Adoption of Blockchain in European Electricity Markets

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The following sections are partly comprised of content taken from the research papers embedded in this thesis. To improve the readability of the text, I omit the standard labeling of these citations.

Abstract

Blockchain has evolved from being a hyped technology to a promising building block for the digital transformation of entire industries. By enabling the rethinking of products and processes, blockchain is considered particularly interesting in industries that are already undergoing profound change. One prominent example being European electricity markets, which are transitioning from centralized fossil power to decentralized renewable energy sources. Blockchain technology, which has become fashionable IT since the rise of cryptocurrencies, promises to provide some essential building blocks for this transition. Due to intriguing narratives embedded in blockchain, such as decentralization, disintermediation and trust, numerous pilot projects have been conducted to explore potential use cases, yet few have succeeded. To understand the underlying reasons and foster the digitalization of the energy transition within Europe, it is crucial to identify relevant use cases, substantiate benefits and challenges, and understand the adoption cycles of using blockchain within energy utilities. A thorough understanding of these three areas within the information systems community is greatly needed to navigate blockchain hype narratives and allow its practical use within organizations. This thesis includes five research papers addressing the according research need by first identifying, categorizing and evaluating use cases and subsequently deriving and evaluating benefits and challenges in terms of their substantive depth. Finally, learnings from the adoption of blockchain in European energy utilities regarding the political, technological and cultural alignment of its narratives with organizational practices are presented. This thesis aims to enhance the understanding of drivers for the adoption of blockchain and blockchain-enabled practices in European electricity markets from an information systems research perspective.

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1 Introduction

1.1 Motivation

Initiatives for climate protection, national sustainability efforts, increased environmental public awareness and the decarbonization of electricity generation are driving a fast-rising demand for digital technologies and concepts (Roth, Utz, et al., 2022; Shahbaz et al., 2022), and this demand is already being addressed by various legal regulations. In the Renewable Energy Communities defined by the European Union's Renewable Energy Directive, for instance, the use of measurement sensors and automated data flows are enabling resident consumers to generate, distribute and use energy generated within a community (Heaslip et al., 2016; Lowitzsch et al., 2020). Energy utilities are also pursuing efforts to enhance existing products, such as electricity tariffs, with certificates for Green Electricity Tariffs (GETs) to attract new customers with a higher level of environmental awareness (Diaz-Rainey & Ashton, 2011; MacPherson & Lange, 2013; Ozaki, 2011). Despite these efforts, however, some customers feel deceived, assuming either that the electricity is not as "green" as stated or that the price does not justify the quality (Mezger et al., 2020). Essentially, criticisms often concern "greenwashing" and trust between customers and energy suppliers. Lacking trust is a concern with not only GETs but also many sustainability and decarbonization efforts, as the large number of actors and complex data flows often lead to a lack of transparency, resulting in distrust. Blockchain technology promises solutions to address these issues in organizational, technological and cultural dimensions.

Blockchain networks are distributed, transnational databases that operate on "nodes" in a peer-to-peer approach (Beck et al., 2017; Rossi et al., 2019) and originated as the technological basis of the Bitcoin network (Nakamoto, 2008). Transactions executed by peers are aggregated into blocks and sequenced by the nodes using cryptographic methods and a consensus mechanism (Ahl et al., 2020; Roth, Utz, et al., 2022). Since each of the blocks has a reference to its predecessors, the retrospective manipulation of a block is easily detected by other nodes, making the network transparent, tamper-resistant and resilient to attacks (Esfahani, 2022). The integration of automation features, such as smart contracts and oracles — that is, interfaces to other IT systems and devices — has extended the use of blockchain technology, initially focused on financial transactions, to other industries (M. C. Lacity, 2018). Examples include the insurance industry (W. Zhang et al., 2021), retail (Bumblauskas et al., 2020) and logistics (Sarker et al., 2021). European electricity markets also already include numerous projects of varying scope, from research projects such as the use of blockchain for machine identities, to pilot projects such as blockchain-based emission certificates, to projects already more broadly implemented in corporate practice such as blockchain green power tariffs and peer-to-peer use cases (Research Paper 2). Yet many of these projects fail to scale and remain in the early product or prototype status. In part, this can be attributed to organizations that are engaging with blockchain due to its "fashionable" nature without being aware of the challenges of transferring it into productive and scalable applications.

Engaging with technologies that are currently "fashionable" is not a new phenomenon. One theory describing such engagement is that of "fashionable management practices," a term coined by Abrahamson (1991). It examines the reasons why some inefficient and impractical innovations have become significantly more widespread than more mature ones from a sociological point of view (Abrahamson, 1991, 1996; Ansari et al., 2010; Piazza & Abrahamson, 2020). Two perspectives can be distinguished: the "supply" and "demand" sides of fashionable management practices. The "supply" side represents the management narrative, which is provided by think tanks, management consultancies or business schools, and the "demand" side represents the organizations engaging with these very narratives (Abrahamson, 1991; Piazza & Abrahamson, 2020). The engagement itself can be divided into four phases.

During the first two phases, innovation and dissemination, organizations are confronted with management narratives by consulting firms (supply side), and initial attempts of interpretation occur. In this up-swing phase, the management narratives are mostly seen as positive and seldom questioned (Abrahamson & Fairchild, 1999). In the third phase, contagion, organizations try to embed the management narratives into processes and products (demand side) and achieve a fit between the political, technical and cultural dimensions and the management narrative (Ansari et al., 2010). In this context, political fit is the degree of alignment between the political narrative of the management practice and the strategic orientation of the organization. Technical fit describes the alignment between the technical narratives of the management practice and the technical infrastructure of the company. Finally, cultural fit concerns aligning the cultural value propositions contained in management practices and integrating them into corporate culture. In the fourth phase, abandonment or retention, the management practices are either discarded or finally embedded in the organization. This phase is often accompanied by a down-swing, which can occur when engagement with the management practice results in disillusionment regarding its actual capabilities and limitations. The choice whether to abandon or retain the management narrative depends on both the achieved level of its political, technical and cultural alignment to the adapting organization and its perception of the management practice during the down-swing phase (Abrahamson & Fairchild, 1999).

Similar to the study of management narratives in fashionable management practices, “fashionable IT” concerns the analysis of narratives of new technologies along political, technical and cultural dimensions (Baskerville & Myers, 2009; P. Wang, 2010; P. Wang & Ramiller, 2009). Again, up- and down-swing phases are cycled through, and organizations have incentives to engage with the narratives. These can be extrinsic (e.g., motivated by an organization’s innovative reputation as it engages with future technologies) or intrinsic (e.g., being motivated by higher potential profits due to the successful integration of fashionable IT narratives). However, engaging with fashionable IT by itself will merely create any added value for organizations. In fact, the effort required to create a political, technical and cultural fit may well be higher than the potential efficiency and effectiveness benefits that fashionable IT brings compared to established technologies (P. Wang & Ramiller, 2009). This also applies to the fashionable IT of blockchain.

1.2 Research Aim

To further decentralization and decarbonization initiatives in European electricity markets, the implementation of digital technologies is essential, and blockchain technology has the potential to make a considerable contribution to these efforts by solving organizational, technological and regulatory challenges. Information systems research has already approached this research topic from different perspectives. For instance, Akter et al. (2020) analyzed the coordination effort required to manage energy flows within a microgrid and the resulting organizational challenges with a focus on reducing them. Esmat et al. (2021) proposed a blockchain-based trading mechanism that balances information security, cost efficiency and transaction speed to address technological challenges associated with using blockchain. Mengelkamp, Schlund and Weinhardt (2019) designed a local energy market model considering organizational, technical and regulatory challenges and proposed possible improvements. Andoni et al. (2019) performed a comprehensive review of the challenges and benefits of blockchain technology in energy markets by analyzing 140 blockchain projects and academic literature. Building on this review, Choobineh et al. (2022) have taken their examination a step further by summarizing the challenges of blockchain applications into five categories through a systematic literature review and identifying four emerging trends that could facilitate the widespread adoption of blockchain technology. Despite extensive discussions on the potential benefits and challenges of blockchain technology in the energy domain, much of it remains theoretical. More research is needed to create a more thorough understanding of the specific benefits of blockchain technology in electricity markets. Following the research call of Liang et al. (2021) to investigate the benefits of using blockchain beyond the hype, the first objective of this paper is thus to provide an empirically substantiated overview of challenges and benefits in blockchain energy use cases. Second is the evaluation of these use cases, focusing on their practical feasibility, following the second research call of Liang et al. (2021) to provide the groundwork for real-world implementation and explore the possibilities of combining blockchain with other advanced technologies. Among others, this evaluation is influenced by Ante, Steinmetz and Fiedler (2021), who have already identified six use case categories based on a systematic literature review, and Di Silvestre et al. (2020), who considers use cases from a prosumer and peer-to-peer perspective and identifies potential trends for future energy systems. Furthermore, Hasankhani et al. (2021) and Hirsch, Parag and Guerrero (2018) explore various potential applications of blockchain in smart grids and microgrids, respectively. Thus, this thesis contributes to closing the gap described by M. C. Lacity (2018) between the technologically promised added value and the actual added value of blockchain in energy use cases.

