.1 Experts Survey LamaPoll

## A.2 Prosumers and Consumers Survey LamaPoll

## A.3 Definition of X and Y variables

Table A 1: Y and X variables for linear regressions

|  |  |  |
| --- | --- | --- |
| Variables | Question | Expression / Definition |
| Y | Would you switch from the current electricity market system (consumers receive their electricity through an electricity supplier) to the peer-to-peer system using a BC (consumers buy electricity directly from regional producers)? | * Yes: 1 * No: -1 |
| X1 | How high do you rate your current level of knowledge with regards to BC technology? | * Briefly known: -1 * Low knowledge: -0,5 * Higher Knowledge: 0,5 * Expert: 1 |
| X2 | Do you need further experience / instructions before you participate in such a peer-to-peer system via BC? | * Yes: 1 * No: -1 |
| X3 | How important is it to you that when introducing BC technology, training courses are offered by service providers or regulators on this topic? | * Not important: -1 * Less important: -0,5 * More important: 0,5 * Very important: 1 |
| X4 | How important is it to you that user-friendly applications (e.g. mobile apps for your smartphone) are available for participation in a local energy market via BC? | * Not important: -1 * Less important: -0,5 * More important: 0,5 * Very important: 1 |
| X5 | How important is it to you that the availability of electricity exists automatically and without active control by you? | * Not important: -1 * Less important: -0,5 * More important: 0,5 * Very important: 1 |
| X6 | How important is it to you that a local energy market ensures permanent security of supply? | * Not important: -1 * Less important: -0,5 * More important: 0,5 * Very important: 1 |
| X7 | Do you have a smart device for measuring your electricity consumption? | * Yes: 1 * No: -1 |
| X8 | If yes - How important is it to you that your smart device is compatible with BC technology? | * Not important: -1 * Less important: -0,5 * More important: 0,5 * Very important: 1 |
| X9 | How important is it to you that the BC technology uses as little energy as possible? | * Not important: -1 * Less important: -0,5 * More important: 0,5 * Very important: 1 |
| X10 | How important is it to you that all processes of an energy network take place exclusively in Germany? | * Not important: -1 * Less important: -0,5 * More important: 0,5 * Very important: 1 |
| X11 | How important is it to you that unauthorized attacks and manipulations on a decentralized, BC-based energy network are prevented? | * Not important: -1 * Less important: -0,5 * More important: 0,5 * Very important: 1 |
| X12 | How important is it to you that the use of BC technology in the energy industry complies with existing regulations on the protection of personal data? | * Not important: -1 * Less important: -0,5 * More important: 0,5 * Very important: 1 |
| X13 | How important do you consider the availability of transparency in a BC network on the local energy market to be? | * Not important: -1 * Less important: -0,5 * More important: 0,5 * Very important: 1 |
| X14 | Would you switch from the current electricity market system to the peer-to-peer system using BC if this would bring financial benefits? | * Yes: 1 * No: -1 |
| X15 | Is your willingness to pay higher, if you know the vendor of the regeneratively produced electricity, or if it comes from the local environment? | * Yes: 1 * No: -1 |
| X16 | How important is it to you that a local energy market using BC technology has a simple payment system? | * Not important: -1 * Less important: -0,5 * More important: 0,5 * Very important: 1 |

## A.4 Category Description for Inductive Category Formation

This section contains 47 categories and their description, created during the implementation of the Inductive Category Formation. These categories are based on results of the expert surveys and are labelled from A to U1 and described as shown in **table A 2**.

Table A 2: Category description for Inductive Category Formation

|  |  |
| --- | --- |
| Category | Description |
| Category A | BC offers transparency regarding price composition and energy origin |
| Category B | BC provides security, consistency, and accuracy of data |
| Category C | BC offers flexible, (monopoly-)independent, regional and decentralized peer-to-peer trade |
| Category D | BC is not yet suitable for masses but can be used as a showcase project in the energy sector – future development is necessary |
| Category E | BC is efficient and economical |
| Category F | Scalability poses a problem for the use of BC in the energy market |
| Category G | BC is complex and must be designed user-friendly for acceptance and trust |
| Category H | BC must be integrated into or compatible with existing processes and systems |
| Category I | BC should provide low energy consumption |
| Category J | BC must offer data protection, reliable data transmission and manipulation security e.g. by using encryption and pseudonymization capabilities |
| Category K | Public BC systems ensure acceptance and transparency in a large network |
| Category L | Private BC systems ensure a secure, confidential, regional and efficient network |
| Category M | PoA serves as an efficient, high-performance, trustworthy and energy-saving consensus mechanism for BC – PoS might be an alternative |
| Category N | BC may not exceed previous costs or must offer cost advantage |
| Category O | BC has to provide permanent security of supply |
| Category P | BC should run efficiently, fast and automatically |
| Category Q | With a peer-to-peer network using BC, "joint participation" in the energy market and the energy transition is possible |
| Category R | BC should have differently accessible user interfaces for different stakeholders depending on complexity and purposes of use |
| Category S | BC is not a competitor system but a complementary system to the existing ones |
| Category T | BC can be considered equivalent or competitive to existing systems |
| Category U | BC requires a new development of the market including comprehensible pricing mechanisms and network separation as well as a reorganization of the current regulatory framework |
| Category V | BC should resemble current payment systems |
| Category W | BC should store selected data on the chain only |
| Category X | A peer-to-peer network using BC should have restricted access (permissioned BC) |
| Category Y | BC could integrate private transactions and secret stores |
| Category Z | Scalability is not a problem for the use of BC in the energy market, but still needs practical application in the field |
| Category A1 | BC does not necessarily have to be compatible and linkable with existing systems and regulations |
| Category B1 | BC must comply with existing laws |
| Category C1 | Prosumers should receive a pre-qualification / license upon registration by an auditor to act as a provider in a peer-to-peer market with BC |
| Category D1 | Prosumers should not receive a pre-qualification / by an auditor in order to act as a provider in a peer-to-peer market with BC |
| Category E1 | BC generates additional technological and economic effort as well as digital dependency |
| Category F1 | BC may cause little to no risk of disruption of business lines for electricity suppliers, network operators and meter operators, but this new technology should still be considered. |
| Category G1 | When introducing BC, the price mechanism through auctioning should be used |
| Category H1 | When introducing the BC, the price mechanism by means of stock exchange price should be used |
| Category I1 | When introducing BC, digital payment system (digital currency) should be used |
| Category J1 | When introducing BC, a conventional payment system (invoice, monthly payment) should be used |
| Category K1 | When a peer-to-peer system using BC technology is introduced, purchase guarantees for prosumers must be contractually regulated and excess electricity must be purchased by market participants |
| Category L1 | When introducing a peer-to-peer system using BC technology, no purchase guarantees for prosumers should be contractually regulated and surplus electricity should be purchased by market participants |
| Category M1 | When a regional peer-to-peer market using BC is introduced, as many participants as possible must be involved and an independent network with different production and storage facilities must be set up |
| Category N1 | When introducing a regional peer-to-peer market using BC, different regional networks have to be connected |
| Category O1 | BC has no environmental benefits and central systems are better suited for the energy market |
| Category P1 | When introducing a regional peer-to-peer market, incentives for the development of decentralized renewable energy facilities are created |
| Category Q1 | BC has to offer transparency regarding price composition and energy origin |
| Category R1 | Central stakeholders should create awareness for the BC technology and its general functionality |
| Category S1 | BC should offer flexible, (monopoly-)independent, regional and decentralized peer-to-peer trade |
| Category T1 | Data processing should take place within the local environment |
| Category U1 | BC does not necessarily have to offer cost advantages |

