MASTER THESIS

Governing socio-technical systems:

Internal governance of decentralised blockchain-based networks

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Table of contents

Introduction

Blockchain technology is one of the most potentially influential emerging technologies from the last decade and remains relevant today through its use in a variety of applications across markets and sectors. One of these applications drawing back on the technological arrangements and principles of blockchain technology is the field of decentralised systems of cryptocurrencies. Similar to conventional forms of currency, each form of cryptocurrency is constituted through a system with a technical and social infrastructure in which the currency is created, distributed, facilitated and secured. Applying blockchain technology in cryptocurrency systems is aimed at creating a system which is characterised through a decentralised structure in which the tasks of monitoring, distributing and creating the currency are not performed by a central authority like a government or bank, but through the system itself. As systems of cryptocurrencies are constituted out of a technical infrastructure and the social relations between individual users of the cryptocurrency, these systems can be perceived as networks with a socio-technical structure. Analysing the socio-technical structure of such networks, the ways in which users of the network themselves are constituting it, as well as how the technical infrastructure of the network influences the social relations within it, will provide useful insights about the interplay between such technologies and societies for researchers, developers and governmental actors. Building upon such an understanding of decentralised cryptocurrency systems, a novel field of research on the implementation of such systems in societies is emerging, showing a transition of such systems being used primarily for financial contexts and markets, towards becoming an underlying structure of decentralised blockchain-based networks in a wide variety of contexts, such as electricity markets.

Research objective

This thesis is aimed at laying the necessary theoretical groundwork towards understanding the implementation and governance of decentralised blockchain-based networks in complex contexts of society such as electricity markets. Understanding the underlying technical structures, social practices and forms of power and governance within such networks requires a thorough examination. This appears to be the necessary first step to arrive at a ground for further analysis of the governance of such networks in the regulatory frameworks and policy structures of the contexts they are implemented in. Thus, the focus of this thesis is set on the internal forms of governance which are present in decentralised blockchain-based networks. It will present a theoretical framework to understand systems of cryptocurrencies based on blockchain technology, as being constituted by technical aspects of their infrastructure, as well as the social relations of users within them. This provides intriguing insights towards analysing how their decentralised character and structure is used as an underlying structure for conceptualising and developing decentralised blockchain-based networks.

Research question and scope

How the socio-technical character and decentralised structure of cryptocurrency systems leads to new forms and a transformation of governance within them, and correspondingly in the decentralised blockchain-based networks they are a part of, is the main research question of this thesis. To answer this research question and to arrive at a sound understanding of the forms of governance[1] within decentralised blockchain-based networks, three core aspects are examined: decentralised cryptocurrency systems as socio-technical assemblages, the constitution of user identities and internal forms of governance in such systems.

The first aspect, understanding decentralised cryptocurrency systems as being characterised and constituted through the technical and the social, is the subject of the first chapter of this thesis. This chapter will define the core terms and concepts which will be used throughout this thesis and lay the theoretical groundwork necessary to examine forms of decentralised cryptocurrency systems and their governance. The analysis of the technical functioning of decentralised cryptocurrency systems will be combined with the examination of the social relations and interactions between actors, which are connected to and situated within the structure of them, identifying them both as co-constituting aspects of their decentralised character. Through this, an account for acknowledging the co-constructing and closely

[1] The understanding of the term *governance* which will be used in this thesis refers to understanding governance as the coordination of interdependent actions from entities in a specific context (Wald & Jansen 2007, 93). Perceiving the various forms of interactions, relationships and interdependencies between entities as a network, the term governance refers to the coordination of such actions in the context of networks.
It is important to note that this understanding of governance in networks, which I have called "internal forms of governance" in this thesis, differs from merely understanding governance as the forms of government and interference from regulatory institutions, in the form of states, ordering and managing societies and citizens (Bevir 2010, 1; Bevir 2012, 25).
Instead, a new understanding of governance provides increasing awareness to the diffusions of power and authority in contexts which are not characterised by the interference of regulatory institutions. Furthermore, such an account acknowledges that governance is characterised by the interplay between various actors and organisations instead of one dominating and central governing actor (Bevir 2007, 364-365). Moreover, this understanding of governance attributes the ability to coordinate actions of entities, such as individuals, corporations and organisations, to networks. Governance with regards to networks thus refers to forms of ordering and managing them (Bevir 2007, 370). From a system theoretical approach, governance can be defined as a self-constituting and -organising system that emerges out of the interplay and interwoven relationships between entities in contexts of society (Bevir 2007, 374). Forms of governance in networks are thus emerging out of a plurality of entities and their hybrid practises (Bevir 2012, 26-27). Therefore, this understanding of governance is fitting to describe the forms of coordination, actions and interdependencies between entities in networks which are characterised by a decentralised, disintermediated structure such as decentralised blockchain-based networks.

intertwined relationship of the social and the technical in decentralised cryptocurrency systems and understanding these systems as socio-technical assemblages will be presented.

Secondly, the aspect of social practices and the constitution of user identities within decentralised blockchain-based networks will be investigated in the second chapter of this thesis. It will be analysed in which ways entities are influenced through the development, structure and transformation of the networks they are situated in. The shaping of contexts of use and the constitution of roles of entities through the network will be presented as core mechanisms at play. In turn, the ways in which interactions and contexts of use for entities within the network are shaping the development and infrastructure of the system will be analysed.

The third core aspect of the thesis deals with the forms of governance at play within blockchain-based networks. To contextualise the insights from previous chapters, electricity markets are presented as a sector which is currently undergoing a transformation leading towards approaches which implement distributed ledger technology for forms of governance, organisation, management and for reaching higher degrees of sustainability in energy markets and -trading. The interaction of energy providers, corporations and governing institutions trying to implement decentralised blockchain-based networks on local and global scales, provides a strong case for investigating the interplay between humans and technological infrastructures occurring at the micro-, meso- and macro-level in societies. Emerging forms of governance and power structures within such networks will be presented and put in perspective with the costs for developing and implementing them.

Two case studies of decentralised blockchain-based networks

Two selected illustrative cases of corporations, trying to implement decentralised blockchain-based networks in electricity energy markets, will be examined in the fourth chapter of this thesis. Through analysing the cases of their decentralised blockchain-based platforms “Power Ledger Ecosystem” and “Pylon Network”, the findings of the previous chapters will be illustrated and contextualised. The discussion of the two cases will present further insights about the implementation of blockchain-based cryptocurrency systems in electricity markets, their alleged influence in the ongoing transition of electricity markets towards more sustainability, as well as confirming their socio-technical character.

Theoretical framework

The account on the internal forms of governance within decentralised blockchain-based networks which I am presenting in this thesis provides a useful addition to the existing body of literature on the technical and social character of blockchain-based cryptocurrency systems in the field of science and technology studies (STS), philosophy of technology and governance studies. Accounts in the field of STS, have presented the interplay between social and technical aspects which are shaped by, and at the same time, are shaping the networks in which they are situated. By acknowledging this complex interplay and using the established theoretical framework of actor-networks, networks are understood as open and constantly evolving, as assemblages which are composed of various human and non-human entities that are interacting with each other (Callon 1986, 31-32; Callon 1989, 93; Callon 1998, 7-8; Granovetter 1973; Latour 2005). Nevertheless, accounts investigating the interplay between the technical and the social specifically in the context of decentralised blockchain-based networks are rather limited in the current body of literature[2]. Building upon these insights, I have developed an account which not only acknowledges this intertwined character of technology and the social but is put into practice through contextualising it in the field of electricity markets. I am combining the technical analysis of decentralised blockchain-based networks and a close examination of the social practices within them with an investigation of the forms of internal governance which arise through this interplay. Through this, I am expanding the body of literature on decentralised blockchain-based networks in the field of STS and provide an account with a specific focus on governance. This investigation of internal forms of governance appears to be an essential basis for further research, investigating how

[2] The body of academic literature from infrastructure studies in the field of science and technology studies should be noted. The academic discourse on infrastructures and cybrerinfrastructures in the field of science and technology studies provides useful insights in which my thesis and the presented theoretical framework could be situated. Accounts in this field describe networks, consisting of various technical and social systems, organisations and entities, as infrastructures (Edwards et al. 2007, 5, 12). They elaborate on the interoperability of systems within networks, the interdependence and relationships between entities, and address notions of coordination, scaling and user communities (Edwards et al. 2007, 9, 12). Furthermore, these accounts present insights on how infrastructures mutually shape and are being shaped by conventions of practice within them (Pipek & Wulf 2009, 453-454).
This conception of networks aligns with the insights of this thesis and could thus provide additional insights for understanding decentralised blockchain-based networks. Additionally, the academic discourse on a shift from "governance of technology" and infrastructures with technical structures to "governance by technology", is acknowledged as intriguing and useful, and should be incorporated in future research which expands the scope of this thesis (Pelizza & Kuhlmann 2018, 3-4). Expanding the theoretical framework of this thesis with the notion of understanding decentralised blockchain-based networks as infrastructures, therefore constitutes an intriguing field of future research. However, as the focus of this thesis is specifically set on understanding the internal forms governance of such networks, the notion of understanding networks as infrastructures is not incorporated in the theoretical framework.

decentralised blockchain-based networks are governed by the regulative frameworks of the contexts in which they are implemented.

Chapter 1: Cryptocurrency systems as socio-technical assemblages

This chapter defines the core terms and concepts which will be used throughout this thesis and lays the theoretical groundwork necessary to examine forms of decentralised cryptocurrency systems and their internal governance. There are several underlying concepts which need to be presented in this chapter towards understanding such systems as being characterised, constructed and constituted through the technical and the social.

First, this chapter examines the technical functioning of blockchain technology which is an essential underlying structure of decentralised cryptocurrency systems. Specific technical arrangements, functioning and developments which characterise these systems, are illustrated through the analysis of the bitcoin network and its underlying blockchain technology. Through this analysis, it is shown how systems of cryptocurrencies should not simply be understood as systems for financial transactions and market structures, facilitating them through technical infrastructures, but rather as complex technical structures which can be used for a multitude of applications and within various contexts constituted by a decentralised structure. Through the examination of the technical aspects of these systems, a second core-defining and constituting aspect of decentralised cryptocurrency systems becomes visible. The social relations and interactions between actors which are connected to and situated within the structure of such systems. This social aspect is influencing the ways in which actors are interacting with the technical functioning, structure and development of cryptocurrency systems.

Second, the social relationships between actors within cryptocurrency systems are a constituting aspect of their decentralised structure. In the third subsection of this chapter, an ontology of cryptocurrencies which are characterised by such decentralised structures is provided, presenting an understanding of such currencies as rather non-financial objects. The fourth and final section of this chapter provides an account for understanding the co-constructing and closely intertwined character of the social and the technical in decentralised cryptocurrency systems as socio-technical assemblages.

1.1 Technological functioning of cryptocurrency systems using blockchain technology

As a starting point for understanding the functioning and development of decentralised cryptocurrency systems, the blockchain technology, which is used in them and building the basis for enabling their decentralised structure, has to be examined. For this, an analysis of the technical characteristics of the bitcoin network is presented as an illustrative case. Through analysing its structure and technical characteristics, insights about the ways in which decentralised cryptocurrency systems are constituted and how they directly influence the interplay between technology, society and the environment, are gathered and put into perspective.

The bitcoin network

The decentralised cryptocurrency system using the virtual currency *Bitcoin (BTC)*, the so-called *bitcoin network*, is publicly accessible to users via the internet by running the software of the bitcoin network, called *bitcoin protocol* on computational devices. The term bitcoin network encompasses every computational device which is running the bitcoin protocol and is connected to the network, constituting it as a part of its technical and physical structure (Antonopoulos 2014, 6, 139). It is this conception of the bitcoin network which is used throughout this thesis. Understanding the technical functioning of the software protocol which is used to facilitate financial transactions within the bitcoin network, illustrates the underlying structure of blockchain technology which is prominently used in decentralised cryptocurrency systems and provides intriguing insights towards understanding the technical aspects which are constituting them.

History of the bitcoin network

Since its creation in 2009, the bitcoin network and its corresponding cryptocurrency Bitcoin, has developed to the most prominently used cryptocurrency system with an enormous political, societal and environmental impact. The bitcoin network can be characterised as an interwoven and closely connected structure of users, interacting with each other world-wide through forms of financial transactions which are facilitated, encrypted and secured by the network through its open-source software protocol and its virtual currency. The self-governing and independent structure of the network draws back on the theoretical formulations of the pseudonym Satoshi Nakamoto in 2008. There, a concept for a peer-to-peer network for electronic currencies was presented, creating the possibility for direct financial transactions between users, higher degrees of encryption, faster transaction speeds and eliminating intermediate steps such as currency exchange; without the need for an intermediary institution or regulating entity which needs to distribute, process and control the currency (Antonopoulos 2014, 1-2, 3; Dilek & Furuncu 2019, 91; Nakamoto 2008, 2; Ølnes 2016, 254-255, 260).

The novelty of this concept, presenting the configuration of a decentralised network for peer-to-peer financial transactions, lies in the elimination of the need for mediating and governing institutions or authoritative actors which are external to the system itself. Establishing connections between users worldwide, distributing the virtual currency within the network, facilitating and securing the transactions between users and managing the financial record and assets of them, is all done through and within the network itself. Additionally, the networks persistence and the financial stability of the virtual currency in terms of inflation, are not ensured through external interference but through the network and its software protocol itself (Antonopoulos 2014, 1-2, 3; Dilek & Furuncu 2019, 91, 94; Ensmenger 2018, 2; Nakamoto 2008, 2, 4; Ølnes 2016, 254-255; Vranken 2017, 1). Understanding how the need for an overseeing and mediating institution or regulating authority of the decentralised bitcoin network can be achieved presupposes analysing how the financial transactions between users and the distribution of the virtual currency within the network function.

Transactions and the blockchain

Users which are connected through their computational devices to the bitcoin network can exchange the virtual currency bitcoin between each other. Information about these transactions, such as the sender, recipient and the amount of the transaction is recorded within the network. The devices which are connected to the network and which are needed to process the transactions of users are called *nodes* (Antonopoulos 2014, xvii-xviii, 1, 19; Nakamoto 2008, 2; Ølnes 2016, 254-255). Groups of transactions between nodes are marked with a time-stamp and bound together in the unit of a *block*, making the transactions identifiable with regards to the existing record of previous transactions in the network and enabling the network to systematically confirm them (Antonopoulos 2014, xvii-xviii, 1, 164; Van Cutsem et al. 2020, 1). Through using a method of *proof-of-work*, nodes validate the transactions within a block through the use of significant computational power, confirming the individual transactions by comparing them with the network-wide records of previously validated transactions. The method of proof-of-work can be understood as a process of nodes calculating complex mathematical equations with an approach of trial and error, whereby finding the solution to a new block leads to the creation of this block in the network and the validation of the bundled transactions (Antonopoulos 2014, xviii, 1, 4, 27, 111-112, 177; Block, 2019; Bitcoin Energy Consumption Index, 2019; Conoscenti et al. 2016, 2; Dev 2014, 1; Ensmenger 2018, 3; Nakamoto 2008, 1; Ølnes 2016, 255; Pereira et al. 2019, 98; Van Cutsem et al. 2020, 1; Vranken 2017, 2). Once a node has found the solution for the new block, the other nodes in the network are informed. They then switch their computational power from the creation of a new block towards confirming the proposed solution. If the newly created block and its solution are confirmed by all the nodes of the network, it is added to the record of blocks in the network and the transactions within it are confirmed and processed. This process of creating a new block is repeated constantly, roughly every ten minutes (Antonopoulos 2014, 2, 28, 177; Bitcoin Energy Consumption Index, 2019; Conoscenti et al. 2016, 2; De Vries 2018, 801; Li, Li et al. 2019, 161; Vranken 2017, 2).