Following the research call of Rossi et al. (2019), the third objective of this thesis is to substantiate the understanding of adoption processes of blockchain narratives in energy utilities and related use cases. Here, the basis is the analysis of the political, technical and cultural fit of blockchain narratives in the adopting organization. First, the political fit of blockchain, that is, the alignment between the values contained in blockchain narratives and the strategic direction of the organization, is evaluated. An example of a good political fit would be the blockchain narrative of disintermediation and the organizational willingness to diversify its product portfolio toward more personal responsibility by customers. Second, the technical fit of blockchain, that is, the match between the technical values of blockchain and the IT infrastructure of an organization, is evaluated. The blockchain narrative of trust and an IT infrastructure that is tamper-resistant against cyberattacks would be a good fit in this regard. Finally, the cultural fit is evaluated. The blockchain narrative of individual empowerment and an organizational commitment to involve customers in the development of new products at an early stage would be a good example. However, in all three forms of fit, successful technology adoption may require either aligning the blockchain narrative with an organization's political, technical or cultural objectives, or vice versa. With this approach, we build on Liang et al.'s (2021) call for IS research to understand what motivates organizations to adopt blockchain technology.

In summary, this thesis first substantiates the challenges and benefits of using blockchain in energy market use cases based on a multi-dimensional research methodology using quantitative and qualitative research methods, then elaborates on the role of blockchain in those cases, and finally explores the adoption of blockchain as a fashionable IT by the adaptation of its narratives. It thus offers researchers and practitioners insights into building blockchain use cases and suggests ways to adapt blockchain narratives to achieve political, technical and cultural fit. It also encourages policymakers to explore the combination of blockchain and other advanced technologies to accelerate the adoption of energy use cases.

1.3 Thesis Structure and Overview of Embedded Research Papers

This cumulative thesis includes five research papers addressing the adoption of blockchain technology in energy utilities within European electricity markets. Figure 1 depicts the embedded research papers and the structure of this thesis.

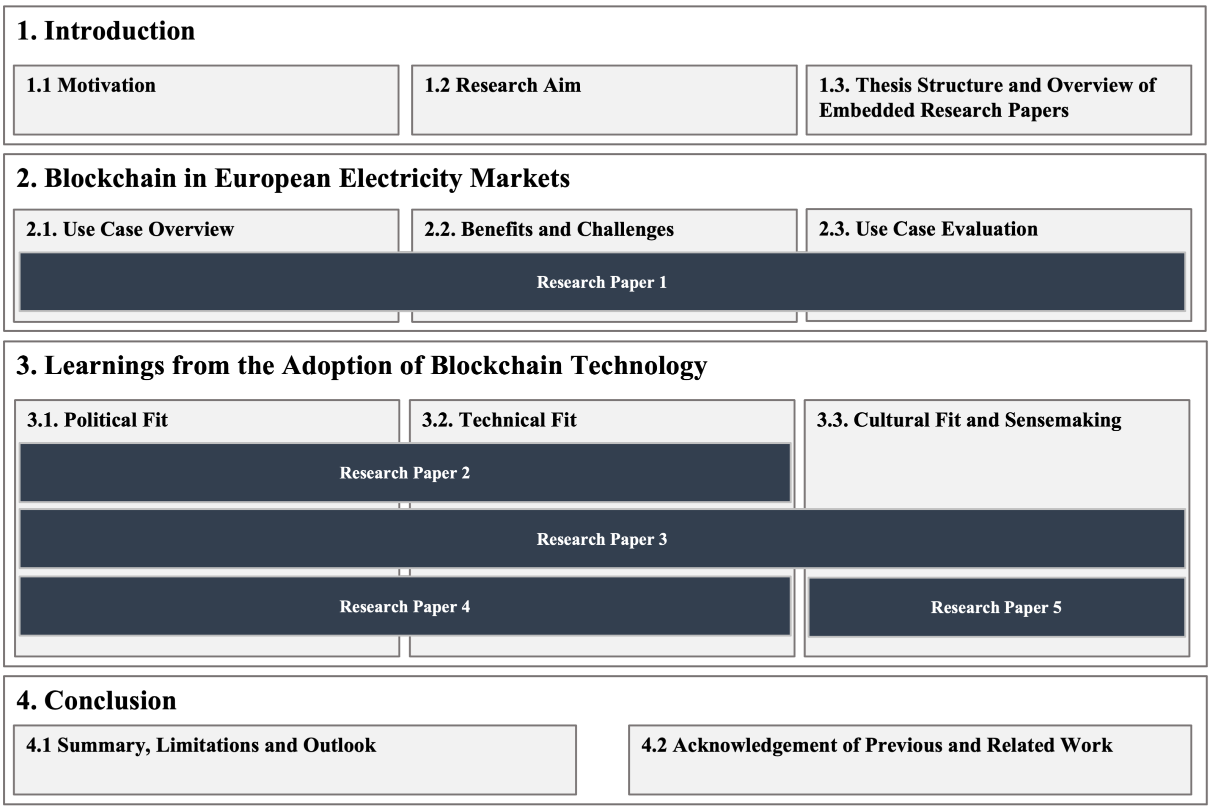

Figure 1: Structure of the doctoral thesis

The introduction has provided a motivation for the need for blockchain adoption research in energy use cases. The current transformation of European electricity markets and relevance of engaging with blockchain as a fashionable IT are described from the viewpoints of political, technical and cultural factors.

In Section 2, a substantiated overview of current blockchain applications in European electricity markets is first provided. Section 2.1 then discusses and categorizes blockchain-based energy use cases that have already been evaluated in academic literature. The benefits and challenges thereby identified are examined in Section 2.2. In Section 2.3, the gained insights are used to evaluate the categorized use cases regarding their feasibility in European electricity markets.

Section 3 addresses the learnings from the practical adoption of blockchain along the political, technical and cultural dimensions. First, the relevance of the fit between the political orientation of European electricity markets, the political blockchain narratives and the strategic orientation of organizations is analyzed (Section 3.1). Building hereon, the alignment between technical blockchain narratives and IT infrastructure of organizations is analyzed (Section 3.2). Finally, Section 3.3 describes the cultural fit between blockchain narratives and corporate cultures. This section also outlines approaches for the reduction of cultural dissonance, that is, differences between cultural blockchain narratives and corporate culture.

In Section 4, the results of this thesis are summarized, limitations are discussed, and an outlook for future research avenues is provided. Furthermore, previous and related work is acknowledged. Section 5 contains the references. Section 6 provides detailed information, such as the abstract and the contributions of each author to the research papers included in this thesis. The full texts of all five research papers are contained in the supplementary material (not intended for publication).