## A.5 Results of the Inductive Category Formation based on Expert Responses

In this section categories of table A 2 are assigned to the questions in which they appeared during the surveys. The **table A 3** shows the question involved, the percentage of a specific expert group participating named a specific category, how often the category was chosen for a question in absolute numbers, and how often a category was chosen in relative numbers with respect to all answers to the respective question.

Table A 3: Frequency table for Inductive Category Formation by experts' results

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1. Where do you see technological opportunities regarding the application of BC technology in the form of a local energy market? | DSO  [1] | BCT [12] | ES [4] | MO [1] | SC [9] | Other [0] | Absolute frequency | Relative frequency (n=19) |
| Category C | 100% | 67% | 50% | 0% | 44% | 0% | 11 | 58% |
| Category A | 0% | 25% | 50% | 0% | 44% | 0% | 7 | 37% |
| Category E | 0% | 25% | 25% | 0% | 22% | 0% | 6 | 32% |
| Category B | 0% | 42% | 25% | 0% | 33% | 0% | 5 | 26% |
| Category D | 0% | 8% | 25% | 100% | 0% | 0% | 1 | 5% |
| **2. Where do you see technological challenges regarding the application of BC technology in the form of a local energy market?** | **DSO [2]** | **BCT [13]** | **ES [4]** | **MO [1]** | **SC [9]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=20)** |
| Category G | 100% | 38% | 50% | 0% | 56% | 0% | 7 | 35% |
| Category D | 0% | 31% | 25% | 100% | 11% | 100% | 6 | 30% |
| Category F | 0% | 23% | 0% | 0% | 33% | 0% | 5 | 25% |
| Category J | 0% | 8% | 0% | 0% | 33% | 0% | 3 | 15% |
| Category H | 0% | 8% | 25% | 0% | 0% | 0% | 2 | 10% |
| Category O | 0% | 8% | 0% | 0% | 0% | 0% | 1 | 5% |
| Category P | 0% | 8% | 0% | 0% | 0% | 0% | 1 | 5% |
| Category U | 0% | 8% | 0% | 0% | 0% | 0% | 1 | 5% |
| Category I | 0% | 0% | 0% | 0% | 11% | 0% | 1 | 5% |
| Category N | 0% | 8% | 0% | 0% | 0% | 0% | 1 | 5% |
| **3. In your opinion, which form of BC (private or public) makes more sense for the regional distribution of renewable energies and why?** | **DSO [2]** | **BCT [12]** | **ES [4]** | **MO [1]** | **SC [9]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=19)** |
| Category L | 0% | 50% | 25% | 0% | 67% | 100% | 12 | 63% |
| Category K | 100% | 50% | 75% | 100% | 33% | 0% | 7 | 37% |
| **4. Which consensus mechanism should be used to validate all blocks in a network of a local energy market and why?** | **DSO [1]** | **BCT [7]** | **ES [2]** | **MO [0]** | **SC [7]** | **Other [0]** | **Absolute frequency** | **Relative frequency** |
| Category M | 100% | 100% | 100% | 0% | 100% | 0% | 12 | 100% |
| **5. How is it possible to make it sufficiently attractive for end-users (consumers) to switch from already established systems (electricity supply by electricity suppliers) to the BC?** | **DSO [2]** | **BCT [13]** | **ES [4]** | **MO [1]** | **SC [9]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=20)** |
| Category N | 100% | 92% | 75% | 0% | 67% | 100% | 16 | 80% |
| Category Q1 | 0% | 23% | 25% | 0% | 44% | 0% | 7 | 35% |
| Category G | 0% | 23% | 50% | 100% | 11% | 100% | 5 | 25% |
| Category P | 0% | 15% | 50% | 100% | 0% | 100% | 4 | 20% |
| Category Q | 0% | 8% | 0% | 0% | 22% | 0% | 3 | 15% |
| Category O | 50% | 15% | 25% | 0% | 0% | 0% | 2 | 10% |
| Category J | 50% | 8% | 25% | 0% | 0% | 0% | 1 | 5% |
| **6. How can the use of the BC system be differentiated for different stakeholder groups?** | **DSO [2]** | **BCT [10]** | **ES [4]** | **MO [1]** | **SC [6]** | **Other [0]** | **Absolute frequency** | **Relative frequency (n=14)** |
| Category R | 100% | 100% | 100% | 100% | 100% | 0% | 14 | 100% |
| Category G | 0% | 0% | 0% | 0% | 17% | 0% | 1 | 7% |
| Category Q1 | 0% | 10% | 0% | 0% | 0% | 0% | 1 | 7% |
| **7. How competitive do you rate BC technology compared to other data management systems?** | **DSO [2]** | **BCT [9]** | **ES [3]** | **MO [1]** | **SC [4]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=12)** |
| Category D | 50% | 67% | 67% | 100% | 75% | 100% | 8 | 67% |
| Category T | 100% | 44% | 100% | 100% | 50% | 0% | 5 | 42% |
| Category U | 0% | 11% | 0% | 0% | 0% | 0% | 1 | 8% |
| Category S | 0% | 11% | 0% | 0% | 0% | 0% | 1 | 8% |
| **8. How can an end user of a BC network use the peer-to-peer system as efficiently and effortlessly as possible?** | **DSO [2]** | **BCT [13]** | **ES [4]** | **MO [1]** | **SC [9]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=20)** |
| Category G | 100% | 70% | 75% | 0% | 56% | 100% | 14 | 70% |
| Category R | 100% | 38% | 100% | 100% | 44% | 0% | 10 | 50% |
| Category Q1 | 50% | 15% | 25% | 0% | 0% | 0% | 3 | 15% |
| Category P | 0% | 23% | 0% | 0% | 11% | 0% | 3 | 15% |
| Category H | 0% | 15% | 25% | 100% | 0% | 0% | 2 | 10% |
| Category N | 0% | 15% | 0% | 0% | 11% | 0% | 2 | 10% |
| Category V | 0% | 8% | 0% | 0% | 11% | 0% | 2 | 10% |
| Category U | 0% | 8% | 0% | 0% | 0% | 0% | 1 | 5% |
| Category Q | 0% | 8% | 0% | 0% | 0% | 0% | 1 | 5% |
| Category C | 0% | 8% | 0% | 0% | 11% | 0% | 1 | 5% |
| **9. How can the protection of private, personal data of individual stakeholders in a decentralized energy network be guaranteed?** | **DSO [2]** | **BCT [9]** | **ES [4]** | **MO [1]** | **SC [7]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=15)** |
| Category J | 100% | 89% | 100% | 100% | 86% | 100% | 13 | 87% |
| Category W | 0% | 22% | 0% | 0% | 29% | 0% | 3 | 20% |
| Category R | 0% | 0% | 25% | 0% | 14% | 0% | 2 | 13% |
| Category Y | 0% | 11% | 0% | 0% | 0% | 0% | 1 | 7% |
| Category X | 0% | 0% | 0% | 0% | 14% | 0% | 1 | 7% |
| **10. Do you consider data manipulation by using a BC in a local energy market critical?** | **DSO [0]** | **BCT [4]** | **ES [0]** | **MO [0]** | **SC [4]** | **Other [0]** | **Absolute frequency** | **Relative frequency (n=6)** |
| Category J | 0% | 100% | 0% | 0% | 100% | 0% | 6 | 100% |
| Category M1 | 0% | 25% | 0% | 0% | 0% | 0% | 1 | 17% |