The network-wide distributed record of blocks, each with an individually identifiable position in the chain of blocks of transactions, is called the *blockchain*. It can be imagined as a network-wide, decentralised and at all-times accessible ledger, which every node has to consult and uphold. This chronological, continuously reinforced and constantly confirmed record, inseparably links the transactions between users to the network. Simultaneously, it enables the network to reliably and securely validate them through itself and its technical structure (Antonopoulos 2014, xvii-xviii, 1, 15, 26, 111-112, 164, 181; Conoscenti et al. 2016, 2; Dilek & Furuncu 2019, 95; Hayes 2019, 59; Li, Li et al. 2019, 161; Nakamoto 2008, 2; Ølnes 2016, 254; Van Cutsem et al. 2020, 1). This universally shared ledger is the basis for all nodes of the network working together, enabling the simple participation of new or old nodes, which only need to catch up to the current state of the blockchain. Additionally, it serves towards combating dishonest nodes that try to validate false transactions and work against the computational power of the majority of nodes in the network (Nakamoto 2008, 4, 8). The analysis of these technical aspects illustrates how the decentralised character of cryptocurrency systems can be created through technological structures in the network, as well as the underlying software protocol. Furthermore, it shows how the transactions can be ensured and upheld without any external interference of mediating entities.

Distribution and validation of the virtual currency

The interplay between the technical structure of cryptocurrency systems and their decentralised character becomes visible through analysing the mechanisms for creating and distributing the virtual currencies used within them. The mechanism for validating transactions between users in the bitcoin network is directly linked to the creation and distribution of the virtual currency bitcoin which is used for transactions. The units of the virtual currency are created by nodes, through their usage of significant computational power in the process of finding a solution to a new block of transactions. This process, called *mining*, is dependent on the nodes' usage of computational power, and thus provides an incentive for nodes towards providing the network with the needed computational resources for solving new blocks and validating transactions in the set interval of ten minutes (Antonopoulos 2014, 1-2, 27-28, 177;

Bitcoin Energy Consumption Index, 2019; De Vries 2018, 801; Hayes 2017, 1309; Van Cutsem et al. 2020, 1). The term *miner* refers to those nodes that are using computational power towards creating new blocks (Antonopoulos 2014, xviii).

As a reward for users investing in the capacities of the computational devices they use for connecting to the bitcoin network as a node, they have the chance to obtain a set amount of bitcoin every time a new block is created. This reward is given only to the node of the network which managed to solve the calculations for a new block the fastest and consequently created the new block. Additionally, this node receives a small amount of transaction fees from each of the transactions bound in the newly created block (Antonopoulos 2014, xviii, 2, 18, 27, 177-178; Bitcoin Energy Consumption Index, 2019; De Vries 2018, 801; Nakamoto 2008, 4). This incentive for nodes towards providing the network with their computational power creates the basis for increasing competitiveness between miners in the network and constantly increasing investments in higher computational power of their nodes by design (Antonopoulos 2014, 177-178; De Vries 2018, 801; Dilek & Furuncu 2019, 96; Nakamoto 2008, 4). By means of the aforementioned mechanisms for validating transactions and distributing the virtual currency, the network eliminates the need of central, authoritative and governing institutions. Instead it provides these functions through its own software structure and reward mechanisms (Antonopoulos 2014, 1-2).

Network stability

Furthermore, the decentralised character of the bitcoin network is further constituted through two mechanisms for stabilising the virtual currency and the network. Proportionately to the amount of nodes in the network and their provided computational power, the complexity of the calculations needed for the creation of a new block is dynamically adjusted every 2016 newly created blocks. This is done through an algorithm implemented in the bitcoin protocol, ensuring that a new block of transactions is only created every ten minutes on average (Antonopoulos 2014, 1-2, 199; Bitcoin Energy Consumption Index, 2019; De Vries 2018, 801; Dev 2014, 5; Nakamoto 2008, 4; Stoll et al. 2019, 1). The second mechanism is to gradually diminish the rewards obtainable for the nodes who created new blocks the fastest. This reward, which at the same time constitutes the issuance of new units of the virtual currency, is halved with the rate of 210.000 blocks, creating a maximum of 21 million units issued by the year 2140 by design. According to the conceptions of the network made by Nakamoto, once this maximum of units is issued, the system will become entirely feasible through the transaction fees which are obtainable by nodes, upholding the incentive for them for providing their computational power to the network (Antonopoulos 2014, 1-2, 177-178, 179, 199; Dilek & Furuncu 2019, 91; Nakamoto 2008, 4; Stoll et al. 2019, 5; Vranken 2017, 2). The controlled issuance rate of the virtual currency and the constant proportional adjustment of it to the available nodes and computational power of the network provide stability to the network by design. It gives the virtual currency a deflationary character in the long-term perspective (Antonopoulos 2014, 1-2, 199; Nakamoto 2008, 4).

Proof-of-concept

The aspect of security which is often criticised in decentralised cryptocurrency systems further shows how the need for a securing and controlling mediator is transformed towards a self-controlling and sustaining network through the usage of technological design and software. The issue of dishonest nodes, reporting the network conflicting records of previous transactions and validating new transactions falsely, is known as the *double-spending problem*. As the software of the system cannot distinguish between valid and invalid confirmations of nodes and solve these discrepancies by itself, the integrity of the whole network is jeopardized (Ølnes 2016, 255). To counter this problem, Nakamoto (2008) built upon the proof-of-work method and extended it towards using a method of *proof-of-concept*. Drawing upon the records of previous transactions and validating new transactions through the usage of significant computational power in the proof-of-work method, a notion of consensus-based voting by nodes is additionally implemented in the software of the network (Antonopoulos 2014, xviii, 3-4, 177; Nakamoto 2008, 1; Ølnes 2016, 255). This consensus-based voting over the validity of the publicly proposed transactions by nodes, which have solved the newest block, is known as the method of *proof-of-concept*. By design, nodes in the network are voting individually, whereby each node only counts as one vote. This effectively means that users, whether they are honest or malicious, are voting with their computational power through their various devices which are connected to the network as nodes (Antonopoulos 2014, 2; Nakamoto 2008, 2; Ølnes 2016, 255). It becomes essential for the increased security the method of proof-of-concept is supposed to provide, that the consensus between nodes is reached asynchronously by each individual node, independently agreeing on the record of transactions stored in the blockchain and validating new transactions (Antonopoulos 2014, 181-182).

The method of proof-of-concept still provides the theoretical possibility of malicious users controlling the network consensus through possessing the majority of computational power and nodes in the network and performing the dishonest transactions faster than the usual pace in which the network operates. However, the extent of such malicious attacks would only reach towards altering newer transactions in the network due to the universally shared and increasingly immutable character of the blockchain (Antonopoulos 2014, 215; Li, Bahramirad et al. 2019, 63-64; Nakamoto 2008, 3). Although this mechanism could become problematic in small networks, when assuming that the majority of nodes in large decentralised cryptocurrency systems are honest, the costs for the computational power needed to manipulate the network would outweigh the profits from using this amount of computational power in the network as an honest node (Antonopoulos 2014, 215; Ølnes 2016, 255). This intriguing and novel mechanism for emerging consensus between nodes by design, constitutes an additional aspect towards a decentralised structure, without the reliance on intermediate entities to confirm transactions and secure the network.

The analysis of the technical characteristics and mechanisms which are implemented in the bitcoin network and its software provides useful insights regarding the ways in which decentralised cryptocurrency systems achieve and transform the functions of currency issuance, distribution and long-term stability, as well as the incentive of users to contribute and uphold the network. Instead of a mediating entity which is needed to uphold these functions and provide the network with a top-down approach towards control, validation and intervention, these functions are constituted through the design of the software and technological functioning inherent in the networks of cryptocurrency systems, making them pivotal for their decentralised character. Arriving at a sound understanding of this interplay between the technical aspects of cryptocurrency systems and their decentralised structure is essential for analysing how such systems are conceptualised, developed and constituted. Later sections of this thesis will build upon this understanding and illustrate how the resulting decentralised structure is related to forms of governance within decentralised blockchain-based networks. After the technical aspects of decentralised cryptocurrency systems have been presented and illustrated through the case of the bitcoin network, the following section will elaborate on the social aspects of such systems.

1.2 Social practices and relationships within decentralised cryptocurrency systems

The following subsection of this chapter elaborates on the social practices which are present in networks based on blockchain technology. Understanding the interplay between social and technical aspects within them is highly relevant towards analysing the intertwined relation of them to the development, constitution and decentralised character of such systems.

Standards

The most dominant social practice which is prevalent in decentralised blockchain-based networks is the establishment of standards which are upheld within the network. Through presenting the process of the standardisation of air-conditioning in buildings in the UK, based on the conceptions of comfort which society became accustomed to, Chappells and Shove

(2005) present how standards are established, evolving and dependent on the conceptions of those who are actively involved in shaping the meaning of the notions ought to be standardised. According to them, established standards are directly influencing how we are perceiving the environmental and social implications of technologies we design and how we are addressing them. This in turn leads to reinforcing already existing standards and societies becoming further accustomed to them and should therefore become the subject of explicit scientific and public debate (Chappells & Shove 2005, 33-34).

Computational power

To understand how this social practice becomes relevant in the context of blockchain-based networks, the case of the bitcoin network illustrates how the standards of increasing investments in computational power are linked to technical aspects of the network and directly shaping its constitution. The presented case of people becoming accustomed to increasing investments in air-conditioning for buildings in the UK by Chappells and Shove (2005) appears to show similar developments, in comparison to the ways in which an increasingly competitive notion between nodes and their increasing investments in computational power is evolving. Through the technical design of the software used in the network and its underlying blockchain, nodes are essentially needed to stabilise the network and provide the computational power it needs to fulfil its functions in facilitating, securing and recording transactions. The aspect of nodes getting rewarded for the provision of computational power and the creation of new blocks appears to create a social practice in which increasing investments in computational power by nodes is normalised. In the analysis of decentralised cryptocurrency systems throughout the last years, it has been shown that miners are switching from participating in the networks with conventional computational devices towards using specifically specialised and optimised hardware solely intended for mining purposes (Antonopoulos 2014, 209; Corbet et al. 2019, 3-4; Ensmenger 2018, 3; Hayes 2017, 1318; Stoll et al. 2019, 1, 3, 5; Vranken 2017, 8).

Competition

The notion of competitiveness between miners using their nodes out of personal economic interests arises, although the technical design and software protocol of the network does not explicitly require such relationships between nodes and their users. In the end, they are conceptualised to dynamically adjust the difficulty of the proof-of-work method. Indirectly stimulated by the design of the network and the resulting notion of competitiveness, the increasing investment of miners in more powerful and energy-intensive hardware, is standardised and not questioned any more as being and further evolving into an essential part of the development of the network. Furthermore, this standardisation of increasing investments by nodes leads to new approaches of miners trying to successfully compete with other nodes with regards to economic profitability. Either they stop their mining endeavours, are accepting lower returns of rewards on the long-run, or find other ways to increase the computational power of their node(s). One emerging social practice is the creation of mining-pools in which miners are bundling their computational power together with the hope of increasing their return of rewards in the long-run and then sharing the obtained rewards based on the amount of computational power which was provided by each member of the group (Antonopoulos 2014, 211-212; Dev 2014, 1). Based on these aspects, it appears that the social practice of normalising increasing energy consumption for proof-of-work methods implemented in decentralised blockchain-based networks emerges partly from the technical design and software of the network, and partly from the relationships between users. This further strengthens the account of understanding such networks as being constituted by technical and social aspects.

Escalation

Regarding the implications of the social practice to normalise the increasing resource- and energy consumption of decentralised blockchain-based networks, operating with a proof-of-work method, the account of Shove (2003) provides intriguing insights for understanding how such a practice can lead to a technological development which can be characterised through the term *escalation*. According to her, questioning how new standards and the conceptions behind them emerge and transform, helps us to address the implications such standards could have on our society and environment (Shove 2003, 396, 415-416). The process of increasing investments of miners in such networks presents a clear direction towards only further increasing in the future due to the persisting degree of competitiveness between miners. Based on the account of Shove, such a development can be described as *ratcheting*. Instead of questioning the nature of the increasing investments and reflecting upon the increasing environmental implications, miners are further enforcing this path dependency through new approaches trying to increase their computational power for instance in mining-pools (Shove 2003, 399- 400). It is important to critically reflect upon which social practices emerge out of the network and its technical structure, as well as reflecting upon the emerging social practices and embedded standards which are in turn shaping the network and influencing its social and environmental implications (Shove 2003, 416).

Throughout this subsection, I have shown that the development of decentralised blockchain-based networks depends on the ways in which standards are, directly or indirectly, conceptualised, emerging and implemented based on the technical design of the network, leading in turn to social practices between actors within the network and their interactions with the network itself. It appears essential with regards to investigating the internal forms of governance in such networks, to acknowledge, examine and challenge such standards and the resulting social practises within the networks. Additionally, the technical design and development should be addressed and alternative solutions and methods which might achieve the same degrees of de-centralisation, stability and security in such networks should be proposed. One example of such an alternative would be using a method of proof-of-stake to validate transactions, offering a far more resource-intensive method to fulfil this function of the network and to diminish the notion of increasing investments in computational power (Bitcoin Energy Consumption Index, 2019; Chappells & Shove 2005, 38-39; Truby 2018, 405, 408). On the basis of the analysis of the social aspects of decentralised cryptocurrency systems as a co-constituting part of them, the following section will present an ontology of blockchains which deviates from the common conception of them in specifically financial contexts.

1.3 An ontology of blockchains

I have shown through the previous analysis of the technical and social characteristics of decentralised cryptocurrency systems, that such systems are constituted and shaped by the closely intertwined interplay between the social and the technical within them. The following sections of this chapter will present the account of Hayes (2019) arguing for understanding blockchains and blockchain-based systems as socio-technical assemblages. This account provides intriguing insights for understanding the interplay between the social and technical aspects of blockchain-based systems. I will build upon this account in later sections of this thesis by linking it to the internal forms of governance within decentralised blockchain-based networks and further contextualise it through the analysis of these networks in energy markets.

Disintermediated trust

The interplay between social and technical aspects of blockchain-based systems becomes visible in the notion of trust which is created and upheld in them. The elimination of the need for an intermediate authority in decentralised peer-to-peer networks is, apart from the technical design and attainability, linked to a notion of trust (Hayes 2019, 50, 61; Ølnes 2016, 254). In comparison to traditional networks and structures used for transactions between individuals, instead of the need for the individuals trust in authoritative and centralised institutions or entities appointed to manage, facilitate and control the network, a notion of trust from individuals in the structure and functioning of the decentralised network itself emerges. This process has become evident in the case of the bitcoin network. Although some scholars describe the bitcoin network as being a trustless structure, their definition of trustlessness refers to the lack of the need of a trusted, centralised governing institution. Nevertheless, these accounts do acknowledge that the trust of users in the network and its currency now lies in the network's software itself (Ølnes 2016, 254). Instead of placing trust in centralised mechanisms and means of overarching interference with the network, trust is now accumulated towards the technical and social relationships which are at play within the peer-to-peer network and its technical characteristics. Through implementing the use of the methods proof-of-work and proof-of-concept, needed for decentralising the functions of currency creation, distribution and the validation of transactions, in the technical design and software of the network, a form of disintermediated trust can be accomplished and upheld. Nodes of the network are incentivised to uphold and indirectly protect the technical structure of the network by contributing to it through their computational power, in return for financial rewards (Hayes 2019, 50, 61).

It therefore appears, that the decentralised character of cryptocurrency systems using blockchain technology does not simply change the facilitation and stability of peer-to-peer networks through technical design and implemented software, but rather constitutes it within the network itself through a complex arrangement of technical and social aspects (Hayes 2019, 50, 61; Ølnes 2016, 254). Building upon these insights, and accounts within the field of Science and Technology Studies, Hayes notes that it is highly important to acknowledge that the context in which an object is constituted, does not create a particular meaning for the object which wholly defines its characteristics and form. The ontology of an object is rather realised through practical engagements with the object in which a particular reality of it is formed and solidified (Hayes 2019, 62; Woolgar & Lezaun 2013, 323–324).

Three cases for blockchain organisation

Hayes presents three explanatory cases in which blockchains can be organised, as systems mainly used for accounting purposes and facilitating transactions, as structures which provide an organisational form based on their technical characteristics and as institutions in themselves (Hayes 2019, 51-52, 62).