2 Blockchain in European Electricity Markets

The use of blockchain in European electricity markets is of interest from several perspectives. First, the profound changes in the electricity generation and distribution structure are changing the roles of energy actors. While the "unbundling" process aims at the elimination of vertically integrated energy utilities and the creation of a basis for innovation through market structures and competition (Alt & Wende, 2020), the current change is creating entirely new roles. Prosumers, who both generate and consume electricity through their own energy assets, are emerging, and with them, new challenges and opportunities (Diestelmeier, 2019). One such challenge is the high level of self-consumption by prosumers, which may lead to a higher level of grid charges being borne solely by consumers (Chen et al., 2023). One advantage, on the other hand, is that new business models and market structures such as smart grids and energy communities enable prosumers to trade their self-generated electricity and thus potentially increase the efficiency of market processes, contribute to the marketing of energy flexibilities and ease congestion in electricity grids (Dong et al., 2022; Hua et al., 2022; Umar et al., 2022). In these, blockchain has an enabling role due to narratives attributed to it, such as technologically embedded trust, disintermediation and decentralized data storage, which are seen as a suitable means to implement these new markets and structures (M. Lacity et al., 2019; Roth, Utz, et al., 2022; Utz et al., 2022). Within Europe, the number of real-world blockchain applications is already among the highest in the world (Q. Wang et al., 2021). However, as the European Union has one of the strictest data protection regulations in the world, the General Data Protection Regulation (GDPR), challenges regarding the adequacy of blockchain to manage these market changes still arise (Belen-Saglam et al., 2023; Rieger et al., 2019). For instance, in public blockchains, the right to delete data and identify actors within the network anchored in the GDPR is challenging to implement (Belen-Saglam et al., 2023). So, while the transformation of European electricity markets and blockchain narratives are conceptually well aligned, numerous challenges must be addressed during its adoption in organizations. In the following three subsections, an empirically substantiated overview of the most common blockchain applications in European electricity markets, followed by an analysis of the expected benefits and challenges, is presented. An evaluation of use case feasibility is subsequently performed.

2.1 Use Case Overview

With over 140 research and pilot projects, European electricity markets are a hotspot for blockchain use cases (Andoni et al., 2019; Ante et al., 2021). Their scope ranges from theoretical concepts and pilot applications to products already applied by customers. The systematic analysis of academic literature, industry studies and expert interviews described in Research Paper 1, based on the five-step approach proposed by Kitchenham (2004), led to the identification of the eight use case categories shown in Table 1. Relevant publications were first identified and then selected, quality assured and evaluated, before finally being aggregated and interpreted.

Use Case	Use Case Definition
Peer-to-peer electricity trading – retail	Processing of transactions in (local) electricity markets for small actors
Peer-to-peer electricity trading – wholesale	Processing of transactions in large commercial markets for electricity
Decentralized system services	Processing of transactions in markets for system services and flexibility
Microgrid operation	Balancing of demand and supply in microgrids, as well as processing of related transactions
E-roaming	Exchange of financial and identity-related data between charging point operators, e-mobility service providers, and e-mobility customers
Labeling of electricity	Tracing of feed-in levels for power generation and storage facilities, as well as processing of related energy purchase agreements
Certificate trading	Processing of clearing and settlement for certificates that provide proof of origin or emission from specific generation and storage facilities
Machine identities	Authentication and validation of identity-related documents that confirm identity attributes of e.g., power generation and storage units

Table 1: Commonly discussed blockchain use cases in European electricity markets.
Source: (Research Paper 1)

The most frequently discussed use case category in both academic literature and entrepreneurial practice is that of peer-to-peer applications. This is partly due to the blockchain narratives of disintermediation fitting well with the small-scale electricity production and distribution structure, and partly due to the blockchain narratives of empowerment of individual actors aligning well with the ideas of the future roles of prosumers in electricity markets (Research Paper 1, Research Paper 3 and Research Paper 4). The disintermediation and empowerment dimensions are analyzed from different perspectives, especially in peer-to-peer retail applications. In addition to creating market access, the automated settlement of small-scale transactions via smart contracts is a key factor considered here (Gu et al., 2018; Thomas et al., 2019). Indeed, smart contracts can be used in energy transactions and the automated control of hardware, such as smart homes and batteries, to represent predefined agreements between multiple actors in an enforceable and self-executing manner (Kirli et al., 2022). Different types of “tokens” also adopt a key role, as, for instance, native tokens can be used to incentivize a certain behavior, such as turning on a battery store (Andoni et al. 2019; Lo and Medda 2020; Research Paper 2; Research Paper 4). Furthermore, there are asset tokens that prove ownership of digital goods and thus enable the establishment of small-scale, cooperative structures of photovoltaic (PV) systems (Westerkamp, Victor, and Küpper 2020; Research Paper 4). The potential application range for smart contracts within peer-to-peer retail applications thus extends from the automation of individual multilateral contracts to the technological modeling of entire electricity market designs (Gourisetti et al., 2021).

In peer-to-peer wholesale applications, the primary focus is not enabling new actors but creating more efficient and secure ways of exchanging information between established actors (e.g., energy utilities and traders) through blockchain-based registries (Alt & Wende, 2020; Esmat et al., 2021; Hoess et al., 2022). In Germany, for instance, energy assets and their operators/owners must already be registered in the *Marktstammdatenregister* (market master data register) (Hampel, 2017) to provide the grid surveillance authority *Bundesnetzagentur* (Federal Network Agency) (Homann, 2021) with a detailed market overview. Continuously maintaining the data consistency and actuality of such registers as new actors and assets are entering and exiting the market might be facilitated by a blockchain-based alternative. Applying blockchain as a trustee service may also reduce the manual processing effort for over-the-counter transactions, that is, the trading of electricity directly between actors (such as energy utilities and automobile manufacturers) without involving the trading exchanges (Alt & Wende, 2020; Sousa et al., 2019).

The provision and management of distributed energy flexibilities, called decentralized system services, is the third area of peer-to-peer use cases. The investigated use cases expect the application of blockchain to enable new market assets, such as heat pumps, air conditioners and batteries, to be coordinated extensively and for manual effort (e.g., for billing) to be reduced (Esmat et al. 2021; Thomas et al. 2019; Tushar et al. 2021; Research Paper 1).

Microgrids are one of the more promising solutions for shaping the transition in European electricity markets, as they might merge generation and consumption at a small-scale level and reduce grid loads through smart management. (Fachrizal et al., 2021; Tsao & Thanh, 2021; van Leeuwen et al., 2020). Furthermore, in microgrid operation, blockchain narratives of trust are prominent, as blockchain networks could provide a trusted communication bridge between technical assets and markets (Wu et al., 2022). Device data (such as state of charge, power consumption, etc.) may be collected via interfaces, or "oracles," in blockchain networks, processed in smart contracts and transmitted by means of connection to standardized market communication protocols in a trustful way (Wu et al. 2022; Research Paper 1).

E-roaming applications address the still complicated and limited access to different charging networks for electric vehicles (EVs). Blockchain could be used to simplify the exchange of charging-related data between EV owners, charging station operators and roaming providers (Hoess et al., 2022; T. Zhang et al., 2018). Transparency and interoperability, as well as the automation of charging and billing processes via smart contracts, are the relevant blockchain narratives in this use case category (Hoess et al., 2022; T. Zhang et al., 2018).

The labeling of electricity is concerned with the differentiation of electricity regarding its origin from renewable or conventional energy sources (Perrons and Cosby 2020; Utz et al. 2022; Research Paper 1). Particularly in the case of small-scale energy assets and a demand for faster transactions, traceability is becoming increasingly difficult, which is expected to be improved by the "tagging" of electricity quantities and the subsequent billing via blockchain (Amend et al., 2021; Hoess et al., 2022; Luke et al., 2019).

Certificate trading as an extension of the labeling of electricity considers the clearing and settlement processes of emission certificates (Karakosta & Petropoulou, 2022). Here, blockchain is intended to be used as a digital trust anchor by storing data (such as asset type and emission volumes) in registers in a tamper-proof manner (Ahl et al., 2019; Diniz et al., 2021; Fernando et al., 2021). Similar to other sectors in which digital certificates are already used, such as for tracking the origin of diamonds in the diamond industry (Pu & Lam, 2023), they are on the rise in electricity markets, as the retroactive "greening" of purchased electricity quantities is still common, leading to increasing allegations of "greenwashing."

Using blockchain for machine identities is one of the most recent application areas in European electricity markets. The underlying idea is to represent the data of energy assets as machine-verifiable credentials within a blockchain network and authorize energy supply and withdrawal in different markets. This is of particular interest regarding the German *Doppelvermarktungsverbot* (ban on double marketing), which states that electricity may not be marketed twice (e.g., traded on an electricity exchange while simultaneously being made available to an industrial company via a bilateral contract) (Linnemann & Linnemann, 2021). By using machine identities, assets could participate in different markets at a higher rate instead of being assigned to only one market due to time-consuming manual processes.

2.2 Benefits and Challenges

The benefits and challenges analyzed in Research Paper 1 can be classified into the three categories, as displayed in Table 2. Efficiency describes the use of the blockchain either to achieve an increased output using the same human and technical resources or to reach the previous output using less resources. Effectiveness is understood as the development of new processes and products, as well as the inclusion of new market actors. Security concerns protecting established processes against cyberattacks and creating additional data transparency.