| **11. Can there be mobile applications for the use of BC technology? If so, how do these mobile applications have to be connected?** | **DSO [2]** | **BCT [9]** | **ES [3]** | **MO [0]** | **SC [5]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=13)** |
| Category R | 50% | 56% | 33% | 0% | 60% | 100% | 7 | 54% |
| Category J | 50% | 11% | 67% | 0% | 20% | 0% | 3 | 23% |
| Category Q1 | 50% | 22% | 33% | 0% | 20% | 0% | 3 | 23% |
| Category G | 50% | 11% | 33% | 0% | 0% | 0% | 2 | 15% |
| Category D | 0% | 11% | 0% | 0% | 0% | 0% | 1 | 8% |
| **12. Is scalability a problem when using a BC in the local energy market?** | **DSO [2]** | **BCT [12]** | **ES [3]** | **MO [0]** | **SC [8]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=18)** |
| Category Z | 50% | 67% | 67% | 0% | 50% | 0% | 10 | 56% |
| Category F | 50% | 33% | 33% | 0% | 50% | 100% | 8 | 44% |
| Category R | 0% | 8% | 0% | 0% | 0% | 0% | 1 | 6% |
| **13. Is it necessary to link BC technology with intelligent measuring systems? How could this be implemented?** | **DSO [2]** | **BCT [11]** | **ES [4]** | **MO [1]** | **SC [7]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=18)** |
| Category H | 100% | 91% | 75% | 100% | 100% | 100% | 16 | 89% |
| Category A1 | 0% | 9% | 25% | 0% | 0% | 0% | 2 | 11% |
| **14. Where do you see opportunities for the integration of BC technology in the local energy market to the existing regulatory framework?** | **DSO [2]** | **BCT [4]** | **ES [4]** | **MO [1]** | **SC [2]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=8)** |
| Category Q1 | 50% | 25% | 50% | 0% | 50% | 0% | 3 | 38% |
| Category C | 50% | 25% | 25% | 0% | 50% | 0% | 2 | 25% |
| Category P | 0% | 0% | 0% | 0% | 0% | 100% | 1 | 13% |
| Category U | 0% | 25% | 25% | 100% | 0% | 0% | 1 | 13% |
| Category B1 | 0% | 25% | 0% | 0% | 0% | 0% | 1 | 13% |
| Category E | 50% | 0% | 25% | 0% | 0% | 0% | 1 | 13% |
| **15. Where do you see regulatory challenges regarding the application of BC technology in the form of a local energy market?** | **DSO [0]** | **BCT [4]** | **ES [2]** | **MO [1]** | **SC [4]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=8)** |
| Category U | 0% | 100% | 50% | 100% | 75% | 100% | 6 | 75% |
| Category B1 | 0% | 0% | 50% | 0% | 25% | 0% | 2 | 25% |
| Category G | 0% | 25% | 0% | 0% | 25% | 0% | 1 | 13% |
| **16. Are there conflicts between the use of BC technology on the local energy market and the European Data Protection Regulation and, if so, how can these be resolved?** | **DSO [1]** | **BCT [6]** | **ES [3]** | **MO [1]** | **SC [6]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=11)** |
| Category B1 | 0% | 67% | 33% | 0% | 83% | 0% | 7 | 64% |
| Category A1 | 100% | 33% | 67% | 100% | 17% | 100% | 4 | 36% |
| Category L | 0% | 0% | 33% | 0% | 0% | 0% | 1 | 9% |
| Category W | 0% | 17% | 0% | 0% | 17% | 0% | 1 | 9% |
| **17. Is it necessary for prosumers to obtain a pre-qualification / license to operate as a provider in a peer-to-peer market?** | **DSO [1]** | **BCT [6]** | **ES [2]** | **MO [1]** | **SC [5]** | **Other [0]** | **Absolute frequency** | **Relative frequency (n=8)** |
| Category C1 | 100% | 67% | 50% | 0% | 80% | 0% | 5 | 63% |
| Category D1 | 0% | 33% | 50% | 100% | 20% | 0% | 3 | 38% |
| **18. Where do you see economic advantages regarding the application of BC technology in form of a local energy market?** | **DSO [2]** | **BCT [3]** | **ES [5]** | **MO [1]** | **SC [3]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=11)** |
| Category N | 100% | 33% | 80% | 100% | 33% | 100% | 7 | 64% |
| Category C | 50% | 33% | 20% | 0% | 0% | 0% | 3 | 27% |
| Category P | 0% | 67% | 40% | 100% | 33% | 0% | 3 | 27% |
| Category E | 0% | 0% | 20% | 0% | 33% | 0% | 2 | 18% |
| Category A | 0% | 0% | 20% | 0% | 0% | 0% | 1 | 9% |
| Category B | 0% | 0% | 20% | 0% | 0% | 0% | 1 | 9% |
| Category P1 | 0% | 33% | 0% | 0% | 0% | 0% | 1 | 9% |
| **19. Where do you see economic disadvantages regarding the application of BC technology in the form of a local energy market?** | **DSO [3]** | **BCT [2]** | **ES [5]** | **MO [0]** | **SC [2]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=10)** |
| Category E1 | 100% | 100% | 80% | 0% | 100% | 100% | 9 | 90% |
| Category G | 0% | 50% | 20% | 0% | 50% | 0% | 2 | 20% |
| Category I | 33% | 0% | 20% | 0% | 0% | 0% | 1 | 10% |
| Category F1 | 0% | 0% | 20% | 0% | 0% | 0% | 1 | 10% |
| **20. Do cost advantages have to be created for all stakeholders by applying the BC in a local energy market? How could this be implemented?** | **DSO [2]** | **BCT [2]** | **ES [5]** | **MO [1]** | **SC [2]** | **Other [0]** | **Absolute frequency** | **Relative frequency (n=9)** |
| Category N | 0% | 100% | 80% | 100% | 50% | 0% | 6 | 67% |
| Category U1 | 100% | 0% | 20% | 0% | 50% | 0% | 3 | 33% |
| Category Q | 50% | 50% | 40% | 100% | 0% | 0% | 2 | 22% |
| **21. How do electricity suppliers, network operators and metering point operators prevent a disruption of their own line of business? Do you see a challenge / opportunity in the development of a peer-to-peer market using BC?** | **DSO [2]** | **BCT [3]** | **ES [5]** | **MO [1]** | **SC [3]** | **Other [1]** | **Absolute frequency** | **Relative frequency**  **(n=11)** |
| Category F1 | 50% | 100% | 80% | 100% | 100% | 100% | 9 | 82% |
| Category O | 0% | 0% | 20% | 0% | 0% | 0% | 1 | 9% |
| Category U | 50% | 0% | 0% | 0% | 0% | 0% | 1 | 9% |
| **22. Which pricing mechanisms should be implemented on the BC for an economically viable local energy market?** | **DSO [0]** | **BCT [2]** | **ES [2]** | **MO+ [0]** | **SC [2]** | **Other [1]** | **Absolute frequency** | **Relative frequency**  **(n=6)** |
| Category G1 | 0% | 100% | 50% | 0% | 100% | 0% | 4 | 67% |
| Category H1 | 0% | 0% | 50% | 0% | 0% | 100% | 2 | 33% |
| **23. Which means of payments should be integrated into the BC of a regional energy market?** | **DSO [1]** | **BCT [3]** | **ES [5]** | **MO [1]** | **SC [2]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=9)** |