Firstly, he describes blockchains as systems which can be used to facilitate transfers of property rights between individuals, record ownership status without intermediator, providing the opportunity for a public and secure, yet anonymised record of transactions and the information which is related to them. In such cases, blockchains can be understood as self-referencing accounting systems, achieving the functions of transaction facilitation, control and recording autonomously (Hayes 2019, 63).

Secondly, Hayes describes that blockchains can be enacted as organisational forms. Due to the technical character of blockchain-based networks, scripts and forms of pre-programmed code can be implemented within the functioning, logic and structure the blockchain uses. Implementing and connecting such scripts to the software of the network, enables the possibility for self-executing processes, managing transactions and the transfer of information and property rights without the need for additional monitoring and enforcing by individuals. Such scripts that are in place for actual contracts, being executed automatically once the conditions of the script are met, are known as *smart contracts*. It is important to note that such smart contracts layered onto blockchains and their automatic execution, are subject to the same degrees of security through methods of proof-of-work, as well as the characteristic of decentralised consensus-making than the non-automated transactions of individuals in the network. Additionally, smart contracts and the actions they execute once the previously set conditions are met, have the same degree of immutability as non-automatically performed transactions, are accessible for every node in the network and are recorded in the publicly distributed ledger (Ahl et al. 2019, 204; Hayes 2019, 64; Li, Bahramirad et al. 2019, 63-64; Van Cutsem et al. 2020, 1).

Hayes provides a third way on how blockchains can be enacted, namely as institutions. The account of Hodgson (1988) provides useful insights towards understanding institutions and how blockchain-based systems present similar characteristics to these conceptions. Hodgson presents an account on institutions which defines them as systems which are characterised by an established set of rules, structuring and influencing behaviour and social interactions (Hayes 2019, 65; Hodgson 1988, 2). Building upon this account, Hayes formulates that blockchains, being socio-technical assemblages, are fitting into this description as institutions due to fulfilling their function to coordinate and enforce transactions of property rights, as well as being technical structures which present an established and structuring set of rules that influences the interactions between actors connected to them and within their network (Hayes 2019, 65). Furthermore, through their technical and social structure in turn leading to their decentralised character, blockchains are disintermediating conventional institutions and reassigning and establishing their conferred functions within themselves. Additionally, the process of structurally disintermediating is also visible in the structures of trust which were present in decentralised blockchain systems. Trust in the integrity, stability and security of the network is disintermediated from central institutions and is placed in the software and technical structure of the network instead. The social relations and forms of trust from conventional and centralised systems for (financial) transactions have not merely been transposed into technical design and software, they have become conjoined with them (Hayes 2019, 50-51, 61). Blockchains are not merely re-creating or replacing centralised institutions and the commitments of individuals to them, they are maintaining the functions and commitments themselves through their socio-technical characteristics and structure. Based on these

characteristics of blockchains, they can be defined as institutions in themselves, being created eo ipso (Davidson et al. 2018, 641, 649; Hayes 2019, 65, 66-67).
In the illustrative case of the bitcoin network, the underlying blockchain and the bitcoin protocol, are presenting this set of rules in the form of dynamically adjusting the difficulty of the process used for proof-of-work, the diminishing rewards for nodes by design and the fixed issuance rate of the virtual currency. The network therefore structures the social interactions within it and the direct interactions from individuals with its blockchain (Hayes 2019, 65). It should be noted that due to the open-source software design of most blockchain-based networks, there can arise various configurations which can be used by individuals, creating independent institutional networks with individual methodological frameworks and functioning to achieve a decentralised structure (Hayes 2019, 65-66).

After Hayes' account on understanding the ontology of blockchains and the systems in which they are used as an underlying structure has been presented, the next section of this chapter combines the insights from the technical and social aspects, as well as the general ontology of such systems. It presents an account of understanding decentralised systems of cryptocurrencies as an interwoven arrangement of these three aspects.

1.4 Decentralised cryptocurrency systems as socio-technical assemblages

Building up upon the aforementioned technical and social aspects of decentralised cryptocurrency systems, the following section will argue for an account which does not specifically focus on the technical functionalities, material infrastructure and social relationships between actors within these systems as separate objects of enquiry, but rather as two intertwined, mutually co-producing aspects of such systems. Through the analysis of its technical functioning and the social relations within the bitcoin network, it has been shown how blockchain-based systems can achieve a stable and functioning decentralised structure which discards the need for a centralised form of control, validation and interference. Therefore, an ontology of systems using blockchain technology and being characterised by a decentralised structure, as socio-technical arrangements which are constituted by social and technical aspects, will be proposed in this section of the thesis (Hayes 2019, 62).

Drawing from accounts in the field of science and technology studies, blockchain-based cryptocurrency systems are enrolling a variety of human and non-human actors that have to be equally examined and which are influential for the constitution, development and functioning of these systems as a whole. Cryptocurrencies and crypto-assets such as bitcoin and their corresponding network can be understood as systems which are mutually co-constituted through technical and social aspects. According to Hayes (2019), they can thus be defined as socio-technical assemblages (Callon 1998; Hayes 2019, 49-50, 68; Latour 2005). These assemblages come together in various characteristics of the network, through technical aspects and through social aspects and relationships, both equally essential for the network's constitution, stability and its functioning. Technical structures in the form of devices and their computational power needed for the networks functioning and security; the algorithms and mechanisms embedded in the software of the network such as the method of proof-of-work; the dynamical adjustment of difficulty and the structured record of transactions in the form of the blockchain. Social relationships and interactions between users of the network; for instance in the form of working together towards securing the network and validating transactions by choosing to participate in the network; as well as partaking in a competitive structure between miners with personal economic interests. Additionally, social relations are existing within the network through the universally distributed character of the ledger, the method of proof-of-concept and implemented incentives of nodes towards providing the network with computational power and to stay honest. Furthermore, the increasing investments of miners which arise due to the diminishing rewards for creating new blocks by design and the creation of a form of disintermediated trust, are all aspects which are constituting the network and contributing to the creation of its decentralised character (Hayes 2019, 62).

Combining Hayes account with the insights from previous chapters, it was shown that through incorporating technical and social aspects such as the structure of a peer-to-peer network, a shared and secured record of transactions and a form of consensus-making by design which eliminates the need for intermediaries, decentralised blockchain-based systems can be defined as socio-technical assemblages (Hayes 2019, 68). Moreover, the provided account for understanding blockchain technology provides intriguing insights towards understanding the internal forms of governance within decentralised blockchain-based networks. I will expand this account with contextualising it in the field of energy markets where platforms are developed which have blockchain technology as their underlying structure in later sections of this thesis.

Chapter summary

To summarise the core insights of this chapter, it has been shown how the decentralised character of cryptocurrency systems can be created through technological structures in the network, as well as through the social practices present within the network. This interwoven co-production of decentralised networks additionally shows a double dynamic in which the network is shaped and constituted through these aspects but in the same turn shapes and structures the interactions within it itself. It has been presented how this complex arrangement of technical and social aspects leads towards understanding the ontology of blockchains and decentralised cryptocurrency systems in which they are used, as being socio-technical assemblages. Through the socio-technical characteristics and structure inherent in the decentralised networks themselves, such networks are achieving and maintaining the functions and commitments necessary to uphold the structure, stability and security of the network, without the need for intermediaries or external interference. This conception of decentralised blockchain-based networks as being institutions in themselves and the ways in which they operate further leads towards the analysis of how such networks configure and influence the ontologies of entities which are situated within or concerned by them. The interactions between entities within the network and how they achieve a form of cooperation and construct a closely interrelated array of relationships with each other will be the subject of the following chapter of this thesis.

Chapter 2: Constituting the role of the user

Chapter 2 will elaborate on the social interactions and relationships between various stakeholders connected to and concerned by the development and usage of decentralised cryptocurrency systems. It analyses in which ways entities are influenced through the development, structure and transformation of the networks they are situated in. The shaping of contexts of use and the constitution of roles of entities through the network will be presented as core mechanisms at play in decentralised cryptocurrency systems. In turn, the ways in which the interactions and contexts of use for entities within the network are shaping the development and infrastructure of the system will be analysed. Through these insights, the socio-technical character of decentralised cryptocurrency systems, established in previous sections of this thesis, will be confirmed further, while providing additional insights helpful towards understanding the functioning and internal structures of them.

First, the network of relationships between actors and entities which emerges out of constant negotiation, validation and transformation of the interactions and relationships between them, will be described. It will be argued for an account which presents the forms of market cooperation and coordination between users and other stakeholders, leading towards a shared underlying reality between them, as a form of embeddedness of agents with each other and the network. Core terms which are used to describe these complex arrangements will be presented accordingly.

Secondly, it will be argued for an account on how the network configures ontologies of actants connected to decentralised systems of cryptocurrencies. It will be examined how the technical functioning of blockchains has a direct influence on entities within decentralised cryptocurrency systems, constituting specific roles for actors, as well as forms of actions, agency and conceptions. In this way, the identity of agents in the network, their processes of decision-making, intentions and behaviour, will be presented as the outcome of the interactions, dynamics and relationships between themselves and other agents within the network. By presenting the concept of framing, it will be elaborated on how the interdependencies between agents interacting with each other are equally shaped by agents themselves and by the context in which they are situated.
The third section of this chapter describes the ways in which these systems influence the role of users by changing them from mere consumers to prosumers and expanding their degree of agency further than in comparison to traditional centralised systems of financial transactions. How such an organisation and transformation of entities and their roles within the systems appears to offer a potential degree of democratisation provided by the decentralised structure of blockchain-based systems, will be the subject of the final section of this chapter.

2.1 Coordination and cooperation between entities within the network

The ways in which decentralised blockchain-based networks operate appears to present a notion of market cooperation and coordination between users and other stakeholders concerned by its development and functioning. Based on the formulations of Callon (1998), it appears that a form of coordination in such networks cannot arise through contingent contracts between the various stakeholders of the network, by formulating and constraining the interaction between them based on pre-defined terms. Due to the emerging, uncertain and open-source character of decentralised networks, such a form of market coordination appears to be rather difficult to achieve. Instead, it appears that there persists an alternative form of market coordination on the basis of shared common knowledge or frame of reference between stakeholders, the so-called *agents* of the network. Such a shared consensus can exist in a shared understanding of rules, ways of interacting with each other and the network itself and explicit or implicit conventions which ought to be upheld (Callon 1998, 6-7). Such forms of intermediate realities in which agents are entangled with each other, lead to the constitution of a more certain, stabilised and predictable behaviour of agents, explaining the emerging notion of cooperation within the network. Although such a notion of cooperation between agents appears to be optimal, it does not necessarily bind agents towards upholding this consensus due to margins of individual interpretation and notions of (initial) uncooperativeness. Callon further formulates that these diverging or conflicting interpretations, hindering optimal market cooperation, can only be solved through engagements of agents towards interacting, negotiating and discussing with each other (Callon 1998, 6-7).

Actor worlds

Setting the focus on a shared, underlying reality as a form of embeddedness of agents with each other and the network, Callon builds upon the formulations of Granovetter (1973) and suggests that agents are entangled with each other through an interwoven web of relations which makes their coordination possible. As agents themselves contain the relations to other agents and thus the means for coordination in the network, they are in themselves what Callon calls *actor-worlds* (Callon 1998, 7-8; Granovetter 1973). An *actor-world* can thus be described as the world of entities which is created by the arrangement of social relations, interactions and dependencies for every actor and entity within the network, constituting the scope, form and extent of their reality and identity. Every agent in the network has a personal actor-world. An actor-world enlists entities, determines their size and the forms of interactions between them and places them in a network (Callon et al. 1986, xvi-xvii; Callon 1986, 22, 34). This is done through a complex process which is closely linked to the actors and entities within an actor-world. This process of *translation* is understood as the entirety and combination of methods which are used by an agent in the network to enrol other agents or entities. Such methods can become present in the form of defining roles and their distribution, imposing strategies towards realising the conceptions by specific actor-worlds and presenting a delineation of a scenario which should become realised in the network, establishing relationships between entities and other agents. This necessarily encompasses speaking for entities, establishing relationships and displacing agents or entities towards the solidification of an actor-world (Callon et al. 1986, xvii; Callon 1986, 25-26, 28). This crucial process has to be elaborated on a bit further to illustrate its significance in the light of actor-worlds.

Process of translation

In the process of translation formulated by Callon (1984), there can be four overlapping moments distinguished in which the identity of actors, the extent and possibility of interactions are drafted and negotiated, leading towards the solidification of an actor-world. In the moment of problematisation, actors are defining the nature and intentions of other actors and entities in their actor-world, linking them towards the actor-world rendering them as indispensable and constituting parts of it. Furthermore, this moment possesses some dynamic properties and defines obligatory passage points in the actor-world which need to be solved through cooperation and negotiation between actors and entities to modify or transform the network of interactions and relationships. In the moment of interessement, actors are trying to lock other entities into these proposed roles, identities and relationships. If this moment of interessement is successful, it confirms the proposed roles within the actor-world and the array of relationships between the cohering entities. This can be done through devices of interessement, such as physical or technical devices, but also through social structures and alliances. If this is successful, enrolment is achieved. The moment of enrolment describes the various strategies, methods and multilateral negotiations which are used by actors to coordinate, test and solidify the allocated roles they have proposed for others in their actor-world (Callon 1984, 1, 6-7, 8, 9-10). Entities are associated with each other, their identities, as well as their relationship to the agent, are defined. It should be noted that such a set of distributed roles and identities embedded in the actor-world of an agent, are not fixed and are not necessarily shaped out as initially conceptualised and imposed on other entities and agents in the network. Furthermore, it is not naturally given that the plurality of actor-worlds of agents in a network are realistic, similar or aligning with each other (Callon et al. 1986, xvi; Callon 1986, 24). In the moment of mobilisation, the proper representation of other actors and the assignment of roles is evaluated and ensured. Through the entirety of these mechanisms, actors while being part of the actor-world themselves, are becoming spokespersons for other entities, able to represent, influence and define them. It is important to recognise that the process of translation is a constantly changing process happening in actor-worlds, rather than a linear set of moments which happen at a specific point. At its end, there emerges a constraining network of relationships between actors and entities that have been negotiated, validated, transformed and solidified to a certain extent. Due to the unpredictable character of this interplay between defining roles, negotiating and displacing entities, bringing entities into relationships with each other and aligning them along the conceptions and associations within an actor-world, this process can be described with the term translation (Callon 1984, 1, 12-13, 14-15, 18-19).

Actor-network

The *actor-network* can subsequently be defined as the internal structure and operation of an actor-world, constituted out of a dynamic variety of interrelated entities. The necessary groundwork for such an organisation and realisation of an actor-world is the process of translation, theoretically leading to the emergence of a well-defined set of entities with defined roles and established relations (Callon 1986, 28; Callon et al. 1986, xvi-xvii). According to Callon, entities in actor-worlds are only existing in the context of relations to other entities, with the actor-world defining their significance and associating them to other entities in the network. The interplay of entities and the relations between them are the essential elements for the actor-worlds structure, consistency and coherence. Therefore, without an intertwined network in which entities are interacting with each other, the entirety of the actor-world cannot solidify and sustain (Callon 1986, 28, 30).

With regards to the durability of such networks, it is important to note that each entity bound into an actor-world is in itself able to enrol other entities and is thus in itself a network. Therefore, the established relationships between entities in a network are stabilised partly through the durability of the networks which they are in themselves (Callon 1986, 31-32). The notion of entities in networks being networks in themselves is closely linked to the process of transforming actor-worlds. If the network of relations between entities in an actor-world is modified, influenced or changed, the networks they in themselves are, are affected as well. As the network is composed of associated entities and agents, shaping their role and identity, the entities themselves might influence, modify or transform the actor-world they are a part of. Due to this mutually co-constituting character, it can be defined by the term *actor-network* (Callon 1986, 31-32). This definition of the actor-network provided by Callon will be used throughout this thesis. Furthermore, as the term *actor-world* emphasises the arrangement of social relations, interactions and dependencies for every actor and entity within the network, constituting their reality and identity, and the term *actor-network* describing the internal structure and operation of an actor-world, constituted out of a dynamic variety of interrelated entities, the two terms will be used interchangeably throughout following chapters of this thesis (Callon et al. 1986, xvi-xvii; Callon 1986, 22, 33-34).