Efficiency	Effectiveness	Security
▪ Digitalization and automation of processes, services, and transactions ▪ Reduction of process, service, and transaction costs ▪ Flexibility of processes, services, and transactions	▪ Decentralization and disintermediation ▪ Autonomy from macrogrids ▪ Empowerment of small actors within energy communities ▪ Market flexibility ▪ Reduction of complexity	▪ Transparency ▪ Data security and data sovereignty ▪ Creation of trust through tamper-resistant data storage ▪ Resiliency and reliability

Table 2: Identified benefits of using blockchain in European electricity markets. Source: (Research Paper 1)

The research papers and projects examined in Research Paper 1 show that, irrespective of use case, the benefits mentioned can hardly be distinguished from each other and are rather generic. Effectiveness benefits essentially revolve around key blockchain narratives in the realm of disintermediation intended to open up energy industry processes such as electricity trading to new actors such as prosumers. However, this hoped-for benefit can neither be evaluated using established business techniques (business case calculations) nor proven in a broader economic sense (e.g., specific macroeconomic added value).

The organizational, technological and regulatory challenges presented in Table 3 are conversely quite different, as they are distinguishable with regard to respective applications and more specific. The relevant organizational challenges are those that arise due to restructuring and the elimination or introduction of processes and functions in organizations. Technological challenges focus on but are not limited to the integration of blockchain technology into established IT infrastructures. Finally, regulatory challenges describe potential conflicts between the roles and processes provided for by legislation and blockchain application in electricity markets.

Organizational	Technological	Regulatory
▪ Low market pressure and need for substantial investments ▪ Low stakeholder acceptance and usability ▪ Complex infrastructural and technological requirements to enable productive applications ▪ Unpredictable and hidden costs ▪ Unpredictable revenues ▪ High organizational complexity of distributed market structures ▪ Difficulties replacing critical, established, and mediating energy actors ▪ Vague market actor responsibilities ▪ Substantial efforts of automating and decentralizing governance ▪ High involvement and participation effort ▪ Difficulties maintaining social justice principles ▪ Difficulties encouraging behavioral change of consumers	▪ Volatility of transaction speed ▪ Lack of interoperability and technical standards ▪ Blockchain trilemma of decentralization, scalability, and security ▪ Complex and nontransparent data management ▪ Few plug-and-play hardware and software components ▪ Difficulties controlling data quality and quantity ▪ High programming effort ▪ Trade-off between privacy and efficiency	▪ Risk of data concentration ▪ Regulatory barriers ▪ Slow adaptation of current regulations ▪ Low investment security and incomplete, ambiguous legal frameworks ▪ Legally required market roles

Table 3: Identified challenges of using blockchain in European electricity markets.
Source: (Research Paper 1)

Disintermediation, which has already been identified and evaluated as an effectiveness benefit, can also be considered a major challenge, in that the establishment of decentralized structures eliminates roles and business units in organizations without considering the often substantial and quantifiable follow-up costs. Similarly, the relationship between efficiency benefits and technological challenges is quite imbalanced. Efficiency benefits arising from automation hopes stand in stark contrast to the associated technological challenges, such as the lack of interoperability and standards. This adds to the imbalance of benefits built on hope and specific challenges, as establishing a meaningful technological bridge between such system landscapes often entails a high development effort involving external service providers.

The empowerment of new actors through the use of peer-to-peer trading apps is another example of the two sides of the coin — the rather optimistic benefits and the actual challenges. Effectiveness benefits, which are built upon the blockchain narrative of empowerment, draw a promising picture of new actors being enabled to fully trade and bill self-generated electricity. However, the associated technological challenges include complex data management and a balance between the privacy and user-friendliness of applications. For instance, for privacy reasons, it is preferable to allow prosumers to handle private keys to their blockchain wallets. From a usability perspective, however, this private key handling is neither sensible nor feasible for the majority of users due to different levels of technological literacy.

The regulatory challenges revolve around two areas: the GDPR and energy market directives within the EU (Morstyn et al. 2018; Rieger et al. 2019; Research Paper 1). The requirements for storing and handling personal data described in the GDPR can be addressed with private blockchain networks — those in which access is only allowed to selected members, usually determined by a consortium (Rieger et al., 2019). However, when organizations collaborate and achieve potentially dominant market positions, competition law issues might arise. In the area of energy market regulation, the defined market roles (e.g., for peer-to-peer approaches) pose a major challenge. In these approaches, market players, such as distribution and transmission grid operators, which are responsible for ensuring grid stability, would have to assume other, more far-reaching roles, such as the real-time analysis of the feed-in of small PV systems, without having sufficient transparency, as grid measurement sensors remain rare (Faruqui et al., 2010; Zhou & Brown, 2017).

2.3 Use Case Evaluation

The objective of this section is to evaluate the clustered use cases using the benefits and challenges to assess their current success and estimate their feasibility for real-life, scalable implementation/use. In peer-to-peer retail applications, a variety of hypothetical benefits are met with substantial challenges. The promises of effectiveness derived from the disintermediation and decentralization blockchain narratives are met with myriad regulatory, technological and organizational challenges. One example illustrating this imbalance involves the legal competences of prosumers within electricity markets. Prosumers, which are often at the center of this use case category, are interpreted entirely differently per country within the European Union (Botelho et al., 2021; Inês et al., 2020). For instance, in Belgium, residents of a multi-apartment rental building cannot trade excess electricity generated from a PV system between each other, while Spain, Portugal, Germany and the Netherlands not only allow but also promote it (Inês et al., 2020). Incentives to participate in prosumer-centric business models also vary widely. While France, Germany, Italy and Croatia have feed-in tariffs and tax relief for the sale of self-generated electricity, Spain has no such incentive system (Inês et al., 2020). Therefore, peer-to-peer retail applications would have to be designed very differently for each electricity market within the European Union and would be met with different levels of acceptance. Furthermore, a potential threat to network stability remains an important factor. From a positive perspective, a high number of prosumers in peer-to-peer electricity trading networks could reduce the need for grid expansion (Maldet et al., 2022; Zafar et al., 2018). However, unilateral action by a single country that decides to remove regulatory hurdles and allow such trading opportunities on a broad scale could lead to failures in the tightly meshed European power grid (Fürsch et al., 2013; Maldet et al., 2022). From a technical point of view, the main challenges are again the availability of suitable hardware and software and the existence of standards for interfaces. These are being addressed in research and pilot projects, and attempts are being made to solve scaling problems in public blockchains by using side channels or private blockchains. At the same time, however, the expansion of smart meters in Europe is progressing slowly (Zhou & Brown, 2017). Therefore, the feasibility of peer-to-peer retail applications is foreseeably difficult due to the high organizational and technological challenges, as well as the fragmented and complex regulatory environment, and hoped-for benefits derived from blockchain narratives.

In peer-to-peer wholesale applications, blockchain networks are utilized to track transactions between energy traders and utilities. In contrast to retail applications, however, peer-to-peer wholesale use cases can often rely on established IT infrastructure, such as the trading interfaces of energy exchanges (Hassan et al., 2019; Lee, 2019). The disruptive approach of peer-to-peer wholesale use cases is substantially less intense than that of retail applications, as the intention is not to restructure entire market designs but rather to leverage the efficiency of existing processes. As the challenges can also be considered more addressable, the chances of success for short-term implementation in markets are higher.

This also applies to decentralized system services. While there are both efficiency and effectiveness benefits, such as the development of new energy flexibility markets and faster demand response services in existing markets, in practice, the focus is on efficiency gains through the aggregation of energy assets through platforms such as Equigy (Equigy 2023; Research Paper 1). Here, new market actors (e.g., prosumers) are enabled to market flexibilities such as stationary battery storage, heat pumps and EVs to distribution and transmission grid operators for demand response or balancing power services (Equigy, 2023). Thus, a higher degree of transparency of the energy assets and a potentially more efficient integration into existing market structures can be achieved. Increasingly decentralized electricity generation, established players such as aggregators and the adaptation of blockchain narratives to market constraints make decentralized system services feasible for near-term implementation. This feasibility is due in particular to the adaptation of blockchain to market conditions, which is discussed in more detail in Section 3. For instance, while prosumers in decentralized system services are extensively enabled as new market actors through the use of blockchain, the narrative of disintermediation must be heavily modified as aggregator platforms such as Equigy are utilized.