| Category I1 | 100% | 100% | 100% | 100% | 100% | 0% | 8 | 89% |
| Category J1 | 100% | 33% | 20% | 0% | 50% | 100% | 4 | 44% |
| **24. How do you guarantee prosumers a definitive energy sale in a peer-to-peer market, even if no suitable buyer is found?** | **DSO [1]** | **BCT [3]** | **ES [5]** | **MO [1]** | **SC [2]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=9)** |
| Category K1 | 0% | 100% | 80% | 100% | 100% | 100% | 8 | 89% |
| Category M1 | 0% | 0% | 20% | 0% | 50% | 0% | 2 | 22% |
| Category L1 | 100% | 0% | 20% | 0% | 0% | 0% | 1 | 11% |
| **25. Where do you see social opportunities regarding the application of BC technology in the form of a local energy market?** | **DSO [3]** | **BCT [4]** | **ES [3]** | **MO [0]** | **SC [6]** | **Other [0]** | **Absolute frequency** | **Relative frequency (n=10)** |
| Category A | 67% | 50% | 33% | 0% | 83% | 0% | 7 | 70% |
| Category Q | 33% | 75% | 67% | 0% | 67% | 0% | 6 | 60% |
| Category C | 0% | 25% | 0% | 0% | 50% | 0% | 3 | 30% |
| **26. Where do you see social disadvantages regarding the application of BC technology in the form of a local energy market?** | **DSO [2]** | **BCT [3]** | **ES [2]** | **MO [0]** | **SC [4]** | **Other [0]** | **Absolute frequency** | **Relative frequency (n=6)** |
| Category G | 100% | 67% | 100% | 0% | 75% | 0% | 5 | 83% |
| Category R1 | 0% | 33% | 0% | 0% | 50% | 0% | 2 | 33% |
| **27. Which possibilities exist to motivate consumers/prosumers to participate in a local energy market with BC technology? Can this increase the acceptance of BC technology?** | **DSO [3]** | **BCT [5]** | **ES [4]** | **MO [1]** | **SC [6]** | **Other [1]** | **Absolute frequency** | **Relative frequency(n=12)** |
| Category N | 33% | 80% | 50% | 100% | 67% | 100% | 7 | 58% |
| Category R1 | 33% | 0% | 25% | 0% | 17% | 100% | 4 | 33% |
| Category Q1 | 33% | 0% | 25% | 0% | 33% | 100% | 4 | 33% |
| Category S1 | 33% | 0% | 25% | 0% | 17% | 100% | 3 | 25% |
| Category G | 33% | 20% | 25% | 0% | 0% | 0% | 1 | 8% |
| Category P | 0% | 20% | 0% | 0% | 17% | 0% | 1 | 8% |
| **28. How do you introduce consumers to BC technology?** | **DSO [2]** | **BCT [5]** | **ES [4]** | **MO [1]** | **SC [6]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=11)** |
| Category R1 | 50% | 60% | 75% | 100% | 67% | 100% | 9 | 82% |
| Category G | 100% | 60% | 75% | 100% | 17% | 100% | 5 | 45% |
| Category Q1 | 50% | 20% | 25% | 0% | 0% | 0% | 1 | 9% |
| **29. From an entrepreneurial point of view, do you see potential for data processing at regional / national level and how can this be ensured? Does this create a higher basis of trust?** | **DSO [1]** | **BCT [2]** | **ES [2]** | **MO [0]** | **SC [3]** | **Other [0]** | **Absolute frequency** | **Relative frequency (n=5)** |
| Category J | 100% | 100% | 100% | 0% | 67% | 0% | 4 | 80% |
| Category T1 | 100% | 0% | 50% | 0% | 33% | 0% | 2 | 40% |
| **30. How important is the secure processing of private data using the BC to you? How can this be achieved?** | **DSO [3]** | **BCT [3]** | **ES [3]** | **MO [0]** | **SC [4]** | **Other [0]** | **Absolute frequency** | **Relative frequency (n=8)** |
| Category J | 100% | 67% | 100% | 0% | 25% | 0% | 5 | 63% |
| Category W | 0% | 33% | 0% | 0% | 50% | 0% | 2 | 25% |
| Category R | 33% | 33% | 33% | 0% | 0% | 0% | 1 | 13% |
| Category L | 0% | 0% | 0% | 0% | 25% | 0% | 1 | 13% |
| **31. How can a local energy market contribute to permanent security of supply?** | **DSO [2]** | **BCT [4]** | **ES [4]** | **MO [1]** | **SC [4]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=8)** |
| Category M1 | 50% | 100% | 75% | 100% | 50% | 0% | 5 | 63% |
| Category N1 | 50% | 0% | 25% | 0% | 25% | 100% | 3 | 38% |
| Category Q | 50% | 25% | 25% | 0% | 40% | 0% | 3 | 38% |
| Category P | 0% | 0% | 0% | 0% | 25% | 0% | 1 | 13% |
| **32. Where do you see ecological advantages regarding the application of BC technology in the form of a local energy market?** | **DSO [2]** | **BCT [3]** | **ES [5]** | **MO [0]** | **SC [5]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=11)** |
| Category E | 100% | 100% | 60% | 0% | 40% | 0% | 5 | 45% |
| Category C | 100% | 67% | 60% | 0% | 20% | 0% | 4 | 37% |
| Category P1 | 0% | 33% | 40% | 0% | 40% | 0% | 4 | 37% |
| Category Q | 0% | 33% | 0% | 0% | 40% | 0% | 2 | 18% |
| Category O1 | 0% | 33% | 40% | 0% | 40% | 0% | 2 | 18% |
| Category N | 0% | 0% | 0% | 0% | 20% | 0% | 1 | 9% |
| Category Q1 | 0% | 0% | 0% | 0% | 20% | 0% | 1 | 9% |
| **33. Where do you see ecological disadvantages regarding the application of BC technology in the form of a local energy market?** | **DSO [1]** | **BCT [1]** | **ES [3]** | **MO [0]** | **SC [2]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=6)** |
| Category I | 100% | 100% | 67% | 0% | 100% | 100% | 5 | 83% |
| Category M | 0% | 0% | 0% | 0% | 50% | 0% | 1 | 17% |
| Category P | 0% | 0% | 33% | 0% | 0% | 0% | 1 | 17% |
| **34. Do you classify energy consumption of BC technology in the form of a local energy market as critical?** | **DSO [2]** | **BCT [4]** | **ES [4]** | **MO [1]** | **SC [4]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=9)** |
| Category I | 100% | 100% | 100% | 100% | 100% | 100% | 9 | 100% |
| Category M | 50% | 75% | 50% | 100% | 75% | 0% | 5 | 56% |
| Category L | 0% | 0% | 25% | 0% | 0% | 0% | 1 | 11% |
| Category X | 0% | 0% | 0% | 0% | 25% | 0% | 1 | 11% |
| **35. Can the use of BC technology in the local energy market contribute to the energy transition?** | **DSO [2]** | **BCT [4]** | **ES [3]** | **MO [0]** | **SC [4]** | **Other [1]** | **Absolute frequency** | **Relative frequency (n=8)** |
| Category P1 | 50% | 75% | 67% | 0% | 75% | 100% | 6 | 75% |
| Category Q | 50% | 50% | 33% | 0% | 25% | 0% | 2 | 25% |
| Category E | 50% | 25% | 33% | 0% | 25% | 0% | 2 | 25% |
| Category O1 | 0% | 25% | 0% | 0% | 25% | 0% | 1 | 13% |
| Category C | 50% | 0% | 33% | 0% | 0% | 0% | 1 | 13% |
| Category A | 50% | 25% | 33% | 0% | 0% | 0% | 1 | 13% |