2.2 The ontology of agents within the network

It is important to clarify the notion of *embeddedness* of agents in the network presented by Granovetter, which has been adapted by Callon. According to Granovetter (1973), networks are not merely connecting entities with each other, but directly configuring their ontology through the variety of relations in which they are involved. Therefore, the identity of agents in the network, their processes of decision-making, intentions and behaviour, namely everything which stabilises their being as agents, is the outcome of the interactions, dynamics and relationships between themselves and other agents. It is in this way that agents are embedded in a network of social relations. Consequently, this means that the agents' ontology is much more intertwined with the network and the relations within it, and not merely framed by the network as an intervening force providing a form of context (Callon 1998, 8; Granovetter 1973). Understanding how agents cooperate in a network, what property rights consist of and how they are transferred in a specific socio-economic context, presupposes carefully analysing and re-constructing the relationships between agents and the constitution of their ontology (Callon 1998, 10).

Framing

The ontology of agents and the cooperation of them within networks is closely linked to the concept of framing, which has been initially presented by Goffman (1974) and is used by Callon to illustrate cooperation mechanisms in markets and strengthen his account of variable agent ontologies in the complex network of social relations within markets (Callon 1998, 248). As the intentions, behaviour and conceptions of an agent in a network of social relations cannot be dissociated from the network itself, the ontology of agents is constantly being re-configured along and directly linked to the constant reconfiguration of the network of interdependencies in which the agent is enmeshed (Callon 1998, 252-253; Goffman 1974). A process of framing from this perspective, presenting a clearly defined boundary between interactions of agents and their surrounding context, as well as imposing a limited set of behaviours, incentives and consequently a defined frame of agents' ontologies, goes against the conception of variable ontologies of agents which emerge out of the interdependencies between themselves and other agents in the network (Callon 1998, 253). It is of high importance to critically reflect upon the implications that such framing processes have in the context of agents situated in socio-technical assemblages.

According to Callon (1986), technological objects and their development cannot be understood without carefully analysing the concomitant actor-worlds of them. The construction and development of technical objects and structures is directly shaped by their actor-worlds, their existence being bound to them inseparably (Callon 1986, 22-23). After having presented how the ontology of agents is directly shaped by socio-technical assemblages such as decentralised cryptocurrency systems, the following section of this chapter will examine in detail how the role of individual users of such networks is influenced and how it appears to be transforming from consumers or mere users to prosumers and constituting parts of the network and its structure.

2.3 Transforming the role of the user

Building upon the insights on how the network configures agents ontologies, specific roles, forms of actions and conceptions, from previous sections of this chapter, this section will describe the ways in which decentralised cryptocurrency systems influence the role of users, changing them from mere consumers to prosumers and expanding their degree of agency further than in comparison to traditional centralised systems of transactions. It will be argued for an account which perceives the role of users in the network in three varying forms, as consumers, producers and prosumers, rather than assuming they are merely taking the role of a passive, weary consumer. This is exemplified through the case of the bitcoin network illustrating this transformation in detail and providing further insights on such systems with regards to user roles and their forms of agency.

The first characteristic of decentralised blockchain-based systems as becoming stabilised, secured and remaining functional through the interactions and emerging relationships within them, is closely linked to users and other entities enmeshed with the network. Along the technical structures and design, a form of cooperation and embeddedness between entities appears to be present, which enables the functions of facilitating, securing and validating transactions, as well as recording transactions and distributing the virtual currency, through the network and its users itself. Furthermore, this leads to the transformation of such systems towards a structure where no intermediate entity or authority is needed to fulfil these functions. The decentralised blockchain-based system is thus highly dependent on entities within it to uphold its decentralised character. Similar to other peer-to-peer networks using blockchain technology as an underlying technical structure, the roles of users and possible transformations of it become visible in analysing the bitcoin network and the entities within it.

Users as consumers

Users who are part of the decentralised network and use its virtual currency solely for purposes to facilitate and perform (financial) transactions are presenting the role of users as consumers. A consumer user can generally be defined as an individual or group of end-users, which use the product, service or infrastructure to satisfy their desires, needs or preferences (Bogers et al. 2010, 857). Users partaking in the decentralised system in this form, are at the first glance not actively contributing to the structural changes and overall character of the network. However, through their usage of the network structure, indirectly upholding the value of the virtual currency by buying it as a form of asset and appropriating the use of the system in general, users as consumers are indeed influencing the system as a whole to a certain extent.

Users as producers

Users of the network can, apart from using the structures and virtual currency for transactions, provide the network with the computational power of their devices and co-constitute and directly partake in the network as nodes. By providing the necessary computational power for the network to fulfil the functions of recording, validating and facilitating transactions, individual users change their relationship to the network and their role from being consumers towards becoming producers (Antonopoulos 2014, 177; Bitcoin Energy Consumption Index, 2019; Conoscenti et al. 2016, 2). Users as producers appear to use the system and its structure not to satisfy their needs and personal preferences, but rather mainly to obtain rewards or compensation for their contribution to the network out of economic interest. They are actively partaking in the system, shaping the networks structure, development and transformation in the long-run and co-constitute the network through their endeavours and through providing the basic structure which is used by consumers. Furthermore, this role shift is visible in the emerging practices of users orientating the form of their participation in the network towards a more economically focused perspective by increasing the number of nodes they operate and increasing the computational power they provide the network with. Along with the increasing requirements to mine virtual currencies efficiently in decentralised cryptocurrency systems, producers switched from using regular hardware which would also be used by consumers in the network towards using advanced and specialised hardware for their mining endeavours (Cocco & Marchesi 2016, 5; Taylor 2017, 61). This did not only increase the requirements of technical knowledge and investments from users oriented to become producers in the network but also gave rise to new sets of innovative possibilities and forms of cooperation. Through combining technical knowledge with the increasing demand for computational power to remain competitive as a producer in the network, users became innovative and translated these two notions into the practice of using advanced hardware specialised for mining. Furthermore, such a change in the role of producers towards requiring increased technical knowledge and innovativeness, as well as the capacity to obtain advanced hardware, did solidify the boundaries for users between being a consumer and becoming a producer in the system further (Bogers et al. 2010, 860; Taylor 2017, 62).

Mining endeavours, constantly increasing investments in advanced hardware with higher amounts of computational power and the emergence of mining-pools, are all visible outcomes of this role transformation in comparison to centralised systems facilitating transactions (Nakamoto 2008, 4). The role of users becoming producers of the virtual currency and the network behind it is also visible with regards to the aspect of security and stability of the network. Through combining the method of proof-of-work with using the method of proof-of-concept, a network-wide consensus is achieved without an intervening and overseeing authoritative entity, although now the system becomes more dependent on users and the interactions and cooperation between them (Antonopoulos 2014, 2, 3-4, 181-182; Nakamoto 2008, 2; Ølnes 2016, 255). Along the closely intertwined network of information which is universally shared across the network, a form of disintermediated trust can be accomplished and upheld based on the intentions of users oriented towards the reward mechanisms which are implemented in the network (Hayes 2019, 50, 61).

Users as prosumers

Apart from the role of consumers and producers, users might take a third role in decentralised blockchain-based systems as prosumers. The role of the prosumer can be defined as a hybrid, indicating the novel form of users simultaneously playing the role of producers and consumers, and blurring the distinction between those two roles (Humphreys & Grayson 2008, 2, 16). In the case of decentralised cryptocurrency systems, users in the role of producers are most likely using the rewards they have obtained through their contribution of computational power to the system, to facilitate transactions, exchange or store the units of the virtual currency in similar ways as consumers in the network do. They are making use of a structure they have contributed to and have constituted it as producers, facilitating their transactions as consumers. The lines between the two roles of consumer and producer thus dissolve in these cases and are merged together within the role of the prosumer.

After having presented how three varying forms of user roles emerge out of the technical characteristics and social structures within decentralised cryptocurrency systems, the following section will elaborate on how such an organisation and transformation of entities and their roles within the systems appear to offer a potential degree of democratisation.

2.4 Decentralised blockchain-based systems as democratising structures

In this section, it will be illustrated how the emergence of varying roles for users of decentralised cryptocurrency systems, is linked to the degree of democratising power which the decentralised character of such systems appears to create. As previously established, the interplay between the technical functioning and social practices within such systems, characterising them as socio-technical assemblages, leads to the constitution, organisation and transformation of agent ontologies and the relationships between them. The tension between these interrelated aspects in decentralised blockchain-based systems has been shown through the case of the bitcoin network, providing intriguing insights on how a democratising potential might emerge out of them.

The first characteristic which allegedly leads to higher degrees of democratisation is the network's ability to stabilise, control and secure itself through its own structure and the interactions between entities within it. By transforming the execution of functions away from centralised institutions, such as distributing the virtual currency, facilitating and securing transactions as well as validating them, and the form of authoritative power that goes along with them, the network in itself possesses a strong notion of techno-political character (Antonopoulos 2014, 178).

The second characteristic of decentralised blockchain-based networks is the aforementioned constitution and transformation of user roles within the network. Individuals become connected to the network as users, performing transactions through the infrastructure the network provides them with, or they contribute to the networks constitution and development directly as producers in the form of operating nodes of the network. The requirements for users changing their role towards being a producer developed, from being initially able to profitably contribute to the system with basic personal hardware, towards the usage of specialised hardware for mining endeavours. Furthermore, the increasing demands of the network and increasing competitiveness between nodes led to the emergence of new innovative possibilities and forms of cooperation, as well as a solidification of the boundaries between the roles of being a consumer or a producer (Cocco & Marchesi 2016, 5; Taylor 2017, 61-62). The degree of decentralisation in these transformations of the network,, appears to have a diminishing effect on the degree of democratisation the network provides, although it aligns with the initial conceptions of Nakamoto (2008) of an open-source platform open to participation from everyone. Theoretically, every user is able to become a producer and to contribute to the constitution of the network as a node. In practice, however, taking the role of a producer or prosumer becomes closely linked to the possession of advanced hardware and technical knowledge, at least with regards to mining endeavours remaining economically profitable (Antonopoulos 2014, 209; Corbet et al. 2019, 3-4; Ensmenger 2018, 3; Stoll et al. 2019, 1, 3, 5; Vranken 2017, 8). Therefore, instead of providing higher degrees of democratisation, the social practice of competitiveness coupled with the technical design of the network appears to lead towards a form of exclusion for some entities.

On the other hand, the emerging practice of mining pools provides the opportunity for miners to combine their efforts and computational power and to stay competitive with regards to the economic profit of their mining endeavours. The rewards which have been obtained by the mining-pool are split between the miners in accordance with the computational power they have provided to the mining pool (Antonopoulos 2014, 211-212; Cong et al. 2019, 1; Dev 2014, 1; Fisch et al. 2017, 3; Luu et al. 2017, 1409). Nevertheless, the supposedly limited degree of exclusion through such practices appears to persist through the fact that mining pools, as complex networks in themselves, are still showing a centralised organisational structure. Most mining pools are characterised by a structure in which a single individual runs the mining pool and divides other participants into groups and assigns tasks, as well as charging fees for participation in the mining pool itself (Cong et al. 2019, 10-11). The case of emerging social practices, such as mining pools, thus shows a limited degree of democratisation.

Chapter summary

The analysis of the decentralised character of blockchain-based cryptocurrency systems presenting degrees of democratisation, reveals the strong societal and political implications of such systems which arise from their socio-technical character. This chapter has presented forms of market cooperation and coordination between users and other stakeholders, leading towards embeddedness of agents with each other and the network, which co-constitutes the ontology and role of agents partly, along the technical and social context of the network in which they are situated. In addition to presenting the concept of framing, the complex dynamics which lead to the definition and transformation of user roles were examined. It was shown how social interdependencies and relationships within networks, in combination with the technical characteristics of it, establish contexts of use and further manoeuvers of exclusion and organisation for entities situated within them. Additionally, this chapter elaborated on the decentralised character of cryptocurrency systems which appears to give rise to degrees of democratisation. It therefore becomes crucial to critically reflect upon the transformation of user roles, social practices, and technical arrangements which not only constitute the decentralised character of such systems but additionally present societal and political implications in the form of democratising potential inherent in them. The entirety of these insights further underlines the account of defining decentralised cryptocurrency systems as socio-technical assemblages.

The following chapter of this thesis will combine and build upon these theoretical insights and utilise them in the context of decentralised blockchain-based systems being implemented in the energy sector.

Chapter 3: Governance of decentralised blockchain-based systems

The power sector is currently undergoing a transformation towards approaches which implement distributed ledger technology for forms of governance, organisation, management and for reaching higher degrees of sustainability in energy markets and -trading. Communities, corporations and energy providers show increasing interest in incorporating the aspect of sustainability. They are trying to use the potential of decentralised blockchain-based systems to achieve these objectives. Through using and implementing the structure of decentralised blockchain-based systems, actors in electricity markets are developing networks which are enrolling various entities such as communities, energy providers, corporations and governing institutions. The networks of these entities interacting with each other is what I am referring to by using the term decentralised blockchain-based networks. The interaction of these entities on local and global scales provides a strong case for investigating the interplay between humans and technological infrastructures occurring at the micro-, meso- and macro-level in societies. Therefore, this sector appears perfectly fitting for analysing the forms of governance within blockchain-based decentralised networks, and the forms of distributed and decentralised structures that they could provide.

In the first section of this chapter, current approaches towards incorporating distributed ledger technology in the form of blockchain-based systems in energy markets will be presented and contextualised. Along with a description of this ongoing transition of energy markets, an overview of formulated expected benefits, as well as concerns about the implementation of decentralised blockchain-based networks for energy markets, will be provided. Thereafter, emerging forms of governance and power structures in such systems will be presented and put in perspective with the costs for developing and implementing them. The third section of this chapter will elaborate on the aforementioned constitution and transformation of user identities and roles in decentralised blockchain-based networks. The theoretical findings of the previous chapters will be put in context to the constitution and transformation of user roles and identities on energy markets. This further confirms the socio-technical character of such systems. Illustrating and contextualising the findings of these three subsections, two selected cases of organisations and corporations, implementing distributed ledger technology in the form of decentralised blockchain-based networks in the power sector, will be examined in the following chapter.

3.1 Decentralised blockchain-based systems in electricity markets

One of the most dominant current problems in the power sector is to ensure an efficient and reliable balance between the demand for energy by consumers and the generation of it in the grid, in combination with the growth of renewable energy sources. This leads to approaches from corporations and energy providers trying to provide new technological solutions. Significant changes with regards to power grid modernisation and infrastructural investments are evidence for an ongoing transition of energy markets, as well as of the structures for energy supply, trading and distribution (Li, Bahramirad et al. 2019, 58, 71; Mengelkamp et al. 2018, 870). A variety of technical solutions and approaches is emerging that are linked to the implementation of distributed ledger technology, in particular blockchain-based systems with a decentralised character and structure. As most of these approaches build upon the general concept of peer-to-peer trading and management of energy, this section of the chapter provides a definition of such structures. It will elaborate on the conceptions and developments of them in local and broader contexts. Additionally, an overview of formulated expected benefits and concerns of this implementation in energy markets will be provided.

Peer-to-peer trading

The accounts which are approaching the transformation of energy markets towards higher degrees of sustainability from a localised perspective, are mostly presenting the concept of localised, peer-to-peer energy markets and communities in which users can profitably trade self-produced energy directly with others in the grid. This self-production of energy and trading it directly with others appears to reduce energy loss in centralised energy distribution systems, stabilise the fluctuations between energy supply and demand locally and to foster the implementation of renewable energy sources into power grids. In addition, these approaches provide a direct incentive for users to not only invest in means for renewable energy generation for themselves and their community, but also to aid stabilising the fluctuations between energy supply and demand themselves locally in a profitable manner (Mengelkamp et al. 2018, 870-871; Zhang et al. 2018, 1, 11).