In microgrid operation, benefits revolve around efficiency gains through automated metering and billing. However, these expected benefits are not considered as having a substantial changing momentum in practice, since established technologies can already be used for secure transactions between many actors (Rodrigues & Garcia, 2023; Zia et al., 2019). In terms of regulation, no EU-wide regulation regarding the use of blockchain in microgrids exists, but different laws such as licensing and prequalification requirements for microgrid participants can be observed at state level, which complicates the rapid and widespread implementation of blockchain-based microgrids.

The evaluation of e-roaming applications is equally heterogeneous. While academic literature, industry reports and experts interviewed in Research Paper 1 expect a high degree of process automation in charging and billing processes through the use of smart contracts and tokens, implementations often fail due to the associated challenges. For instance, when using native tokens as a means of payment, strong price fluctuations occur frequently; when using self-developed tokens, e-roaming providers and customers involved quickly find themselves in a gray area of financial market regulation. Alleged efficiency benefits are currently often simply cannibalized by more user-friendly and available alternatives, such as credit cards or established online payment services. However, a combination of blockchain and self-sovereign identities (SSI), that is, an identity management system that digitally represents physical identity management systems using "verifiable credentials" (VCs), may lead to "decentralized e-roaming" applications (Hoess et al., 2022). Here, blockchain or tokens are intentionally not used as a means of payment, but the blockchain network is used as a trust layer to store the VCs (Hoess et al., 2022). Information about the issuing bodies of these VCs can also be stored in this layer, ensuring that only authorized charging station operators are able to invoice EV owners. Decentralized e-roaming is currently still at an early stage of research, yet it might be feasible and present security advantages over existing IT architectures for e-roaming.

In labeling of electricity and certificate trading, a growing but still manageable regulatory framework is met with a strong increase in social perception and demands to mitigate greenwashing in organizations (Mateo-Márquez et al., 2022; Research Paper 1). Thus, the need for transparent and tamper-resistant green power and emission certificates is high (Babel et al., 2022; Müller et al., 2023). In both areas, initial pilot applications, such as Smart Energy Communities (SMECS) (FraunhoferIAO, 2022) for green power labels and Carbonfuture as a platform for "carbon removal credits" (Carbonfuture, 2023), thus already exist. As in decentralized e-roaming applications, here too, blockchain is used predominantly in the form of a trust layer in which data of the emission issuing entities is stored. The issuance and distribution of the certificates is conducted via smart contracts (Research Paper 1). The high degree of transparency and unequivocal ownership history therefore make certificate trading use cases promising. However, technical standards and the associated cross-border interoperability are still lacking, which is why scaling within the EU cannot be expected in the short term.

The hoped-for benefits of the currently hyped machine identities applications sound promising. New, more effective ways of exchanging data between energy assets ought to be achieved by autonomously transferring relevant data and storing it for interested stakeholders. Also, the more efficient identification and authentication of such assets for participation in different electricity markets can be enabled. Moreover, decentralized data storage is expected to mitigate the risks of potential identity theft through cyberattacks. However, due to the lack of an adequate number of practical applications, which are still in the early development phase, the expected benefits have not yet been proven in practice. The potential for combination with other promising technologies such as SSI is nonetheless high and currently being investigated by numerous projects, most of which are still in the concept phase, such as the Blockchain Machine Identity Ledger (Babel et al., 2023).

Overall, the hype surrounding blockchain as a disruptive technology for electricity markets has failed to materialize in practice to date. Expected benefits from blockchain use are often no more than hopes derived from its technology narratives. In contrast, specific and often quantifiable challenges have been identified. This imbalance of benefits and challenges is particularly evident in peer-to-peer applications. Here, the many benefits incorporated in blockchain narratives are offset by high organizational, technological and regulatory challenges in real-world conditions. These use cases also contain a high disruption potential for existing electricity markets, which would necessitate a profound and widespread transformation of generation, distribution and consumption structures. Therefore, peer-to-peer use cases will foreseeably be very difficult to implement in a scalable manner. A similar picture emerges for microgrids. Here, the heterogeneous legislation regarding the role of prosumers in EU member states is a barrier to scalable applications. Therefore, the use of blockchain will not be a game-changer here either but will instead find application in niches. Applications in less regulated areas that do not require the disruption of entire markets can be implemented much faster. For instance, blockchain can indeed be used as a trust layer in the labeling of electricity and certificate trading. And blockchain-based interaction between energy assets in machine identities or charging stations and EVs in e-roaming applications is also certainly feasible in the near future. However, here too, blockchain is only one building block among many, such as SSI and VCs. The blockchain can thus certainly make a contribution to the transformation of electricity markets in Europe, but it will be more limited than was anticipated during the initial hype phase.

3 Learnings from the Adoption of Blockchain Technology

Blockchain adoption, or the integration of blockchain technology into all areas of organizations, is still in full swing. Since 2017, when smart contracts made process automation increasingly feasible, blockchain became fashionable IT not only in the field of cryptocurrencies (M. Lacity et al., 2019; Rossi et al., 2019; Research Paper 5). Intrigued by the capabilities of this fashionable IT and driven by decentralization and digitization trends in electricity markets, utilities have since been examining blockchain narratives. Blockchain as an enabler of decentralized processes or as a means of disintermediation, as well as many other narratives, emerged. However, these narratives cannot be adopted in an organizational context in a one-to-one manner. Rather, a fit between narratives and the strategic orientation of the organization (political fit), the existing IT infrastructure (technical fit) and the cultural mindset (cultural fit) is required. The learnings drawn from Research Papers 2–5 regarding the adoption of blockchain as fashionable IT are described in the following three subsections.

3.1 Political Fit

The political fit between EU energy policies, blockchain narratives and the strategic orientation of companies, is the first important factor in the adoption of blockchain as fashionable IT (Research Paper 5). In the EU, the political will or commitment to use blockchain in different markets is described in the “blockchain strategy” of the EU Commission (European Commission, 2023a). For instance, the European Blockchain Services Infrastructure (EBSI) has intended to enable blockchain-based data exchange between public authorities since 2021 (European Commission, 2023d). Furthermore, the legal framework for crypto-assets is intended to be created through the Regulation of Markets in Crypto-assets, and Amending Directive (MiCA for short), agreed between the European Commission and Parliament and the EU Council (European Commission, 2020). Here, crypto-assets are understood to be the “digital representation of value or rights which may be transferred and stored electronically, using distributed ledger technology or similar technology” (European Commission, 2020). The final version of the directive has been available to the EU Parliament for decision since October 2022. In addition to the creation of IT infrastructure and legal certainty, the focus is on improved interoperability. Therefore, organizations and research institutions intend to work together in the International Association of Trusted Blockchain Applications on the development of standards, such as the ISO/TC 307 for Blockchain and distributed ledger technologies (INATBA, 2023; International Organization for Standardization, 2023). In addition to creating a binding EU-wide legal framework, the EU Commission also provides research funding. Between 2016 and 2019, around €180 million were made available in the Horizon 2020 program to fund innovative projects that conduct research on blockchain and artificial intelligence applications (European Commission, 2023e). Between 2021 and 2027, the Digital Europe Programme (DIGITAL) intends to provide around €580 million in strategic funding for further research in the field of digital technologies and the development of qualified digital experts (European Commission, 2023f). The European Blockchain Observatory and Forum, funded by the European Parliament, has set itself the goal of identifying and monitoring blockchain initiatives in the EU (European Commission, 2023c). Moreover, the EU's "Digitalisation of the Energy System" action plan (European Commission, 2023b), published by the EU Commission at the end of 2022, aims to promote the "[...] interoperability and seamless exchange of data between different actors while respecting privacy and data protection," the "empower[ing] [of] consumers [...] to benefit from new ways to engage in the energy transition" and the "[…] energy consumption of digital technologies and promote greater efficiency […]" (European Commission, 2023b).