## A.6 Tender Specification

Usually a tender specification contains an introduction to the overall project, the existing situation, tasks for the target condition, interface description and requirements in categories. (61 p. 4)

These parts are not included at this point, as background and the existing situation on the energy market have already been described in section 1 and 2.

A single requirement consists of the requirement number, the title, the requirement itself, the justification as well as a classification. With introduction of a peer-to-peer market using BC technology requirements in **table A 4** were recognized.

Table A 4: Catalogue of requirements

|  |  |
| --- | --- |
| No.: 1 | User-friendly Application |
| **Requirement** | The system must offer an application that is easy for users to handle and to understand. |
| **Justification** | As shown in table 4-4, 74% of consumers and prosumers consider it rather important or very important that user-friendly applications are available to participate in a local peer-to-peer market via BC. This statement could also be supported by the results of the binomial test in table 4-7 and the ordinary linear regression with a P-value of 0,0033 for variable X4.  Also, Category G appeared in 10 different expert questions in table A 2 in appendix A4. I.a. category G was chosen from 70% of respondents for question 8 and from 83% of respondents for question 26. Besides usability, 96% of experts believe according to question 4 in table 4-12, that it is possible that mobile applications for the use of a BC can exist.  Since this statement received support from both stakeholder groups and was remarkably noticed due to frequent mentioning, this requirement ranks first. |
| **Classification** | Non-functional requirement due to its quality characteristic of usability, but also as functional requirement as applications are a technical implementation. |
| **No.: 2** | **Transparency** |
| **Requirement** | The system must provide transparency regarding energy origin and price composition. |
| **Justification** | 57 out of 90 responding prosumers and consumers to question 2 of table 4-6 would pay more for electricity if the energy origin and/or seller were known. This statement is also supported by the ordinary linear regression and the significant p-value of 0.008 for X15 in table 4-10. In addition, about 9% of the answers to the last question in table 4-4 fall on transparency in a local energy market with BC. Also, for the direct request of transparency as shown in table 4-5, for 92% it is important to see that transparency is dominant in a local energy market. This is additionally supported by the result of the binomial test results in table 4-7.  The topic of transparency was very well received by experts. As can be seen from table A 3 in appendix A.5, the relevant category Q1 appeared in 8 different questions. The category was i.a. addressed by stakeholder group 2 in connection with how to motivate end users to use a BC (33% of the responding experts) or how to deal with the BC as efficiently as possible (15% of the responding experts).  In two cases, this request appears less than the former and received slightly less percentual approval from experts. Hence, this request is ranked in second place. |
| **Classification** | Non-functional requirement since transparency defines a quality criterion that describes the ‘how’-state. |
| **No.: 3** | **Financial benefits** |
| **Requirement** | The system must offer financial benefits for all stakeholders. |
| **Justification** | A very strong statement can be captured by the first question of the frequency table 4-6. At this point around 91% of the prosumers and consumers would switch to a peer-to-peer system with BC if this brings financial benefits. This is supported by the result of line 13 in table 4-7 and the significant p-value of 0.038 of the ordinary linear regression for variable X14.  Experts mentioned category N regarding cost advantages in 7 different questions. 80% of respondents believed the attractiveness of a BC in the local energy market for consumers increases as a result of cost advantages. That there is no need for cost advantages, the experts only addressed once with category U1.  Since consumers will be main payers for electricity costs, their interest outweighs that of the experts. Although these also expressed themselves in favor of cost advantages, there was the possibility with category N that costs would remain the same. However, the opinion of prosumers and consumers is slightly prioritized, which is why this requirement comes third. |
| **Classification** | Non-functional requirement since financial benefits defines a quality criterion that describes the ‘how’-state. |
| **No.: 4** | **Information exchange and instructions** |
| **Requirement** | Central stakeholders such as service providers or regulators must create awareness for the BC technology and offer information material on its general functionality also before an implementation. |
| **Justification** | As prosumers and consumers confirm in frequency table 4-3 and question 3 with 87%, it is necessary to inform these stakeholders already before implementing a peer-to-peer market by means of BC. In this regard, information brochures should be available in advance, as can be confirmed by 44% of prosumers and consumers. With the introduction of the BC, additional training courses by service providers or regulators should be offered. This can be confirmed by the 74% of prosumers and consumers who confirmed this as rather important or very important. The binomial test also did not allow the null hypothesis to be rejected in this respect, as can be seen from table 4-7. Only in the question of training courses by service providers or regulators, the null hypothesis was rejected in the case of an importance greater than or equal to 85%. Nevertheless, the switch to a peer-to-peer network via BC is positively correlated with such course offerings as the significant P-value to variable X3 in table 4-10 shows.  Experts also addressed the topic of introduction to BC technology. The focus of this was on central stakeholders communicating the general functionality to end users and thus creating awareness. Associated category R1 was mentioned in three questions in table A 3 in appendix A.5. It was particularly highly echoed by 81% in question 28 on how consumers should be introduced to BC technology.  The corresponding category of this requirement appeared in fewer questions but was also confirmed by ordinary regression. Therefore, it is set in fourth place. |
| **Classification** | Constraint since information exchange is necessary to motivate people to participate. |
| **No.: 5** | **Data security** |
| **Requirement** | The system must provide secure data processing. |
| **Justification** | Almost 98% of the respondents from stakeholder group 1 consider it more or very important that a BC-based energy network avoids manipulation and hacker attacks, as shown in table 4-5. Line 10 in table 4-7 also shows that the hypothesis cannot be rejected in any case. Nevertheless, no significant correlation can be established between the variable X11 and the Y variable, neither for the multiple nor for the ordinary linear regression. On the other hand, 61% of experts in table 4-13 do not believe that there is criticality of data manipulation when using a BC in a local energy market. Nevertheless when looking at the results in table 4-14, almost 67% of experts consider it more or very important that secure processing of private data must be ensured when using BC.  In addition, the corresponding category J about data protection was used when answering 7 questions. For example, in question 9, about how important the protection of personal data is for experts, the category was chosen by 87% of the respondents.  Since this requirement received high approval but could not be confirmed by multiple regression as previous requirements did, it is in fifth place. |
| **Classification** | Functional requirement as data security describe a technical criterion and therefore the ‘what’-state. |