The term *peer-to-peer trading* in energy markets hereby refers to individuals or groups of energy customers interacting with each other through forms of direct trading of energy. Energy customers or peers in this context, are equally able to locally generate energy on their own, are consuming energy, or doing both of these actions simultaneously. The form of trading and the resulting interactions in such markets and communities change with regards to conventional systems of power distribution. Conventional structures with a centralised approach to power supply and distribution result in unidirectional interactions, energy being supplied to consumers, and consumers trading money for its consumption back to the energy suppliers. In contrast to this, peer-to-peer energy trading enables a form of multidirectional trading of energy and the supply of it. The trades in peer-to-peer energy markets are often facilitated by systems based on information and communication technology and can, in the right configuration and network, thus be performed independently from conventional systems of energy distribution and energy suppliers (Zhang et al. 2018, 1, 2).

Microgrids

The operation of such local energy community markets, often referred to as *microgrids*, is mostly envisioned to be facilitated by distributed ledger technology which should integrate private users and local communities into the already existing network of corporations, energy providers and consumers. The decentralised structure of blockchain-based systems, providing information symmetry among all participants without regulatory interference of central intermediaries, seem to suit these requirements and to support the development of future electricity markets (Jiang et al. 2020, 1; Mengelkamp et al. 2018, 870, 872, 879; Van Cutsem et al. 2020, 9). Through the usage of local and on-site generation of energy, for instance solar- or wind power, such small-scale and self-controllable power grids connect the local consumption of energy to its local production. Additionally, microgrids are often connected to a general, centralised power grid or distribution system, enabling the possibility for energy exchange and consumption from both systems for local consumers. There is a wide array of possible grid structures in the context of microgrids; they can be conjoined with a main grid, they can be isolated as self-sustaining systems or be connected with geographically close microgrids. Although microgrids are currently still being conceptualised, developed or operated on a small scale, they have the theoretical potential to fundamentally change the existing forms of power generation, consumption and distribution on a large societal, as well as national and international level through the forms of structure and management they enable. The potential benefits of these technological and social infrastructures could provide are mainly envisioned as optimizing energy flow and distribution in power grids, increased degrees of efficiency, stability and security, as well as higher degrees of resiliency, and increased usage of renewable energy sources. It appears that the implementation of such systems, characterised by a decentralised peer-to-peer structure for energy trading and management, various and different alterations and benefits arise for stakeholders concerned by the systems. Whereas users and user collectives can profit from decreased energy costs and their own energy production, reduced operational and transaction costs of the grid become beneficial for energy retailers and suppliers. The ways in which consumers, energy providers, and distributors exchange and share information and resources with monetary value, appear to change from a centralised structure towards a more transactive system, challenging conventional paradigms with regards to efficient power distribution and management, as well as their underlying regulatory frameworks (Ahl et al. 2019, 200-201, 203-204; Andoni et al. 2019, 151-152, 167; Jiang et al. 2020, 2-3; Li, Bahramirad et al. 2019, 58-59, 62, 71; Liu et al. 2018, 689-690; Noor et al. 2018, 1389, 1394-1395; Plaza et al. 2018, 1; Van Cutsem et al. 2020, 1; Zhang et al. 2018, 1, 11).

Transactive energy

In the context of decentralised blockchain-based energy networks, a new conceptual form of energy can be perceived, which is closely linked to the market structure present in power distribution systems. Li, Bahramirad and their colleagues (2019), present the term *transactive energy* which refers to energy being exchanged directly between the main grid and microgrids. These exchanges are based on a market-based value of generated energy, which is necessary to enable the peer-to-peer exchange of energy between the microgrid as a local system of energy consumption and generation, and the main grid as a centralised system of energy production, consumption and distribution. According to Li, Bahramirad and their colleagues, microgrids can be perceived as aggregated prosumers which are performing energy transactions between each other and with the main grid. Furthermore, they note that the predefined rates for energy value in such transactions, at least in its current existing form, constitutes a form of centralised regulation which appears to hinder the efficiency, flexibility and scalability of microgrids (Li, Bahramirad et al. 2019, 59). How such a conception of energy and a corresponding form of regulation, influencing the market interaction within microgrids, is implemented in current approaches towards implementing blockchain technology in energy markets, will be investigated in following sections of this thesis.

Citizens become energy citizens

Through making use of the disintermediated, decentralised structure that such systems provide, local communities have the opportunity to transform into self-sufficient *citizen utilities* or so-called *energy citizens*, generating their own electric power, managing and trading it in more efficient, transparent ways. They also profit from the degree of resilience which is created through the emerging trust between involved entities in the microgrid. Additionally, this allows citizen utilities to combine their local efforts towards decarbonizing the electrical grid and to incorporate more renewable energy resources locally and in cooperation with other energy communities (Ahl et al. 2019, 202; Goulden et al. 2014, 21,24; Green & Newman 2017, 289, 292; Martiskainen & Watson 2009, 181-182; Mengelkamp et al. 2018, 871; Van Cutsem et al. 2020, 8-9).

These self-sufficient communities also change the relations of trust within the energy market. As mentioned in the previous chapter of this thesis, the form of trust which emerges between entities in decentralised blockchain-based networks on electricity markets, shifts from trust in the functioning and reliability of centralised institutions towards trust in the network itself and the community within it (Hayes 2019, 50-51, 61). By enabling the disintermediation through decentralisation, peer-to-peer energy trading and management in microgrids based on blockchain technology, will ultimately shift from technological integration in the electricity market towards decentralised blockchain-based networks that become the market and its organisation itself (Diestelmeier 2019, 189). The technical infrastructure and resulting network is being trusted by the participants and is expected to maintain reliable and secure. The participants also expect that its conceptualised information symmetry among all participants in the network will be upheld. Additionally, the notion of monitoring other participants is being transferred to the software protocol within the network itself, which regulates and enforces rules (Hansen et al. 2020, 9; Noor et al. 2018, 1395). Although these rules have been conceptualised by participants of the network, it appears that this leads to a new form of responsibility among participants within decentralised blockchain-based networks emerging out of this notion of trust.

Microgrid energy markets and their underlying blockchains could thus facilitate the balancing of energy supply and demand in a localised, sustainable and reliable manner, not only transforming energy systems towards higher degrees of sustainability, but also by changing the roles of users and entities connected to the emerging decentralised grid. Furthermore, they provide the possibility for reducing inefficient energy transportation costs and increase sustainability as well as reducing energy prices overall (Mengelkamp et al. 2018, 870-871, 879).

3.2 Forms of governance in decentralised blockchain-based networks

The decreasing technological costs towards implementing the technical infrastructures and software for blockchain-based solutions in energy markets appear to become a less hindering factor with regards to developing and investing in such emerging technological solutions. However, the factor of governance costs is still persisting, perhaps even more than ever (Pereira et al. 2019, 95). The term g*overnance costs*, as used throughout this thesis, refers to the entirety of efforts, monetary investments and other approaches that are needed for a successful implementation and stabilisation of a decentralised blockchain-based network on the micro-, meso- and macro-level, in the short and the long-term. The costs and efforts for maintaining already existing forms of centralised governance in networks can be weighed against the possible advantages. These can be compared to the governance costs for decentralised networks. This appears to strongly influence the decision of stakeholders whether or not to invest in blockchain-based solutions. Especially the costs for the new forms of governance which emerges in decentralised blockchain-based networks will be examined further throughout the following section of this chapter as one of the aspects shaping the ongoing transition of energy markets.

Governance costs

Blockchain technology in itself potentially decrease transaction costs in networks, through automatic and instant facilitation and validation of transactions, as well as through lower degrees of opportunism and uncertainty from stakeholders resulting from the automatic and self-executing character of smart contracts which are implemented in the system (Davidson et al. 2018, 651; Pereira et al. 2019, 96-97). The cost for these lowered degrees of opportunism and uncertainty, resulting from the new forms of information symmetry and disintermediation of control, are, on the one hand, the establishment of an openly accessible network and, on the other hand, a change in complexity and coordination within the network. This increased form of coordination is related to the immutable character of the blockchain, which validates transactions and records them on a tamper-proof basis. Increased forms of coordination would be needed in case of stakeholder errors, when transactions have been wrongly performed and would need to be reversed. A technical solution for such user errors, as well as wrongly programmed smart contracts, is the implementation of mechanisms for altering transactions through the software protocol of the blockchain. This will, however, impede with the very conception of the irreversible and immutable character of the record of transactions that is the network's blockchain. As this very characteristic is the fundament for the network's security, stability and decentralised character, an implementation of such a mechanism would not only require extensive programming, but also a corresponding form of decentralised decision making for cases in which such an alteration should take place. The complexity and coordination efforts and costs for such approaches appear to increase exponentially with the size of the network, as well as with the increasing complexity of transaction processes and implemented smart contracts (Pereira et al. 2019, 96-97). Additionally, these forms of increased coordination and complexity costs are indirectly leading to higher technological and resource costs for the verification processes and consensus mechanisms which are underlying the technological functioning of the blockchain. In cases where proof-of-work approaches are used, this then results in higher electricity costs and increasing demand for advanced technical hardware, which have previously been mentioned (Cocco & Marchesi 2016, 5; Pereira et al. 2019, 98; Taylor 2017, 61).

The costs for coordination are directly related to the existing and developing frameworks of regulation and the resulting forms of governance which are concerning the development and implementation of decentralised blockchain-based networks in general and on energy markets. According to the account of Pereira and her colleagues, the mechanisms for transaction verification and consensus making with a disintermediated character and distributed forms of information, open accessibility and power, together are a trustless and relatively secure and stable governance system. Although the implementation of those mechanisms and integral parts of the network is costly and might be opposed to issues of efficiency, it is essential for the overall constitution of the network (Pereira et al. 2019, 100).

Forms of governance

The forms of governance which are present in blockchain-based platforms are dominantly related to the embedded software protocol of the blockchain used as the foundation of the peer-to-peer network. It defines the general functioning, boundaries of user interactions, the form of smart contracts which can be implemented, as well as the data infrastructure which is in place in the network, giving it its shape and context (Davidson et al. 2016, 6-7; Pereira et al.

2019, 95). Further, can the decision-making processes about the maintenance and further development of the software protocol and the corresponding network be made openly accessible and available to change in decentralised decision processes. Such a form of decentralised governance, present in most current blockchain-based networks, regardless whether they are proprietary or a companies decentralised network based on a public blockchain, strongly changes the form of power structures, responsibilities and possibilities for intervention at play in the network, creating the disintermediated character of it. This form of governance not only shapes the ways in which such networks are being developed, operating, and changing, but also the extent of influence individual stakeholders within the network are able to have (Pereira et al. 2019, 95). Additionally, novel stakeholders and alterations of roles with regards to governance and responsibility in the network might emerge, changing the forms of interactions and power relations between stakeholders and their influence in the network (Hansen et al. 2020, 9). Whereas decisions about which stakeholders are invited and enabled to participate in the networks development, usage and maintenance are regulated through governance by overseeing institutions or authorities in centralised peer-to-peer networks, these aspects are presented in a much more open and distributed character in decentralised blockchain-based networks. The disintermediated character of such decentralised networks which was already mentioned in previous chapters of this thesis, not only concerns the facilitation of functions which are needed to stabilise and uphold the network's structure, but also the forms of governance which persist within it. In the process of validating transactions within the network, for instance, relying on a trusted and centralised entity which has the autocratic power to decide which transactions are valid, shifts towards distributed power and responsibility of independent validators and mechanisms to ensure a tamper-proof structure and convention of trust. Joining such a decentralised blockchain-based network therefore encompasses complying with an established consensus mechanism implemented in the software protocol of the network and the existing notion of trustlessness which has been previously mentioned as well. Additionally, the decision-making processes about which consensus mechanism is ought to be implemented and uphold are being regulated by the entities within the network itself, either through influencing the form of the software protocol, as it is usually openly accessible software, or through selecting the blockchain and corresponding software protocol on which the network should be operating (Davidson et al. 2018, 339-340, 343; Pereira et al. 2019, 96).

The verification of transactions is only one of the specific functions of the network which presents a new paradigm of governance which appears to be enabled through the implementation of blockchain technology in network infrastructures and the development of peer-to-peer networks in market contexts (Pereira et al. 2019, 96). The efforts for shifting towards decentralised network structures instead of adhering to centralised forms of governance require high levels of participation and (market) coordination from entities within the decentralised network. Their efforts in the form of taking functions such as currency creation, distribution, validation of transactions, maintaining, securing and stabilising the network, are stimulated through incentive mechanisms which increase interaction between stakeholders and their commitment to upholding these functions as a distributed network of independent entities (Davidson et al. 2018, 343, 345, 349; Pereira et al. 2019, 96). Apart from this form of governance at the application and interaction level in decentralised blockchain-based networks, a change in the form of governance is also visible at the data infrastructure level of such networks. This mainly concerns the redundancy of information which, previously being dependent and limited by the agency of a government or authoritative entity, is being disintermediated through the distributed character of the shared record of transactions in the blockchain. The power resulting from the forms of control over information ownership and accessibility is therefore changing through the character and infrastructure of decentralised blockchain-based networks itself (Pereira et al. 2019, 96).

Based on these aspects, it is shown that decentralised blockchain-based networks present a transition in their internal forms of governance, influenced by the decentralised character and resulting infrastructure and social practices which are present in such networks. Through the transition towards disintermediated and distributed governance mechanisms and power structures, blockchain-based networks enable free interactions of network participants based on a distributed and transparent data infrastructure, lower the degree of central market power and control and lower transaction costs (Pereira et al. 2019, 96). These forms of power structures and underlying forms of governance can be perceived in the ongoing transition of energy markets and should be further illustrated through the analysis of selected case studies in the last chapter of this thesis.

3.3 Users in decentralised blockchain-based networks in electricity markets

The decentralised character of blockchain-based networks implemented in energy markets implies new roles for various stakeholders situated within the network and influencing its development and implementation. Additionally, new forms of relationships between such entities, as well as new forms of influence they possess emerge. The transformation of the roles and identities of such entities, for instance users, local communities and energy providers or distributors, as well as the resulting changes in the interplay between them, should be analysed in this section (Plaza et al. 2018, 1). Building upon the insights from the previous chapters of this thesis on the role of users as well as the constitution and transformation of their identity in decentralised blockchain-based networks, this section will especially elaborate on the role of users in such systems in current energy markets.

Users in decentralised blockchain-based networks can use the network's structure as a means to facilitate their transactions, in which they profit from the increased degrees of privacy, efficiency and lowered transaction costs. Apart from this role as being a consumer, users can also become producers, constituting the network itself as nodes and contributing to its structure through the computational power they provide. Additionally, users can take the role of being a prosumer, blurring the distinctions between the roles of consumer and producer and merging their behaviour and contribution to the network in this hybrid role (Humphreys & Grayson 2008, 2, 16). Drawing upon these defined user roles and combining them with the insights from previous sections of this chapter, it appears that these three user roles are also visible in the context of electricity markets in which decentralised blockchain-based networks have been implemented or are being conceptualised. Consumers in such markets are merely consuming energy either in their local communities or from a centralised power grid. Their role remains rather passive with regards to the constitution of the network and the resulting network of transactive energy trading. The role of producers in such context can both relate to energy suppliers, providing energy to a grid infrastructure in exchange for money from consumers, or relate to individuals or communities which are producing their own energy for their own localised microgrid or to transfer it to a centralised power grid in exchange for its monetary value. The role of producers is therefore far more active, users are directly influencing the energy landscape and structures in their surrounding grid networks, as well as contributing to the decentralised network's influence on existing relations of power generation, distribution and consumption. The hybrid character of the role of prosumers on electricity markets becomes visible in cases where individuals or communities produce energy locally, trade it among themselves or with an external power grid, either in the form of a centralised grid or other microgrids, and at the same time, consume energy which they have either produced themselves or have been provided with by other grids. Although the roles of consumer and producer are integral to the functioning of the power grid and the resulting energy market, the most intriguing user role with regards to the ongoing transition of energy markets appears to be the role of the prosumer (Ahl et al. 2019, 202; Green & Newman 2017, 292; Li, Bahramirad et al. 2019, 59; Lowitzsch et al. 2020, 1; Mengelkamp et al. 2018, 870-871; Van Cutsem et al. 2020, 8-9; Zhang et al. 2018, 1-2, 11).