The described establishment of a legal framework, funds and initiatives strongly addresses the blockchain narratives of interoperability, security, transparency and empowerment, indicating a fit between the EU's policy goals and blockchain narratives. Furthermore, energy utilities are also increasingly aligning their business models with those policy goals (e.g., by transforming themselves into "Green Energy Utilit[ies]" or "Prosumer Facilitator[s]") (Bryant et al., 2018). Established structures, such as the generation, distribution and trading of energy, which has been in place for decades, are being cannibalized to some extent (Hall & Roelich, 2016; Richter, 2012, 2013). The perception of utilities as organizations reliably providing energy is giving way to that of solution providers for energy services and platform operators (Zarakas, 2017; Research Paper 3; Research Paper 4; Research Paper 5), which in turn strongly resonates with the aforementioned blockchain narratives. Thus, energy policy goals, blockchain narratives and the strategic orientation of organizations are considered to be aligned. This alignment, coupled with the commitment of numerous organizations to engage with blockchain due to its fashionable IT character, has led and continues to lead to pilot projects – and in these, the achievement of a technical fit is often seen as a key challenge.

3.2 Technical Fit

Technical fit between an organization's IT infrastructure and technological blockchain narratives is an important factor in progressing from conceptual considerations to initial prototypes (Research Paper 3; Research Paper 5). Among the dominant technical blockchain narratives is that of an inherently trust-less technology (Da Xu & Viriyasitavat, 2019; Gorkhali et al., 2020; Research Paper 3). According to De Filippi et al. (2020), blockchain shifts trust in humans to trust in mathematics. This understanding is seen as a basic assumption in many use cases, without, however, elaborating what types of trust exist, for instance, in the relationship between customers and energy utilities, or how those trust types are changed when using blockchain (Research Paper 3). Based on a blockchain-based customer loyalty program of an energy utility designed and implemented in Research Paper 3, both the trust dimensions and challenges for establishing a technical fit can be evaluated.

First, customer trust is an important prerequisite for customer loyalty (Chu et al., 2012; Stathopoulou & Balabanis, 2016). Customers believe that organizations have an interest in a long-term contractual relationship without being able to initially prove this through control mechanisms (Dietz & Gillespie, 2011; van der Werff et al., 2019). When switching from gray to green electricity tariffs, it is this type of trust in utilities that they will deliver on their promises to supply green electricity (Hartmann & Apaolaza Ibáñez, 2007; Rosell & Ibáñez, 2006). This institution-based trust comprises the three dimensions of calculation-, cognition- and knowledge-based trust (Cheng et al., 2021; D Harrison McKnight et al., 2017).

The calculation-based trust that customers have in energy utilities is based on their assumed integrity (Bilgic et al., 2019; Moody et al., 2017). Utilities are perceived as competent and reliable through their public actions or adherence to the contractual agreements of their electricity tariffs (Ibrahim & Ribbers, 2009; Muzahid & Noorjahan, 2009). Building on this presumption of integrity, customers take what they perceive as a "calculated risk" (Bilgic et al., 2019, p.4) by trusting the energy utility. The second trust dimension, that of cognition-based trust, builds hereon. The more information that can be gathered about the energy utility's competence and integrity, the more trustworthy it becomes. Thus, while a certain amount of trust is granted in the case of calculation-based trust, this is ideally reinforced by cognition-based trust, relying on facts, such as the construction of a wind farm to keep the promise of green electricity. Finally, knowledge-based trust builds on customers' own experiences through a long-term contractual relationship with their energy utility (Moody et al., 2017). Yet in this relationship, not only are factors such as proven competence and integrity important, but also those of benevolence (Moody et al., 2017). Customers positively assume that the organizations will comply with the contractual agreements and will not actively try to deceive customers (Moody et al., 2017). Increasingly, however, energy utilities are confronted with the accusation of "greenwashing," in that they do not participate, or do not participate sufficiently, in the construction of new wind and solar power plants but only "green" their electricity generated in conventional power plants through certificates. Thereby, ambivalence is created in the formation of all three described forms of institution-based trust (Jarvenpaa & Majchrzak, 2010; Moody et al., 2014). As a consequence, distrust may arise due to a "lack of confidence in the other, a concern that may act as to harm one [...] not [caring] about one's welfare [...]" (Govier, 1994, p. 240). Thus, the three factors of building trust — integrity, competence and benevolence – are complemented with their negative counterparts of distrust — deceit, incompetence and malevolence (D. H. McKnight & Choudhury, 2006; D Harrison McKnight et al., 2017; Moody et al., 2013).

If customers perceive an energy utility as dishonest (e.g., due to the suspicion of greenwashing electricity), the feeling of possible fraud quickly arises. As a result, customers more closely examine whether the utilities' value proposition is being kept. In the case of green electricity, this would entail that one's own consumption capacity can be completely covered by renewable generation capacities. Failure to do so results in vigilance-based distrust (Harrison McKnight & Chervany, 2001; Kramer, 1999). Here, the energy utility need not necessarily have bad intentions or intend to harm customers. Often, the origin of vigilance-based distrust can also be traced back to differing levels of knowledge of the actors. While energy utilities perceive the subsequent "greening" of conventionally generated electricity as acceptable and legally correct, customers often perceive this as an inability to generate and deliver actual green electricity (D Harrison McKnight et al., 2017). This presumption of incompetence leads to the build-up of skepticism-based distrust (Harrison McKnight & Chervany, 2001; Kramer, 1999). Here, customers seek tangible examples to get to the root of what is perceived as deliberate and fraudulent greenwashing. Finally, control-based distrust ensues, in which customers check all available facts and obtain opinions from third parties, as they suspect a malevolent intention of the energy utility (Harrison McKnight & Chervany, 2001; Kramer, 1999).

In a long-standing, trusting customer relationship, the actions of an organization, such as attempts to be more sustainable or "greener," can thus lead to ambivalence in the customer's perception, eventually threatening to trigger the spiral of mistrust. If tipping points are crossed, even long-standing customers cannot be retained. Therefore, it is important for organizations such as energy utilities to not only prevent institution-based distrust from arising in the first place but also try to strengthen institution-based trust and thus customer loyalty as depicted in Figure 2 (Cheng et al., 2021; D Harrison McKnight et al., 2017; Moody et al., 2014; Olsen et al., 2005). Here, blockchain steps in as part of the loyalty program described in Research Paper 3.

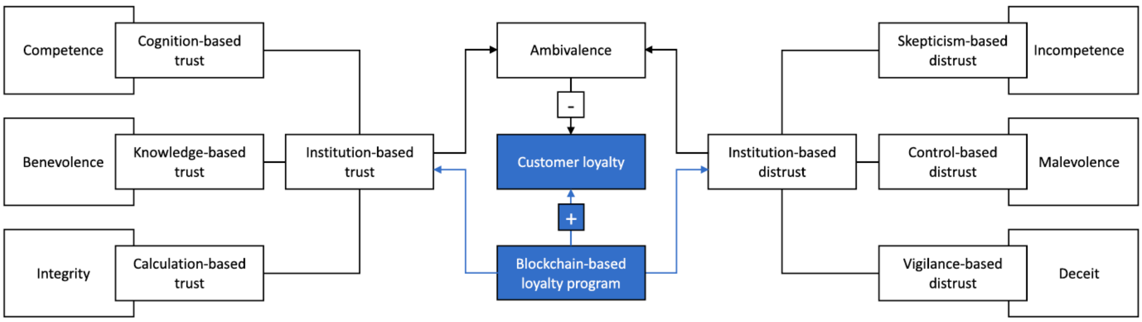

Figure 2: Overview of positive effects of a blockchain-based loyalty program on trust, distrust and ambivalence. Source: (Research Paper 3)

The blockchain-based loyalty program Nexo Energy, developed at a German energy utility using design science research methodology (Peffers et al., 2012), enables customers to consume electricity when it is particularly green. From an IT architecture perspective, three layers had to be developed. The data source layer provides generation and consumption data from sources such as renewable electricity indexes and electricity consumption meters installed in customers' households. The logic components of Nexo Energy are embedded in the data processing layer. Customizable rules are applied to the data transferred from the data source to the data processing layer (e.g., switching on lights if the share of green electricity within the power grid is above 50%). In the third layer, the trust layer, not only is relevant data from the two other layers recorded in a blockchain network, but "bonus points" are also minted and emitted as tokens using two smart contracts. These tokens are consequently distributed to the respective customer blockchain wallets. The design of these smart contracts is based on the Ethereum-based smart contract ecosystem developed in Research Paper 2. While Research Paper 2 focuses on the technical feasibility of using smart contracts for energy market processes such as metering, settlement and clearing, Research

Paper 3 evaluates the technical characteristics of immutability and selective transparency of the Ethereum blockchain network to achieve trust in the generated and stored data. Since large portions of the data source and processing layer are also stored in the trust layer, retroactive manipulation by an energy utility is technologically difficult to implement and easily detected by customers. In addition to the design of tokens to represent energy management processes (Research Paper 2) and the distribution of tokens as a reward for shifting electrical consumption (Research Paper 3), the ownership of energy assets can also be represented with such tokens. For instance, in the Prosumer Asset Ownership System developed in Research Paper 4, the logic for reading data from meters and subsequent billing initially developed in Research Paper 2 is applied in a "billing contract" as presented in Figure 3.