| **No.: 6** | **Security of supply** |
| **Requirement** | The system must ensure permanent security of energy supply for all network participants. |
| **Justification** | Almost 99% of prosumers and consumers were in favor of it being rather or very important for them to be guaranteed permanent security of supply. Although the corresponding null hypothesis in table 4-7 could not be rejected, the variable X6 in linear regressions was not confirmed.  Experts also consider security of supply to be important, as can be seen from the fact that the category O in table A 5 has been used three times, but only at percentages of 5, 9 and 10%.  This requirement was confirmed by a very high number of prosumers. Although the corresponding category O for the experts did not meet with a very high percentage of approval, this requirement should be placed in sixth place. The reason for this is that stakeholder group 2 will be highly dependent on electricity supply. In addition, it is possible that experts took this category and the requirement itself for granted and therefore mentioned it scarcely. |
| **Classification** | Constraint since security of supply is necessary to motivate people to participate. |
| **No.: 7** | **Compatibility with given regulations** |
| **Requirement** | The system must comply with existing regulations. |
| **Justification** | More than half (73%) of prosumers and consumers consider it very important that the use of BC in a local energy market complies with existing regulations for the protection of personal data. The result in table 4-7 in line 11 also clearly shows this, as the hypothesis cannot be rejected. Both linear regressions, on the other hand, do not confirm a significant correlation.  Also, with regard to question 16 on compliance with the European Data Protection Regulation in table A 3 in appendix A.5., 64% of the experts were in favor of compliance with applicable law and thus category B1. 36%, on the other hand, did not seem to be convinced of the need to comply with existing regulations and chose category A1.  While both, stakeholder group 1 and stakeholder group 2, support compliance with current legislation, there are also opponents. In addition, category U, the possibility of a reorganization of existing processes, was mentioned 6 times, which makes it clear that regulatory adjustments could also be considered. Therefore, this requirement is in 7th place. |
| **Classification** | Constraint as regulatory compliance is required in Germany. |
| **No.: 8** | **Low energy consumption** |
| **Requirement** | The system must ensure a low energy consumption. |
| **Justification** | 80 out of 88 prosumers and consumers state that it rather important or very important for BC to have a little energy usage. Also, in table 4-4, question 7 shows the importance of this requirements based on the 18% that this statement was chosen. Furthermore, the result by the lower tailed binomial test line 8 within table 4-7 supports this argument additionally. The hypothesis that low energy consumption is important for consumers and prosumers cannot be rejected. X9 from table A 1, which was tested for correlation with the Y variable, cannot record a significant p-value. Neither for the multiple nor for the ordinary linear regression.  Only a small tendency for the criticality to the energy consumption of BC can be seen from the expert opinion in table 4-15. Only 7 out of 15 experts think that energy consumption of BC technology in form of a local energy market is critical.  But, experts mentioned category I from table A 2 in appendix A.4 four times (in questions 2, 19, 33 and 34). In question 33 on ecological disadvantages, the category of 83% was mentioned and in question 3 regarding the criticality of energy consumption, exactly 100% of the experts who answered this question the category was mentioned.  Almost as important as requirement 7 can be made the requirement of low energy consumption by the BC due to the agreement of both parties |
| **Classification** | Non-functional requirement since low energy consumption defines a quality criterion that describes the ‘how’-state. |
| **No.: 9** | **Automatization, efficiency and speed** |
| **Requirement** | The system must run automatized, efficient and fast. |
| **Justification** | It is important for almost 95% of prosumers and consumers that electricity exists automatically and without active control. This can also be supported by the result that the null hypothesis is not rejected with the lower-tailed binomial test in table 4-7, but not by the conducted linear regressions.  That a peer-to-peer market using BC should work efficiently, automatically and fast was mentioned by experts with category P in 8 different questions, as shown in table A 3 in appendix A.5. Thereby between 5 and 27% per question were achieved.  Automatization, efficiency and speed seems to be of enormous importance for prosumers and consumers, experts also agreed with this, but to a lesser extent. Possibly also because this is already assumed. Therefore, this requirement is placed in ninth place. |
| **Classification** | Non-functional requirement since automatization, efficiency and speed define a quality criterion that describes the ‘how’-state. |
| **No.: 10** | **Compatibility with other systems (smart devices) and processes** |
| **Requirement** | The system must be compatible with existing processes and systems. |
| **Justification** | It is important for almost 92% of eleven consumers and prosumers who own a smart device that this is compatible with BC technology. Although this the hypothesis cannot be rejected according to table 4-7 it cannot be supported by results of the ordinary or multiple linear regression in table 4-9 or 4-10.  Experts also mention category H from on compatibility and integrity with other systems and processes on 3 different questions (2, 8, 13). It should be noted that in question 13 on compatibility with intelligent measurement systems, 89% of the responding experts cited category H.  Even though only 12 people took part in answering the corresponding question for prosumers and consumers, almost all of them were in favor of compatibility with other systems. Furthermore, many experts, which have more background knowledge regarding compatibility with other systems supported the corresponding category. Therefore, their feedback should be prioritized in connection with it, which explains that this requirement is the tenth place. |
| **Classification** | Functional requirement as compatibility with other systems (smart devices) and processes describe a technical criterion and therefore the ‘what’-state. |
| **No.: 11** | **Payment methods** |
| **Requirement** | The system should provide digital as well as conventional easy-to-use payment methods. |
| **Justification** | 79 out of 88 respondents from stakeholder group 1 consider it as important that a local energy market by means of BC enables a simple payment system. This is further confirmed by the fact that the associated hypothesis of the penultimate line from table 4-7 cannot be rejected. However, the linear regression with variable X16 is not associated with a change to BC.  As can be seen from question 5 in table 4-6, prosumers and consumers have a tendency towards conventional payment systems. Almost 64 per cent of those surveyed in this group tend to prefer bank transfer or payment on invoice. However, no further results were obtained from the linear regressions or the binomial test in this respect.  Furthermore, category V about the resembling of current payment systems was once stated by experts in question 8 of table A 3 in appendix A.5. Even if this is only a small percentage of 10% by responding experts.  Both categories, which advocated either for digital (I1) or for conventional (J1) payment methods, were selected by experts. However, digital payment methods had a larger advocacy group of experts with 89%, whereas the conventional methods reached about 44%. This shows that there was overlap and some experts argued for the availability of both payment options.  The requirement is on eleventh place due to the aforementioned aspects. |