The potential of prosumers, constituting and contributing to the energy market, as well as the infrastructure for energy production, management and distribution, is being recognised as a promising way towards the development of future energy markets and especially higher degrees of sustainability (Jiang et al. 2020, 1). In the context of local energy communities, prominently being envisioned or developed in the form of microgrids, the role of being a prosumer now enables new forms of participatory power for users, directly contributing to the network's structure through investing in their own forms of energy production, as well as their forms of interaction with the main power grid or other microgrids through energy transfers. This form of transactive energy exchange further empowers users or user communities through the opportunity to balance energy demand and supply locally, increased efficiency of transactions with lower transaction costs and ultimately, becoming self-sufficient and self-sustainable energy communities. Additionally, investments in local energy production are incentivised through the possibility for individual profitable market participation, as well as the prospect of creating an independent, self-sufficient power grid (Ahl et al. 2019, 200, 205; Li, Bahramirad et al. 2019, 59; Lowitzsch et al. 2020, 1; Mengelkamp et al. 2018, 870-871). The notion of power and influence in the market participation of users is extended through the role of becoming a prosumer, not only being able to consume the energy they have produced themselves but also through the possibility of being able to participate in the decision on who supplies them with energy. Being able to decide who supplies oneself with energy and through which resource it was generated, is a degree of agency of users which is enabled through the character of the decentralised blockchain-based network (Ahl et al. 2019, 205; Mengelkamp et al. 2018, 871). With the transformation of the role of users and the empowerment of them, new potential forms of user behaviour emerge. Apart from the apparent behavioural change in participatory aspects of the network such as participating in energy generation, trading and decision-making processes about the networks structure and functioning, the implementation of peer-to-peer energy trading market mechanisms might change users behaviour of energy consumption. Zhang and his colleagues (2018) formulate that users might consume more energy if they are producing more energy in their local energy community and grid (Zhang et al. 2018, 11). As such forms of behaviour are mostly not anticipated in the discourse and go against the general conception of implementing decentralised blockchain-based networks towards more sustainability in energy markets, investigating resulting behavioural changes from users with regards to personal energy consumption further is a pressing subject of future research.

With regards to the formulated promises, anticipated changes in user identities and the empowerment of them through becoming prosumers enabled by decentralised blockchain-based networks, a notion of under-appreciation for the social relations within such networks and the need of them for successful implementation of such systems, appears to persist in the body of academic literature and general discourse on this topic (Hansen et al. 2020, 8). According to Hansen (2020), there exists a fallacy of perceiving technological solutions and their underlying software as the main entity which heralds and influences the transition of users towards becoming prosumers. While confirming the previous formulations on the anticipated forms of autonomy for users, the increased opportunities for self-sufficiency and the disintermediation of functions towards more decentralised forms, Hansen notes that such a conception of prosuming might lead to a decreased acknowledgement of the importance of social interactions and practices within the network (Hansen et al. 2020, 8). The driving force of technological solutions towards prosuming in the context of energy markets thus appears to require extensive reflections on the social relationships and power structures, as well as the necessity of involving social entities within the management, development and constitution of the network. With regards to network management, the forms of power attributed to the networks technological infrastructure and software protocol might even be shifted away from prosumers towards entities mainly concerned with the role of system operation (Hansen et al. 2020, 8; Buth et al. 2019, 201, 203).

The importance of social practices and relationships within decentralised blockchain-based networks in the context of user roles on energy markets becomes visible in the requirements for users to become prosumers. Becoming a prosumer in the context of decentralised cryptocurrency systems, requires extensive technological resources, hardware and technical knowledge. This further solidified the boundaries between prosumers and users being either consumers or producers (Cocco & Marchesi 2016, 5; Bogers et al. 2010, 860; Taylor 2017, 61-62). It appears that this need for expertise in technical knowledge and on market mechanisms, as well as investments in technological infrastructure are also visible with regards to becoming a prosumer on modern energy markets where decentralised blockchain-based networks are implemented. Contrary to this, the emergence of collective attempts to decrease the requirements for (profitable) participation in the form of mining pools appears to be mirrored in the development to the ongoing development of localised energy grids, combining the prosumer interactions, perspectives and efforts of individuals in aggregated communities. Miners in decentralised cryptocurrency systems are combining their computational power with the intention to achieve a greater influence on the market and keeping their efforts profitable, enabling individuals lowered thresholds for successful participation (Antonopoulos 2014, 211-212; Cong et al. 2019, 1; Dev 2014, 1; Fisch et al. 2017, 3). Similar to such collectives of miners, individuals in localised energy communities are combining their efforts towards changing the landscape of the existing market, while at the same time sharing the rewards of their endeavours and providing themselves with a coordinated structure and power dynamics. The requirements for becoming a prosumer in energy markets appear to be lowered through partaking in such energy communities. An elaboration on how such requirements for becoming prosumers are being realised and shaping out in actual cases of implementing distributed ledger technology in energy markets will be part of the following section of this chapter.

Chapter summary

It appears that a close reflection on the mechanisms, enabling prosumers the possibility to become integrated into the power structures and decision-making processes regarding system operation, is needed and should become the subject of further investigation. Furthermore, clear definitions of the identity and influence of entities are needed, appearing to be an essential part of successfully implementing and maintaining decentralised blockchain-based networks in energy markets (Ahl et al. 2019, 205; Hansen et al. 2020, 9).

The new forms of empowerment and user identities as being prosumers described in this section can be summarised as users becoming empowered through the decentralised character of blockchain-based networks in energy markets, leading to a shift for user identities from being focused on self-consumption, towards being enabled to strive for becoming self-sufficient (Ahl et al. 2019, 205; Jiang et al. 2020, 1). The described constitution of user roles and the forms of social practice on energy markets appear to further strengthen the hitherto presented account of decentralised blockchain-based networks being socio-technical assemblages. The constitution and transformation of user identities and roles in energy markets will be contextualised further through the analysis of two selected illustrative cases of corporations, implementing distributed ledger technology in the form of decentralised blockchain-based networks in the power sector, in the next chapter of this thesis.

Chapter 4: Decentralised blockchain-based networks in electricity markets

Illustrating and contextualising the findings of previous chapters, two selected[3] cases of organisations and corporations, implementing distributed ledger technology, specifically in the

[3] The cases of Power Ledger with the Power Ledger Ecosystem, and Pylon Network with their identically named platform Pylon Network, have been selected as two illustrative cases for the implementation of distributed ledger technology in the form of decentralised blockchain-based networks on electricity markets. I have identified both cases as fitting illustrations for the theoretical framework I am presenting in this thesis. Both platforms are characterised by structures which are showing the technical functioning of decentralised cryptocurrency systems, with their underlying blockchains, software protocols and cryptocurrencies in the form of tokens. Additionally, both platforms present social practices within them, which are mutually influencing and being influenced by these underlying technological structures. Both platforms are constituted out of a technical structure and social practices between the various entities they encompass. Such entities present in both platforms are for instance platform developers, corporations, governing authorities and users. I am identifying the complex array of relationships, interactions and dependencies between these entities and the technical structures in such platforms as a network with a decentralised character. I am thus defining both platforms as decentralised blockchain-based networks that are presenting aspects which illustrate and confirm my theoretical framework of understanding decentralised cryptocurrency systems and the networks in which they are embedded, as socio-technical assemblages.
The methodology of my case study and the selection of these two cases is as follows: In the body of academic literature on decentralised cryptocurrency systems and the use of distributed ledger technology in the power sector, the platforms developed by Power Ledger and Pylon Network are mentioned (Adeyemi et al. 2020, 5; Andoni et al. 2019, 157, 161-162; Cali & Fifield 2019, 248; Dorsman et al. 2020, 68; Gough et al. 2020, 36-37; Johanning & Bruckner 2019, 2, 4; Kuzlu et al. 2020, 3; Mollah et al. 2020, 21; Wang et al. 2019, 9). Although other similar platforms and approaches are also mentioned in the body of literature, I have specifically selected these two cases and platforms due to their technical functioning, blockchain-based structure, forms of used cryptocurrencies, decentralised character and focus on the decentralisation and sustainability within electricity markets. Additionally, it should be noted that although some other cases might provide an equally fitting and illustrative character for my account, the extent of this thesis did not allow for an extensive analysis of more cases. Instead of providing a limited overview on a variety of cases, I have decided to select these two cases and examine them thoroughly.
The Power Ledger Ecosystem and the Pylon Network are described as cases for the implementation of distributed ledger technology in electricity markets and are analysed in terms of the forms of peer-to-peer energy trading they might enable and the degree of decentralisation they might provide to the contexts in which they are implemented. It should be noted that the accounts describing these platforms are rather limited descriptions of the envisioned functioning of the platforms and are mainly focused on presenting and evaluating the implications the platforms could have with regards to market interaction, energy generation and -distribution. Additionally, the social practices between entities within the platforms are not sufficiently presented and examined in these accounts. Moreover, although the academic discourse on distributed ledger technology is relatively new, acknowledging and analysing the socio-technical character of decentralised blockchain-based networks in electricity markets is not present and sufficiently discussed. Based on their mentions in the body of academic literature, I have become aware of both platforms and investigate them individually and separately from their descriptions in the academic discourse. I am analysing the ways in which both corporations present their envisioned platforms and the corresponding pilot projects in their whitepapers, on their websites, in public blog posts and public Q&A sessions (Power Ledger 2017a-b; Power Ledger 2018; Power Ledger 2019; Power Ledger 2020a-e; Pylon Network 2017; Pylon Network 2018a-b; Pylon Network 2020). I am using the information from these sources, describing the technical functioning, forms of market interactions, and apparent influence on the decentralisation and sustainability of electricity markets, to identify them as decentralised blockchain-based networks. Furthermore, I am investigating if the underlying technological structure aligns with my previously provided explanations on the technical functioning of decentralised cryptocurrency systems. Based on the description of these platforms, I am analysing the

form of decentralised blockchain-based networks in the power sector, will be examined in the following sections. The previously established understanding of such systems as socio-technical assemblages will be revisited and confirmed further. Additionally, the presented conceptualisations and envisioned benefits of these systems will be contrasted with currently persisting limitations for their implementation, elaborating on the aspects of technical realisation and issues of scalability.

4.1 Power Ledger Ecosystem

The 2016 founded, Australian company Power Ledger (PL) and their envisioned Power Ledger Ecosystem, is an illustrative case for the implementation of distributed ledger technology for energy trading and management. According to the mission statement presented in the white paper describing their approach and platform, PL believes in the empowerment of individuals and communities, enabling them to take part in the creation of future energy markets and power systems which are ought to be characterised by greater degrees of resilience, sustainability and are publicly owned (Power Ledger 2019, 1; Power Ledger 2018, 15-16, 33;

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social practices, relationships and forms of governance within them and compare them to the theoretical framework I have presented previously. Moreover, building upon the descriptions of the two platforms, I am investigating their implementation in electricity markets through their presented pilot projects and (envisioned) contexts of operation. Finally, I am contrasting their presented apparent promises and implications for such markets against accounts from the body of academic literature which present limitations and hindering factors to the implementation of distributed ledger technology in electricity markets. Through my analysis I am identifying both platforms as fitting illustrative cases for the socio-technical character of decentralised blockchain-based networks in electricity markets.
My methodology for analysing these case studies presents limitations which have to be acknowledged. Firstly, the selection and discussion of only two case studies present a limited account on the current development and implementation of decentralised blockchain-based networks in electricity markets. Although analysing a broader set of cases would provide a broader account on such networks, selecting a limited number of cases for a thorough examination, instead of providing a multitude of general analyses of more cases, appears to be more fitting with regards to the extent of this thesis.
Secondly, the focus on mainly analysing the forms of self-presentation of Power Ledger and Pylon Network has to be noted. This focus implies to carefully analyse the presented descriptions and formulated promises of the platforms, and to critically reflect upon them with regards to their technical attainability and actual implications. Although such a critical reflection about the platforms is provided in this thesis, it could be further expanded by including accounts on decentralised power structures from the fields of electrical engineering and energy management studies. Although the analysed sources provide sufficient information to analyse the envisioned platforms, their underlying technological structure and the entities within them, a more extensive analysis through personal interviews or participatory observations in workshops could provide further insights. As such an analysis is too extensive for this thesis, this constitutes a field for future research which can build upon the insights of this initial analysis. Thirdly, the fact that Power Ledger and Pylon Network are currently testing their platforms in pilot projects and have no previous records to analyse the long-term development of their envisioned platforms, has to be acknowledged. This therefore implies, that the presented descriptions and envisioned implications of both platforms can only be contrasted with current results from pilot projects and accounts which are critical about the implementation of distributed ledger technology in electricity markets in general. However, as the implementation of decentralised blockchain-based networks in electricity markets is in a current state of development and experimentation, this constitutes a field for future research which can build upon the insights of these case studies.

Power Ledger 2017a, 1). The emerging market and integration of distributed energy resources (DER), the creation of microgrid structures and energy communities, has shifted the power relations within grid networks away from centralised authorities towards the consumer. A new platform is needed, which enables users to build upon their desires for more control over their energy consumption, and their demand for more sustainable, socially-responsive, local and more democratic energy supplies. According to PL, the PL Ecosystem is such a platform to provide a successful transition of energy markets towards decentralised and citizen-controlled forms on a global scale (Power Ledger 2019, 5, Power Ledger 2018, 16, 33; Power Ledger 2020e). To understand the implications and benefits that this platform might have, an overview about its conception and technical functioning will be provided in the following section, presenting the envisioned forms of structure, user roles and interactions, as well as power structures within the system.

Platform for peer-to-peer energy trading

According to PL (2019), the network of energy consumption, trading, distribution and supply, needs to be reimagined as a platform which is characterised by a transparent, decentralised structure and a notion of trustlessness. Through the introduction of the user role of being prosumers, selling energy to peers and the grid, a bi-directional flow of energy is created, enabling citizens to profit from their contribution to the network and the incentive to invest in renewable forms of energy generation. The introduction of peer-to-peer energy trading also enables the creation of citizen utilities, sharing energy among themselves and incentivise the focus on community needs, self-sufficiency and long-term sustainability instead of personal profit. The notion of trustlessness described by PL is based on the implementation of blockchain technology as an underlying platform structure, a distributed database, facilitating transactions, securing the market and upholding its efficiency instead of a centralised authoritative institution. Trusting a centralised institution to uphold such functions, is shifted towards being able to trust the outputs of the decentralised system itself without the reliance on trust between actors within the network. Such a notion of trust also holds for smart contracts in the network, implemented for the automated facilitation and verification of transactions based on predefined conditions. The enabled form of peer-to-peer energy trading will thus transform energy networks towards multilateral trading ecosystems being co-created by prosumers and investors. PL notes that this form of platform will see increasing levels of automation and resilience, based on the emerging multiplicity of localised investments instead of limited, large-scale centralised approaches (Power Ledger 2019, 7-8, 9-10). According to PL (2019), the Power Ledger Platform supports a wide variety of energy applications and enables the interoperability of diverse energy management and pricing mechanisms. It provides the necessary structure and transparent governance framework which is needed to adapt to a multiplicity of energy markets in local and global contexts. Furthermore, the platform is adaptable and scalable in various regulatory environments and legal frameworks, able to provide stable energy trading applications even under occurring local policy changes concerning the local energy grid and environment (Power Ledger 2019, 11-12, 16-17, 25).