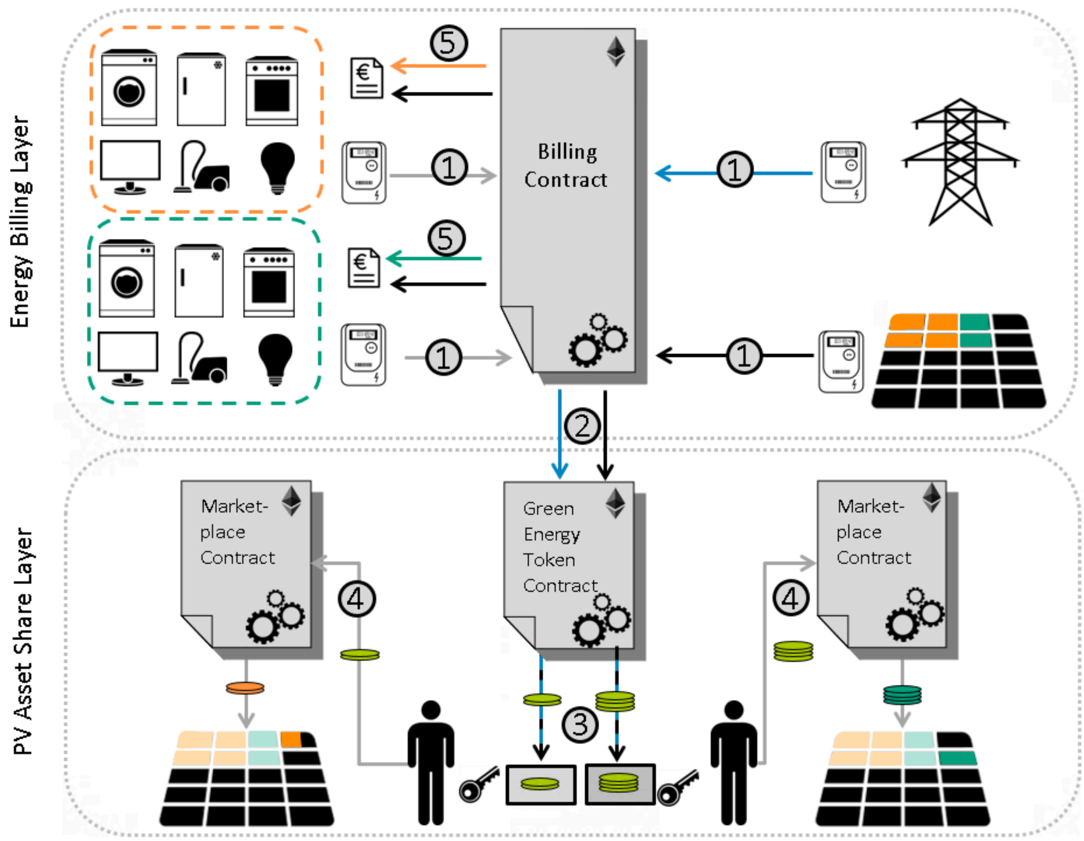

Figure 3: Structure of Prosumer Asset Ownership System. Source: (Research Paper 4)

Data from this billing contract is applied to distribute bonus tokens for a high proportion of green electricity in the Green Energy Token Contract, similar to a smart contract designed in Research Paper 3, to reward customers for more sustainable consumption. These tokens can then be exchanged for shares in energy assets such as PV systems using the Marketplace

Contract. At future consumption, the electricity generated from the token-based share of the PV system is free of charge for the customer. Thus, the more the customers' consumption behavior aligns with the generation curve of the PV system, the more bonus tokens can be collected and redeemed for system shares by customers and the less balancing energy is required by energy utilities. Accordingly, the system can be economically profitable for both customers and energy utilities within Renewable Energy Communities (Research Paper 4).

However, applying smart contracts and trust layers, which are driven by blockchain narratives of technological trust, to energy market processes and integrating those into existing enterprise IT infrastructures requires a high degree of two-way technological customization. First by adaptation of technological narratives to the existing IT infrastructure. In Nexo Energy's case, the implementation of the process logic in a completely decentralized manner using smart contracts within the blockchain network was initially planned to demonstrate maximum transparency to customers while ensuring the highest level of security against tampering. Due to non-standardized interfaces and complex data management structures between the blockchain network and the existing IT infrastructure, however, the logic was instead implemented in a processing layer in the energy utility's data center. Second by adaptation of the organization's IT infrastructure to the technological blockchain narrative. At Nexo Energy, this adaptation path was implemented by storing all data in the decentralized trust layer in addition to the processing layer. Thus, a fit between technological blockchain narrative and IT infrastructure can indeed be achieved. However, to turn a pilot application into a feasible product and embed its related product values into organizations, an alignment between blockchain narratives and corporate culture is crucial.

3.3 Cultural Fit and Sensemaking

The cultural fit between blockchain narratives and corporate culture is currently both the least scientifically studied form of fit in the context of fashionable IT and the one that is most difficult to achieve (Research Paper 5). The stark contrast between blockchain narratives, which are often perceived as highly disruptive, and a long-established, rather static corporate culture often leads to cultural dissonance. Reducing this dissonance requires an organization's intensive engagement with the use of blockchain. As depicted in Figure 4 the cultural sensemaking process that follows this engagement can then be achieved either through narratives being adapted to the corporate culture or corporate culture being transformed in the direction of the narratives through an iterative process (Research Paper 5).

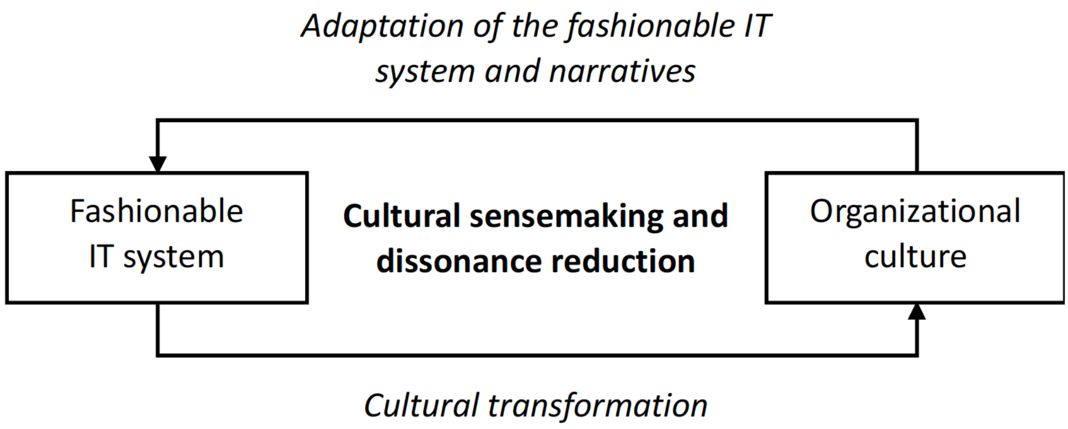

Figure 4: A tentative model of cultural sensemaking and dissonance reduction for fashionable IT. Source: (Research Paper 5)

The question of which of the two paths, the adaptation of fashionable IT narratives or cultural transformation, should be taken cannot be answered universally. Nexo Energy can be used as an example to determine the components of both paths and the fundamental importance of cultural fit for the successful adoption of blockchain projects in organizations.

The process of cultural transformation in Nexo Energy began with the cooperation narrative. Although the energy utility's departments had already worked together in various projects, Nexo Energy broke up the more formal structures of cooperation. Due to the complexity and novelty of blockchain, a common understanding of its diverse range of application had to be developed. Everyone involved in the project had to be brought up to a similar technological level, which was not feasible with the previous form of formal collaboration based on specific performance requirements. The corporate culture of the energy utility was thus transformed by Nexo Energy into a more informal collaboration between departments.