| **Classification** | Functional requirement as payment methods describe a technical criterion and therefore the ‘what’-state. |
| **No.: 12** | **Different user interfaces** |
| **Requirement** | The system should offer different user interfaces for different groups of participants. |
| **Justification** | According to question 6 in table A 3 in appendix A.5, stakeholder group 2 is convinced that various user interfaces should be available for various user groups. All respondents to this question declared themselves in favor of that. The matching category R was also mentioned in 5 further questions.  Since this requirement seems to be very important for the group of experts, but did not receive feedback from consumers and prosumers, the twelfth place was chosen because of this one-sided view. |
| **Classification** | Functional requirement as different user interfaces describe a technical criterion and therefore the ‘what’-state. |
| **No.: 13** | **Purchase guarantees for prosumers** |
| **Requirement** | The system should contractually purchase guarantees for prosumers even if there is excess electricity. |
| **Justification** | Table A 3 shows that experts have a clear position on the sales guarantee for prosumers. In fact, question 24 shows that 89% are in favor of a contractual sales guarantee by referring to category K1. 11%, on the other hand, were in favor of category L1 by making comments and thus expressed their opposition to a contractually agreed sales guarantee.  Slightly less than the twelfth requirement, but still quite highly acclaimed by experts, requirement number 13 was met, which is why this rank was selected. |
| **Classification** | Constraint because purchase guarantees describe regulatory specifications. |
| **No.: 14** | **Consensus mechanism** |
| **Requirement** | The system should implement a PoA consensus mechanism. |
| **Justification** | As can be seen from the descriptive data results in table 4-12, question 2, almost 74% of experts are in favor of choosing a PoA consensus mechanism in a local energy market. Consumer or prosumer data are not known.  Also, category M appeared about three times in table A 3 and assumes the use of a PoA mechanism as the best option.  Slightly less percentage of agreement than the previous request is given to the requirement about the consensus mechanism, which was placed with rank 14. |
| **Classification** | Functional requirement as a PoA mechanism describes a technical criterion and therefore the ‘what’-state. |
| **No.: 15** | **Pre-qualification / license necessary** |
| **Requirement** | The system should be able to pre-qualify or license providers to operate in the network. |
| **Justification** | Two thirds of the 15 responding experts in table 4-13 believe that there should be a pre-qualification / license to operate as a provider in a peer-to-peer market.  This is also evident from the reference to category C1 by around 63% of the experts for question 17 in table A 3 in appendix A.5. There is no customer data on this statement.  Since there are no consumer and prosumer data available about prequalification, and two thirds of the recommend an implementation of this, this requirement was ranked 15th. |
| **Classification** | Constraint because a pre-qualification / license describes a regulatory specification. |
| **No.: 16** | **Flexible, (monopoly-)independent, regional and decentralized peer-to-peer trade** |
| **Requirement** | The system should offer flexible, (monopoly-)independent, regional and decentralized peer-to-peer trade. |
| **Justification** | According to stakeholder group 2, BC should enable flexible, (monopoly-)independent, regional and decentralized peer-to-peer trade. In this context, the associated category S1 in table A 3 under question 5 was also discussed. 25% of experts indicated the category with their answers and highlighted the fact that user acceptance is growing as a result.  The abovementioned statements confirming this requirement justify their priority on rank 16. |
| **Classification** | Non-functional requirement since a flexible, (monopoly-)independent, regional and decentralized peer-to-peer trade defines a quality criterion that describes the ‘how’-state. |
| **No.: 17** | **Scalability** |
| **Requirement** | The system could regard scalability as a challenge on which further research should be don also before an implementatione. |
| **Justification** | Scalability was rather less (6,72%) chosen by stakeholder group 1 regarding the question of important characteristics of a BC in table 4-4.  As can be seen from the results of questions 2 and 12 for stakeholder group 2 in table A 3, category F turned up at 25 and 44%.  Yet within one question in table A 3 it was noted that although scalability is not a problem, it still has to be tested in practice. 56% of respondents agreed with this category Z in question 12.  Since scalability is not considered as a major problem by any stakeholder group but is important to look at and ensure further research, the 17th place was chosen for this requirement. |
| **Classification** | Non-functional requirement since scalability defines a quality criterion that describes the ‘how’-state. |
| **No.: 18** | **Number of participants** |
| **Requirement** | The system could involve a sufficient number of participants including different production and storage facilities. |
| **Justification** | Category M1, which states that as many participants as possible must be involved and an independent network with different production and storage facilities must be set up, appears three times in table A 3. It was mentioned by experts in question 10 on data manipulation at 17%, in question 24 on the sales guarantee at 22% and finally in question 31 on permanent security of supply at 63%.  This requirement was only created on the basis of expert statements, but its placement is also justified by the fact that a high number of participants can also increase protection against manipulation. |
| **Classification** | Constraint as a high number of participants describes an organizational specification. |
| **No.: 19** | **Selected data on BC only** |
| **Requirement** | The system could save selected data (no personal data) on BC only. |
| **Justification** | According to the experts, only selected data should be stored on the BC. Corresponding category W has been listed three times. However, the percentage lies in the lower third, for question 9 at 20%, for question 16 at 9% and for question 30 at 25%.  Also, for this requirement, only experts' data are available, which tend to be in the lower third. Therefore, the 19th place was selected. |
| **Classification** | Functional requirement as selected data saving describes a technical criterion and therefore the ‘what’-state. |
| **No.: 20** | **Connection of different regional networks** |
| **Requirement** | The system could connect different regional networks. |
| **Justification** | Category N1, which addressed the networking of various regional networks, was mentioned once in question 31 in table A 3. Thereby, the issue of long-term security of supply was addressed, with N1 being referred to by 38% of the experts.  As the corresponding category of this request only occurred once, the 20th place was assigned. |
| **Classification** | Functional requirement as the connection of different regional networks describes a technical criterion and therefore the ‘what’-state |
| **No.: 21** | **Secret stores und private transactions** |
| **Requirement** | The system could integrate secret stores und private transactions. |
| **Justification** | One single person indicated in question 9 of table A 3 that private transactions and secret stores should be enabled by BC.  Since this requirement was only named by one person, but can be reasonably considered, it was given last priority. |
| **Classification** | Functional requirement as secret stores und private transactions describe technical criterions and therefore the ‘what’-state |