Market flexibility

The supposed market flexibility of the PL Ecosystem is ensured through a dual token system, operating with two underlying blockchains. Therefore, two forms of pre-purchased, virtual tokens are present on this platform. The Power Ledger token “POWR” allows entities, such as individuals or application hosts, the access and use of the platform. The second energy trading token “Sparkz” is issued against escrowed POWR tokens, and used by application hosts. Application hosts are corporations which are running an application for their customers on the PL platform. Sparkz are based on fiat currencies (established currencies which are backed by a state or government such as the US Dollar or Euro). Sparkz can be purchased and redeemed using fiat currencies in trading platforms of application hosts which offer the exchange of generated energy for Sparkz. This token is designed to represent the monetary value of a unit of electric energy across the varying markets connected to the PL Ecosystem. As Sparkz maintains a steady exchange rate between the prices of local energy markets and the price of POWR tokens, the duality of these tokens connects the functions of local energy pricing and market mechanisms with the decentralised structure and transparency of the network. Through their customers and prosumers, energy trading applications connected to the PL Ecosystem are thus creating Sparkz in exchange for POWR (Power Ledger 2019, 11-12, 16-17, 18). It should be noted that through the exchange rate between POWR and Sparkz, application hosts are required to balance the number of POWR tokens they have obtained with the demand of Sparkz tokens corresponding to their consumers and their energy exchange behaviours (Power Ledger 2019, 19-20; Power Ledger 2020b-c).

Underlying blockchain

PL currently uses two blockchain-based approaches as the underlying structure for their platform: the EcoChain blockchain and an Ethereum consortium blockchain. The EcoChain blockchain, a private proof-of-stake blockchain, was developed by PL in 2016 and tested in application cases in Australia and New Zealand (Power Ledger 2019, 23-24; Power Ledger 2018, 12, 15). This blockchain, designed as an alternative to the power-intensive proof-of-work algorithms of other blockchains, is currently used to facilitate ongoing projects and services from application hosts. The blockchain stores data about energy generation and consumption from smart power meters in households or local grids of energy communities and provides it to the application hosts as well as to other prosumers and consumers on the platform (Power Ledger 2019, 22, 23-24, 27). While retaining the EcoChain blockchain in their ecosystem, PL is currently testing forms of an Ethereum consortium blockchain. The concept behind a consortium blockchain is that the functions of transaction facilitation and validation are upheld by only a few selected nodes, making it a partly public and partly private blockchain. For the future, PL aims at entirely switching towards a public proof-of-stake blockchain (Power Ledger 2019, 22, 23-24, 27; Power Ledger 2018, 33-34).

The various forms of energy trading applications, being conceptualised or already developed by PL and connected to the PL Ecosystem, include general infrastructures enabling peer-to-peer energy trading, enabling smart energy demand and supply management for retailers supporting prosumers contribution to energy trading, as well as optimised energy data management (Power Ledger 2019, 12-13). One of these peer-to-peer energy trading applictions is the "FuseBox", created by PL and used as an illustrative case to explain their conceptualised ecosystem. PL has already developed this application and is currently trailing it in projects with corporations in various contexts and national settings (Power Ledger 2019, 25). Through the application, peer-to-peer energy trading is enabled for prosumers and consumers interacting in a network characterised by a structure which has both the possibility to include industry market intermediaries or not. In cases that include industry intermediaries, this application allows corporations to manage and integrate their own customer base into the PL ecosystem and thus profit from the decentralised and transparent structure of the network. The dual token system of POWR and Sparkz is already fully implemented in this application. Although externally developed applications may also be integrated into the network, in such cases, PL manages the conversion rate of POWR and Sparkz. This depends on the reputation of the corporation and feedback from the customer base that ought to be integrated. Additionally, with the prospect of deregulation on localised energy generation, PL also conceptualises a form of direct peer-to-peer trading between prosumers and consumers in for instance localised contexts such as microgrids, interacting on the PL platform without intermediation of application hosts at all (Power Ledger 2019, 16-17, 18; Power Ledger 2020a).

Users

The themes of empowering users and sustainability appear to be closely linked together in the narrative of the PL ecosystem. Users should become empowered through the platform by enabling them to choose their energy supplier independently, as well as the form of energy generation which was used for the energy generation (Power Ledger 2019, 1, 28; Power

Ledger 2020d-e). The investment of local communities into renewable energy sources, and incorporating such energy communities as part of the conventional energy system by application hosts on the PL platform, becomes essential for PL's sustainability vision. Through the implementation and wide usage of their PL ecosystem, PL aims to stimulate a transition of energy supply, distribution and consumption, prioritising the adaption of renewable energy resources, towards a more sustainable energy infrastructure with lower carbon emissions (Power Ledger 2019, 1, 20-21, 28). This sustainability focus is extended by the incorporation of incentives for prosumers, consumers and application hosts. The generation and purchase of sustainable energy generated from renewable energy resources in the PL ecosystem is rewarded by obtaining a small amount of POWR tokens. The rewarded tokens are funded by the entities in the network themselves, through being charged a small fee for every peer-to-peer transaction. Through the exchange of POWR tokens for Sparkz, these rewarded tokens present both an incentive to invest in sustainable energy, as well as in the consumption of it. PL describes that the prospected increased generation and trading of sustainable energy leads to broader usage of their platform on energy markets as a "virtuous cycle" towards a more sustainable energy future (Power Ledger 2019, 20-21).

4.2 Pylon Network

The Spanish company Pylon Network (PN) is presented as the second illustrative case for the implementation of distributed ledger technology on energy markets. Building on open-source blockchain technology, they have developed a transparent, neutral energy database, also called the Pylon Network. The development and implementation of this network is aimed at increasing the participation of stakeholders in energy markets, especially incorporating end-users towards more democratised energy markets in the future (Pylon Network 2018a, 1; Pylon Network 2018b, 1). According to PN (2018a), such a focus on increased end-consumer participation and contribution is essential towards a successful transition of energy markets and is bound to transparent and distributed energy data management and structures (Pylon Network 2018a, 3-4). PN identifies a form of information asymmetry about energy data on energy markets. Although consumers are able to access records of their energy data from their retailer, such as their consumption and their energy supply, there exists no shared platform enabling and facilitating the exchange of energy data across all stakeholders of the energy sector (Pylon Network 2018a, 6-7).

Underlying blockchain

The Pylon Network is presented as a solution for this problem of information asymmetry. Based on blockchain technology, a transparent database enables users to control their personal data, to independently select their energy supplier and thus to have a stronger position with regards to their active market participation. In addition to this form of empowerment for consumers and prosumers in the network, energy retailers profit from the shared and transparent data and are able to adapt their forms of energy production and service models directly to the demands of the market (Pylon Network 2018a, 8-9; Pylon Network 2018b, 2-3; Pylon Network 2020). The underlying blockchain for the network was developed by PN and is accessible to all entities on energy markets via open-source access. The open character of the network and its development was set up with the intention to create an openly accessible, scalable and effective framework for data exchange, cooperation and trust. Through this, the ecosystem of the Pylon Network should accelerate the energy transition towards more transparency, trust, decentralisation, innovation and cooperation (Pylon Network 2018a, 10-11; Pylon Network 2018b, 4-5).

Pilot project

The Pylon Network has been extensively tested in a pilot project with real market conditions with energy data of 100 users from the Spanish energy retailer Goiener. The role of users in this pilot o included energy communities, prosumers and smaller energy retailers incorporated in the user base of Goiener, and was not limited to regular consumers. Applications and tools were developed and tested towards achieving more participation of end-users, as well as adding more market value and focus to their demands and intentions. This was achieved through three notions of the network. Energy retailers were enabled to provide transparent records of users' energy data to them and provide them with new insights regarding where the supplied energy was created and through which resource. Consumers and prosumers could build upon these new insights and change their consumption behaviour, as well as achieving a new form of control, now being able to select directly and effortlessly where their energy should come from. An additional layer of privacy was enabled for consumers and prosumers through the network, as they were able to control which data they are willing to share with third party energy retailers. The access and management for users’ energy data were enabled through a structure of smart meters (in households or energy communities) and through the access to the network via online control panels or a mobile app (Pylon Network 2018a, 11-12; Pylon Network 2018b, 14-15). In this pilot, a conceptual shift for energy retailers and the developers of the Pylon Network could be noticed, from designing energy supply and service options for passive consumers, towards providing favourable conditions for consumers to become more active and to articulate their demands for energy supply, energy distribution and participation in energy markets (Pylon Network 2018a, 11-12).

Governance mechanisms

There is a set of mechanisms governing the Pylon Network and aimed at promoting and rewarding investments from energy producers and consumers towards more decentralised and sustainable forms of energy generation, distribution and consumption (Pylon Network 2018a, 13; Pylon Network 2017).

Firstly, in the Pylon Network, exist two forms of virtual tokens, the Pylon Token (PYLNT) and the Pyloncoin (PYLNC). PYLNT is a digital asset which enables entities, such as energy retailers, the access to the Pylon Network, the participation and the ability to obtain shares of the distributed rewards within it. PYLNC is a digital currency, designed for the reward system for nodes within the Pylon Network. These two tokens are freely exchangeable in digital exchanges, making their value and price determined by the market (Pylon Network 2018b, 6, 10, 11-12, 14-15).

The second mechanism is the existence of two types of network nodes with differing forms of operation and roles, corresponding to the different market players they represent: light nodes and full nodes. Light nodes take the form of monitoring hardware, such as smart meters, integrated into the Pylon Network and being operated by energy producers or prosumers. They record their energy data, validate their transactions and synchronise them with the blockchain. Full nodes are operated by PYLNT holders, such as energy retailers, energy cooperatives and service providers, which obtain a number of PYLNC to become a full node. The access to this initial investment remains blocked during their network participation. This ensures the credibility and security of all federated nodes. These nodes are responsible for storing energy data of regular consumers, as well as maintaining the network by validating the records of light nodes and combining it with their own energy data, ultimately creating new blocks of the blockchain. Full nodes are federated nodes, representing all PYLNT holders in the network. For the inclusion of a new full node, a majority vote between all federated notes must be passed, in which each node is weighted the same. It should be noted that regular users, although being part of the network, are not operating any form of nodes (Pylon Network 2018b, 6-7).

The creation of a non-competitive, non-resource intensive mining environment within the network, is a third mechanism of governance. A predefined set of consensus rules for nodes in the network is implemented, eliminating the need for approaches such as proof-of-work, which is characterised by extensive resource consumption and hardware costs for the sake of achieving network-wide consensus between nodes. These predefined rules in the Pylon Network are called proof-of-cooperation, leading to decreased forms of competitiveness among miners (Pylon Network 2018b, 5). This form of consensus is achieved and upheld through the federated full nodes in the network and their voting mechanism on new additions to their group. Through this mechanism, the process of mining for nodes in the Pylon Network is facilitating energy transactions and validating them in a non-competitive manner (Pylon Network 2018a, 10-11; Pylon Network 2018b, 4). Furthermore, the total amount of distributable PYLNC is limited to 100,000,000, designed to be created in an interval of 20 seconds, becoming the reward for nodes for the validation of new blocks of energy transactions in the blockchain. This obtainable reward is designed to gradually increase until 60% of PYLNC have been created, after that the reward will remain lower on a fixed rate until the total supply of PYLNC has been distributed. After this, no new PYLNC tokens will be created in the validation process of transactions (Pylon Network 2018b, 8-9, 10). This appears to be an incentive mechanism for nodes to increase the production of renewable energy they contribute to the network.

The fourth mechanism governing the Pylon Network is differing reward systems for the two types of nodes. Light nodes are rewarded based on the amount of contributed energy to the network. As this reward of PYLNC is a fixed percentage of the contributed energy, overtime all nodes are rewarded with a proportional share of their contribution to the network. Through this mechanism, light nodes are incentivised to increase the production of the renewable energy they are contributing. Full nodes are being rewarded a share of the mining rewards in the form of PYLNC, distributed equally between them and diminishing with increasing amounts of full nodes (Pylon Network 2018b, 6-7). According to PN, through these mechanisms and its decentralised structure, enabled by blockchain technology, the Pylon Network is able to provide a transparent, neutral energy database which can be perceived as a new disruptive model for conventional energy markets, increasing the democratisation of energy markets and advancing the ongoing transition towards more decentralised and sustainable global energy markets (Pylon Network 2018a, 1, 13).

4.3 Discussion of case studies

This section contextualises the descriptions of the two case studies with the insights from previous chapters of this thesis. For this, the notions of decentralisation, user identities, governance and sustainability will be examined. The presented conceptualisations and envisioned benefits of these systems will be contrasted with currently persisting limitations for their implementation, elaborating on the aspects of technical realisation and issues of scalability. The discussion of these cases leads to insights about the implementation of blockchain-based cryptocurrency systems in energy markets, their alleged influence in the ongoing transition of energy markets towards more sustainability, as well as the confirmation of their socio-technical character.

4.3.1 Decentralisation

Both examined cases build on the decentralised character of blockchain technology as the underlying structure for their conceptualised ecosystems. This enables transparent disintermediated peer-to-peer transactions. Confirming the insights from previous chapters, the forms of cooperation, network stability, transparency and the facilitation of functions within the platforms, are being upheld by the network itself (Antonopoulos 2014, 1-3; Dilek & Furuncu 2019, 91, 94; Ensmenger 2018, 2; Nakamoto 2008, 2, 4; Ølnes 2016, 254-255; Vranken 2017, 1). Mechanisms incorporated within both platforms ensure that these necessary functions are upheld and that a notion of trustlessness can be achieved, shifting trust in a centralised structure towards trusting the decentralised structure of the network (Hansen et al. 2020, 9; Hayes 2019, 50-51, 61; Noor et al. 2018, 1395; Ølnes 2016, 254; Power Ledger 2019, 7-10, 22-24, 27; Pylon Network 2018a, 10-11; Pylon Network 2018b, 4-5). Conventional and resource-intensive approaches of proof-of-work or proof-of-concept are transitioned towards more sustainable forms of consensus-making, are designed to incentivise providing the network with sustainable energy and to decrease the notions of competitiveness within the network (Antonopoulos 2014, xviii, 1-4, 18, 27, 177-178, 199; Bitcoin Energy Consumption Index, 2019; De Vries 2018, 801; Dilek & Furuncu 2019, 96; Nakamoto 2008, 1-2, 4; Ølnes 2016, 255; Power Ledger 2019, 20-22; Pylon Network 2018a, 10-11; Pylon Network 2018b, 4-10). Overall, both corporations are presenting the vision of transitioning energy markets towards higher degrees of transparency, sustainability and democratisation, especially with regards to empowering consumers and prosumers, all enabled through the implementation of their platforms on a broad global scale (Power Ledger 2019, 5, Power Ledger 2018, 16, 33; Pylon Network 2018a, 1, 10-11, 13; Pylon Network 2018b, 1, 4-5).

Drawing back on the account of Chappels and Shove, this analysis shows how such an establishment of standards for energy creation, trading and consumption as well as a notion of competitiveness in such networks arises and further how this leads to the establishment of practices, such as the formation of mining pools or citizen utilities. Through accepting the new standards of energy consumption and increasing investments in computational power for operating decentralised blockchain-based networks, thus influences the ways in which societies become accustomed to them and how we address their development and implications (Chappells & Shove 2005, 33-34; Shove 2003, 396, 415-416). Thus, these accounts provide useful insights for further investigating how the establishment of such networks contributes to the ongoing transition of energy markets and how their influence is addressed in the context of governing them.

4.3.2 User identities

The influence of decentralised cryptocurrency systems on the constitution of user roles and identities within the contexts they are implemented in is present in the selected case studies. The transition for the users' identity from consumers towards becoming prosumers, and through that an integral part of the networks constitution and development, are deeply embedded in the vision and conceptual design of both platforms. Furthermore, the emerging forms of power and self-sufficiency of users are perceived as the most promising and impelling feature with regards to the ongoing transition of energy markets (Ahl et al. 2019, 202; Green & Newman 2017, 292; Li, Bahramirad et al. 2019, 59; Lowitzsch et al. 2020, 1; Mengelkamp et al. 2018, 870-871; Power Ledger 2019, 1; Power Ledger 2018, 15-16, 33; Power Ledger 2017a, 1; Pylon Network 2018a, 8-9; Pylon Network 2018b, 2-3; Van Cutsem et al. 2020, 8-9; Zhang et al. 2018, 1-2, 11).

Transformation to energy citizens

The opportunity for users and communities to transform into self-sufficient citizen utilities, generating their own electric power, managing and trading it in more efficient, transparent ways, is incorporated in both ecosystems. This is not just a secondary feature, but is one of the major pillars of the networks towards achieving higher degrees of decentralisation, democratisation and sustainability in energy markets (Ahl et al. 2019, 202; Green & Newman 2017; 292; Mengelkamp et al. 2018, 871; Power Ledger 2019, 1, 5; Power Ledger 2018, 15-16, 33; Pylon Network 2018a, 8-9; Pylon Network 2018b, 2-3; Van Cutsem et al. 2020, 8-9). Additionally, such forms of transactive energy exchange and management are related to mechanisms within networks to incentive market participation and investments in local, sustainable energy production. Such rewards systems, empowering users and transforming their identity and behaviour, are present in both platforms (Ahl et al. 2019, 200, 205; Jiang et al. 2020, 1; Li, Bahramirad et al. 2019, 59; Lowitzsch et al. 2020, 1; Mengelkamp et al. 2018, 870-871; Power Ledger 2019, 1, 20-21, 28; Pylon Network 2018b, 6-7).

Building upon the accounts of Callon, this analysis shows how the actor-world of these platforms enlists entities, determines their size and the forms of interactions between them and places them in a network. Market participants are defined, their roles are determined by the decision of developers or by the design of the network and they are placed in an interwoven network (Callon et al. 1986, xvi-xvii; Callon 1986, 22, 34). The process of translation is visible in the ways in which developers of the platforms define contexts of use, impose strategies towards realising the conceptions by their specific actor-world and presenting a delineation of a scenario which should become realised in the network, namely the transition of energy markets towards higher degrees of sustainability and decentralisation. Through their implemented mechanisms, software design and regulations of network access, they speak for entities, establish relationships and displace agents towards the solidification of their conceptualised actor-world (Callon et al. 1986, xvii; Callon 1986, 25-26, 28). Moreover, this analysis shows that such networks are actor-networks, in which entities themselves might influence, modify or transform the actor-world they are a part of (Callon 1986, 31-32). Investigating the transition of user identities, actor-worlds and decentralised blockchain-based networks as actor-networks thus provides intriguing insights towards understanding their internal forms of governance.

4.3.3 Governance

Forms of internal governance that shape the ways in which such networks are being constituted, operating, and transformed, as well as the extent of influence entities within the network have, become visible in both platforms in the form of assigned roles and network access (Pereira et al. 2019, 95). Users are able to transform into prosumers, able to influence their own market participation, energy data and consumption without any intermediary. These increased forms of citizen-control and transparency of energy markets constitute a new form of governance, which is enabled through the implementation of blockchain technology in energy markets (Power Ledger 2019, 5, Power Ledger 2018, 16, 33; Pylon Network 2018a, 8-9; Pylon Network 2018b, 2-3). Decisions of developers regarding conversion rates of tokens, market access, the established consensus mechanism in the software protocol are additional forms of governance which need to be accepted for participation in the network and profiting from its transparent and decentralised structure (Pereira et al. 2019, 96; Power Ledger 2019, 17, 19-20, 22-24, 27; Power Ledger 2018, 33-34; Pylon Network 2018a, 10-11; Pylon Network 2018b, 4-7).

The account of Hayes (2019) is helpful towards understanding the interplay of these network aspects. He presents three cases in which blockchains can be enacted: 1) as systems mainly used for facilitating transactions, 2) as structures providing an organisational form based on their technical characteristics and, 3) as institutions in themselves. All of these forms have been shown to be present in decentralised blockchain-based networks, illustrated through the examined platforms (Hayes 2019, 51-52, 61-63, 65-67). Moreover, their character as networks that are mutually co-constituted through technical and social aspects, thus being socio-technical assemblages, has been presented and put in perspective with regards to the forms of governance within them (Hayes 2019, 49-50, 68). It is an intriguing topic of research to investigate this character of decentralised blockchain-based networks and how it influences the ways in which they are developed, implemented and governed, which will be expanded through increasing forms of experimentation and investments.

4.3.4 Sustainability

Both selected cases present a platform which aims at solving the, by design, extensive resource consumption of conventional decentralised blockchain-based networks, while at the same time providing structures which enable and incentivise the investment of users, prosumers and energy retailers in renewable energy generation on future energy markets (Antonopoulos 2014, 177-178; De Vries 2018, 801; Dilek & Furuncu 2019, 96; Nakamoto 2008, 4; Power Ledger 2019, 1, 20-21, 28; Power Ledger 2018, 15-16, 33; Power Ledger 2017a, 1; Pylon Network 2018a, 1, 13). Rewarding the generation and purchase of sustainable energy generated from renewable energy resources is presented as a mean to further incentivise broadening the usage of their platform and accelerating the transition of energy markets (Power Ledger 2019, 20-21; Pylon Network 2018a, 13; Pylon Network 2018b, 6-10). Both approaches are presented as platforms for increasing the democratisation of energy markets and advancing the ongoing transition of future global energy markets towards more decentralised and sustainable structures (Power Ledger 2019, 1; Power Ledger 2018, 15-16, 33; Power Ledger 2017a, 1; Pylon Network 2018a, 1, 13).

4.3.5 Limitations and challenges for implementation

Regardless of the great potential that the implementation of decentralised blockchain-based networks appears to offer, it should be closely examined to what extent envisioned blockchain solutions for energy trading and -management are actually realisable, scalable and are providing increased value with regards to the organisational and technical effort their implementation requires. This further requires extensive investments and experimentation which should not only provide new insights about technical possibilities and more efficient and sustainable solutions but also increase the awareness of companies which have shown to underestimate the organisational and social dimensions in earlier implementations of blockchain technology (Andoni et al. 2019, 166; Perrons & Cosby 2020, 6-7).

Although the provided presentation of both platforms and their development align with the general narrative of the ongoing transition of the energy market towards more decentralisation and achieving higher degrees of sustainability, critical reflection about the realisation and actual implications of both platforms is essential. The following section presents the most dominant challenges which currently impede the broad implementation of decentralised blockchain-based networks and examine how these challenges are addressed in the presented platforms. To realise the envisioned benefits and long-term values of implementing decentralised blockchain-based networks in energy markets, the following issues need to be addressed and overcome: scalability and speed of transactions supported by the platform, privacy issues arising through the transparent and universally shared record of transactions and the alignment with legal and regulatory frameworks (Andoni et al. 2019, 159-160; Arslan-Ayaydin et al. 2020, 82; Mollah et al. 2020, 14; Wang et al. 2019, 7).

Scalability

The cost of implementation regarding the needed technical structures, such as smart meters in households, energy consumption, energy transportation costs and costs for educating market participants to use the network, are not addressed by either corporation as an aspect of the network. These costs need to be contrasted to the benefits which are provided by the network (Andoni et al. 2019, 166; Adeyemi et al. 2020, 6-7; Gough et al. 2020, 29; Mengelkamp et al. 2018, 873-874). This becomes especially important to consider with regards to the costs of the system in large-scale implementations. Additionally, the lack of widely accepted technical standards of such devices limits the interoperability and scalability of the platforms and is not acknowledged as an issue between current approaches and for the future (Andoni et al. 2019, 158; Gough et al. 2020, 23; Mollah et al. 2020, 22).

Although part of the empowerment of consumers is framed in both platforms as the ability choose energy suppliers directly, and thus decide how sustainable the consumed energy is, this is not technically possible as physical energy flows in large and decentralised grids cannot be tracked or controlled directly (Gough et al. 2020, 19, 31).

The consensus algorithms used in the networks have a crucial impact on their scalability due to the arising significant trade-offs between security, speed and resource intensiveness. While PoW algorithms are more secure, they are slow and resource-intensive than the consensus algorithms in the two presented platforms. Although the choice for less energy-intensive algorithms is justified with regards to achieving more sustainability, neither PL nor PN sufficiently address the arising challenge of selecting an algorithm which upholds security while remaining sustainable with significantly increasing amounts of nodes and transactions on the platforms (Andoni et al. 2019, 166; Gough et al. 2020, 20).

Privacy and security

In addition to the issue of security stemming from the consensus mechanism in the network, the limited amount of nodes in the network and the vulnerability of the platforms smart contracts and underlying software protocol against malicious users or hackers, constitute challenges which need to be solved for the successful widespread implementation of the envisioned networks (Andoni et al. 2019, 166; Mollah et al. 2020, 22). Moreover, with increasing amounts of participants and transaction records in the networks, issues of privacy and responsibility arise. Privacy of participants and the confidentiality of their data needs to be ensured while simultaneously upholding the transparent character of the network (Andoni et al. 2019, 167; Gough et al. 2020, 29; Mollah et al. 2020, 22). Both of these aspects are not sufficiently presented by both corporations and rather depicted as challenges which are solved with increased market participation and larger contexts of implementation, as well as through the functioning of their platforms (Power Ledger 2019, 22; Pylon Network 2018a, 10, 12; Pylon Network 2018b, 4, 15).

The question of responsibility for the protection of data and network participants arises. As the network itself is in place of a central authority which is trusted and would be responsible, this issue needs to be addressed and solved among all participants in the network (Andoni et al. 2019, 167; Gough et al. 2020, 19). Although issues of responsibility are indirectly addressed through disclaimers and disclosure documents regarding the loss of assets or user errors, the question of responsibility for errors caused by the network itself is not addressed by both corporations (Power Ledger 2017a, 1; Power Ledger 2017b, 4, 7-16).

Regulation

Although the decentralised character which is tried to be established is supposed to decrease the need for intermediaries and overarching regulation, regulation becomes a necessary and elementary component for setting the legal environment which is ought to be obeyed for the development and implementation of both platforms (Mengelkamp et al. 2018, 875). Aligning platform functioning with the legal and regulatory frameworks of the energy market or amending existing forms of regulations towards being able to test and implement the envisioned platforms on larger scales, is a reaming challenge for the implementation of decentralised blockchain-based networks. This concerns enabling peer-to-peer energy trading in the grid, new forms of contracts reflecting the forms of user roles and interactions within the networks and more flexible forms of electricity tariffs across the whole energy grid (Adeyemi et al. 2020, 8; Andoni et al. 2019, 167; Arslan-Ayaydin et al. 2020, 81; Gough et al. 2020, 22; Perrons & Cosby 2020, 6-7; Wang et al. 2019, 23). In both cases, acknowledging this challenge remains rather missing, or is presented as being solvable through the interoperability and adaptable character of the platform (Power Ledger 2019, 11-12, 16-17, 25).

Chapter summary

In this section I have shown, that while the presented platforms address new forms of participation, promise a more efficient and transparent system and present economically favourable aspects for all market participants, the examination of the technical possibility and necessity of such novel forms of empowerment are not questioned adequately enough with regards to the broad global scale in which these platforms are envisioned in the future. Further large-scale testing of the platforms needs to be done to arrive at grounded insights which are convincing enough for investors and regulating authorities to take the risk of transitioning energy markets through the implementation of decentralised blockchain-based networks or provide developers with the necessary experience which would enable them to solve these issues (Arslan-Ayaydin et al. 2020, 82; Gough et al. 2020, 23; Johanning & Bruckner 2019, 5). Furthermore, I have shown how accounts from the field of STS provide intriguing insights for understanding the internal forms of governance of decentralised blockchain-based networks which are constituting the basis for further research on the governance of such networks in energy markets.

Conclusions

This thesis was aimed at laying the necessary theoretical groundwork towards understanding the implementation and governance of decentralised blockchain-based networks in complex contexts of society such as electricity markets. I have argued that such an understanding presupposes a thorough examination of the underlying technical structures, social practices, and forms of power and governance within such systems in the first place. Thus, the focus of this thesis was set on the ways in which systems of cryptocurrencies based on blockchain technology are constituted by technical aspects of their infrastructure, as well as the social relations of users within such systems. Moreover, I investigated how their socio-technical character and decentralised structure leads to new forms and a transformation of governance within them, and correspondingly in the decentralised networks they are a part of.

Three core aspects

To arrive at a sound understanding of the forms of governance within decentralised blockchain-based networks, three core aspects were examined.

Firstly, from an understanding of decentralised blockchain-based networks as systems which are characterised, constructed and constituted through the technical and the social, an ontology of such systems as socio-technical assemblages was presented. Furthermore, it was shown how such networks are able to achieve and maintain the functions and commitments necessary to uphold the structure, stability and security of the network, without the need for intermediaries or external interference.

Secondly, the aspect of social practices and the constitution of users identities within decentralised blockchain-based networks was investigated. I have shown how the technical and social context of the network, being characterised through a decentralised organisational and power structure, gives rise to forms of market cooperation and coordination between entities within the network, leading towards their embeddedness with each other and the network. These social interdependencies and relationships, in combination with the technical characteristics of decentralised blockchain-based networks, thus establish contexts of use, manoeuvers of exclusion and overall co-constitutes and transforms the ontology and role of entities within them.

The third aspect that was examined, are the forms of governance at play within blockchain-based networks. A transition in the forms of governance enabled through and emerging from the decentralised structure of blockchain-based networks and social practices within them was identified. A transition from centralised forms of control and operation towards disintermediated and distributed governance mechanisms and power structures in blockchain-based networks was shown, further confirming the socio-technical character of decentralised blockchain-based networks.

The three core aspects investigated throughout this thesis were further contextualised and confirmed through investigating the implementation of decentralised blockchain-based networks in the context of energy markets. The ongoing transition of energy markets, presenting approaches towards implementing decentralised blockchain-based networks, has shown to provide fitting examples for the new forms of governance, an empowerment of users, and a shift in their identities from being focused on self-consumption, towards being enabled to strive for becoming self-sufficient.

Theoretical framework

Through combining the three core aspects of this thesis with the analysis of two empirical cases, a theoretical framework for understanding the constitution, development and implementation of decentralised blockchain-based networks in complex contexts of society, such as electricity markets, was presented. This framework enables to recognise the ways in which forms of governance within such networks are created and transitioning along the development and reconstitution of the network, further providing the essential, as well as intriguing insights for the analysis of how decentralised blockchain-based systems itself are governed with regards to the contexts in which they are implemented.

By providing insights on decentralised blockchain-based networks extending from explaining their underlying technological structure to their implementation as decentralised platforms in specific market structures, this thesis combined accounts from the existing scientific literature on cryptocurrencies, blockchain technology and decentralised networks, and expanded the scientific discourse in these fields. The presented framework for understanding the internal forms of governance and the transformation of them overcomes the limitations of individual approaches, either not addressing and acknowledging these notions in their approaches towards implementing such networks, or merely focusing on selected aspects of decentralised blockchain-based networks. Building upon this framework appears to be essential for understanding the ongoing transformation of energy markets, where such networks are being conceptualised or already implemented, and provides the ground for conducting extended future research, investigating how the development and implementation of such networks is regulated and addressed in current governance approaches.

A conceptual shift from perceiving the character of blockchain technology as fundamentally unsustainable towards using this technology as the underlying structure of networks aimed at achieving higher degrees of sustainability in the markets they are implemented in, was shown. Increasing investments for higher computational power and a notion of resource-intensive competitiveness among network participants have transitioned towards forms of cooperation and incentives towards locally generating and consuming energy from renewable energy sources. This transition was further confirmed through the analysis of selected cases on energy markets. Building upon these insights, investigating the sustainability of decentralised blockchain-based networks in the context of energy markets and how the conceptualised degrees of sustainability are being realised in practice, is an important aspect to examine in further research. Additionally, analysing the ways in which the environmental impacts of such networks are addressed, how dominantly they are represented in the public and academic discourse, appears to be closely related to the forms of governance of them, thus constituting an intriguing topic of future research.

Investigating current approaches towards governing systems that are characterised by a decentralised structure, and evaluating how governing authorities are trying to influence, control, or steer the development of such systems in future research, will provide new insights to the fields of governance studies and public administration. Understanding the ways in which governing entities are addressing and presenting societal and environmental implications of such networks, as well as legitimising their influence in such ongoing transitions of markets, is essential for this endeavour. Furthermore, expanding the here presented internal governance perspective on decentralised blockchain-based networks is essential for understanding the ongoing transition of energy markets. This can be done by analysing the arising tension between established centralised infrastructures and novel, emerging decentralised approaches and the market contexts they are implemented in.

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