## A.7 Indifferent Requirements

This section shows all indifferent requirements which did not allow a clear identification of a tendency from the prosumer/consumer survey or the expert survey results.

With introduction of a peer-to-peer market using BC technology requirements in table A 5 were documented.

Table A 5: Catalogue of indifferent requirements

|  |  |
| --- | --- |
| No.: A | Private or public BC |
| **Requirement** | The system could use a private or public BC. |
| **Justification** | Prosumers and consumers tend to prefer a public form of BC, as the result of the survey in table 4-3 shows. The corresponding hypothesis in table 4-7 line 1 is also rejected, which could indirectly confirm the trend for a public BC. However, a linear regression was not applied.  In contrast to this, experts are more in favor of choosing a private BC, which can be seen from the 65% for a private BC in table 4-12.  This is also confirmed by the four times appearance of category l about private BC in table A 3 in appendix A.5, whereas category K about public BC only appears once.  Furthermore, results of questions 9 and 34 in table A 3 describe that a permissioned BC should be used. Though it is a small percentage of 7 and 11% of the respondents. This contradicts to the functionality of a public BC |
| **Classification** | Functional requirement because the form of a BC describes a technical criterion and therefore the ‘what’-state. |
| **No.: B** | **Regional data processing** |
| **Requirement** | The system could allow regional data processing only. E.g. data processing in Germany or the local area only. |
| **Justification** | As can already be seen from table 4-5 on the topic of security for stakeholder group 1, there is a slight trend that all processes of an energy network should take place in Germany. 40 are against, but 48 people are in favor. However, the binomial test cannot confirm the statement according to the trend, as can be seen from table 4-7, line 9. The two linear regressions also cannot establish a significant connection between the switch to BC technology and a regional data processing in Germany.  Stakeholder group 2 also only mentioned the associated category T1 within the answer to the question on local data processing. The category reached 40% of the responding experts. |
| **Classification** | Non-functional requirement since regional data processing defines a quality criterion that describes the ‘how’-state. |
| **No.: C** | **Pricing mechanism** |
| **Requirement** | The system could use fixed pricing mechanism or auctioning for price determination. |
| **Justification** | Slightly more than half of the questioned consumers and prosumers voted for a fixed price mechanism with 60.61%. There are no test results neither for the lower-tailed binomial test nor for the two linear regressions.  In contrast, experts were more likely to support an auction price mechanism. This was selected from around 67% in table A 3 in appendix A.5 for question 22, while a pricing mechanism by stock exchange ended up at barely 33%. |
| **Classification** | Functional requirement as the pricing mechanism describes a technical criterion and therefore the ‘what’-state |

## Abbreviation Index

|  |  |
| --- | --- |
| BC | Blockchain |
| BCT | Blockchain Technology Expert |
| CPU | Central Process Unit |
| DSO | Distribution System Operator |
| EEG | ‘Erneuerbare-Energien-Gesetz’ – Renewable Energy Act |
| ES | Energy Supplier |
| GDPR | General Data Protection Regulation |
| GWh | Gigawatt hour |
| kWh | Kilowatt hour |
| MO | Meter Operator |
| PoA | Proof-of-Authority |
| PoS | Proof-of-Stake |
| PoW | Proof-of-Work |
| S | Scientist |
| SPSS | Statistical Package for Social Sciences |
| TWh | Terawatt hour |
|  |  |

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