The second narrative that transformed the corporate culture was that of empowerment and customer agency. Before Nexo Energy, the product development process was conducted internally and without extensively engaging customers. Product functions were optimized for simplicity of use to not overwhelm customers with complexity. The iterative product development process at Nexo Energy, which involved multiple customers at an early stage, transformed the corporate culture in two ways: first, through the realization that customers can not only deal with complex products but even actively demand to do so. For instance, when storing bonus tokens in the blockchain wallets mentioned in Section 3.2, customers expressed the desire to be able to actively manage those tokens themselves, despite the technical complexity. Secondly, customers were included in product development processes to identify their actual needs at an early stage.

The third narrative focused on the data sovereignty made possible by blockchain. Through the rules embedded in the blockchain networks source code, read and write rights of transactions can be precisely defined within the network, even if the data storage is decentralized. Through Nexo Energy, this concept of data sovereignty and control was also implemented at the energy utility for new product development. It replaced the physical control of data, such as storing data in one's own data center.

The fourth corporate culture-transforming narrative is that of the community. Contrary to the cooperation narrative, the focus here is not on internal collaboration but rather on the inclusion of a large number of external stakeholders in the product development process. The involvement began with the recruiting of external developers, designers and IT-savvy students. Inspired by the community narrative, the energy utility participated in university hackathons and presented internal challenges intended to be solved in this context. Further event participations followed, for instance, Coding Nights. The strong interaction with and building of communities has changed the product development projects and respective corporate culture of the energy utility sustainably.

Overall, when adopting blockchain technology in organizations, dissonances can emerge due to differences in values between blockchain narratives and organizational culture. Resolving these cultural dissonances can be achieved by employing two approaches – either by aligning the blockchain narratives with the organizational culture or by changing the corporate culture to align with the narratives. Dissonance reduction and enhanced cultural sensemaking can thus drive IT project success and create transformative cultural change.

4 Conclusion

4.1 Summary, Limitations and Outlook

Digitalization and decentralization in European electricity markets are advancing rapidly. By reducing interaction complexity and communication costs, digital technologies enable the systematic integration of new electricity market actors and assets into such markets. Blockchain has gained popularity in recent years due to its associated narratives of decentralization, disintermediation and trust, which fit well with the changing needs of electricity markets. To be seen as innovative or to avoid being left behind in an important technological trend, many organizations are exploring potential uses for blockchain. Hence, myriad use cases of varying maturity have already emerged.

Despite the hype, however, blockchain has failed to gain widespread adoption in European electricity markets. This is due to several factors, including a mismatch between its benefits in terms of efficiency, effectiveness and security, which are often merely aspirational, and the more specific organizational, technological and regulatory challenges. Accordingly, it is difficult to calculate viable business models and adopt blockchain in the development of scalable products. Furthermore, political, technical and cultural alignment with the fashionable blockchain narrative varies across organizations.

The political and technical fit between blockchain narratives and corporate strategies as well as IT infrastructure in energy industry use cases is already in place (Research Papers 3–5); establishing a cultural fit, however, remains challenging. Here, promising narratives, some of which are perceived as disruptive, clash with long-established corporate cultures. Organizational engagement with blockchain thus also often leads to cultural dissonance. Reducing this dissonance can be achieved by adapting blockchain narratives to corporate cultures, or vice versa.

This thesis comprises five research papers that address blockchain adoption in energy utilities in European electricity markets. In the introduction, the current state of blockchain use cases and its adoption as fashionable IT in organizations has been described along its political, technical and cultural dimensions. Section 2 has identified, clustered and evaluated blockchain use cases and resulting benefits as well as challenges in European electricity markets. In Section 3, learnings from the adoption of blockchain in energy utilities have been presented.

This thesis contributes to information systems research on the adoption of blockchain technology in energy utilities by highlighting learnings from the implementation of blockchain use cases in organizations in terms of their political, technological, and cultural dimension. The benefits expected from blockchain in these use cases are often merely more than hopes, which face specific and hard-to-tackle challenges that hinder the transition from pilot projects to scalable applications. This thesis also provides insights into how blockchain itself is not sufficient to drive momentum for new products or processes in the electricity markets and should instead be combined with other advanced technologies. Furthermore, this thesis explores the factors influencing the organizational adoption of blockchain as well as possibilities for how a fit between the political, technical and cultural dimensions of blockchain narratives and corporate strategy, IT infrastructure and culture can be achieved. Thereby, it contributes to a more profound understanding of the barriers and enablers for the successful adoption of blockchain in energy utilities.

It is important to note that this thesis has limitations and is not able to fully examine all of the factors influencing the adoption of blockchain in European electricity markets. First, technology based on blockchain (e.g., for the encryption of data) is developing rapidly, making related technological challenges more addressable. Second, the analysis of the political, technical and cultural fit of blockchain as fashionable IT is based on two case studies, which may not provide a complete understanding of alignment processes.

This thesis and the embedded research papers provide many avenues for further IS research. For instance, the identified promising use cases of e-roaming and machine identities should be further substantiated using quantitative research methods. Focus could be placed on the interaction between blockchain and SSI, such as in settling charging transactions. The role of blockchain in dynamic electricity tariffs could be quantified regarding the amount of energy that might be shifted in accordance with renewable energy generation. Using blockchain in a customer loyalty program to increase institutional trust and reduce institutional distrust might further be explored in terms of the complex interplay of trust and distrust factors in customer-organization relationships. Moreover, further research might examine measures such as regulatory sandboxes and their influence on the use of blockchain in energy communities. As the cultural fit and sensemaking model presented in this thesis are currently only tentative, further qualitative and quantitative investigations are necessary to detail and possibly extend the model, thereby advancing the IS discourse on the adoption of fashionable IT.

4.2 Acknowledgment of Previous and Related Work

For all research papers embedded in this thesis, I collaborated with colleagues from the Research Center Finance & Information Management (FIM), the University of Bayreuth, the Department of Smart Grids, Fraunhofer Institute for Solar Energy Systems and the Interdisciplinary Centre for Security, Reliability and Trust at the University of Luxembourg. The following presents the way in which the five research papers included in this thesis are built on previous and related papers.

First, the papers by Strüker et al. (2019), Körner et al. (2022), Babel et al. (2022), Hoess et al. (2022), Rieger et al. (2019), Sedlmeir, Smethurst, et al. (2021), Sedlmeir, Völter, et al. (2021), Sedlmeir et al. (2022) and Andoni et al. (2019) have strongly influenced not only the research gap but also the analyses and evaluations of Research Paper 1. Research Paper 2 builds on Fridgen et al. (2018), Albrecht et al. (2018) and Risius and Spohrer (2017). Research Paper 3 extends the work of Sedlmeir et al. (2022) and Roth, Stohr, et al. (2022). Research Paper 4 builds on the work of (Surmann et al., 2020). Finally, the analysis of cultural fit in the organizational adoption of blockchain technology as fashionable IT builds on Roth, Utz, et al. (2022) and Utz et al. (2022).

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6 Appendix

6.1 Research Papers Included in This Thesis

The supplement contains papers 1–5. Please note that for the sake of layout consistency, the formatting may differ from that of the published papers. Each paper has its own reference section; figures, tables and footnotes are numbered separately where appropriate.

Research Paper 1

Roth, T., Utz, M., Baumgarte, F., Rieger, A., Sedlmeir, J., & Strüker, J. (2022). Electricity powered by blockchain: A review with a European perspective. Applied Energy, 325, 119799.

DOI: 10.1016/j.apenergy.2022.119799

VHB Jourqual 3: NA, SNIP 2021: 2.652, SJR 2021: 3.062, CiteScore 2021: 20.4

Research Paper 2

Utz, M., Albrecht, S., Zoerner, T., Strüker, J. (2019). Blockchain-Based Management of Shared Energy Assets Using a Smart Contract Ecosystem. In: Abramowicz, W., Paschke, A. (eds) Business Information Systems Workshops. BIS 2018. Lecture Notes in Business Information Processing, vol 339. Springer, Cham.

DOI: 10.1007/978-3-030-04849-5_19

Research Paper 3

Utz, M., Johanning, S., Roth, T., Bruckner, T., & Strüker, J. (2022). From ambivalence to trust: Using blockchain in customer loyalty programs. International Journal of Information Management, 102496.

DOI: 10.1016/j.ijinfomgt.2022.102496

VHB Jourqual 3: C, SNIP 2021: 5.416, SJR 2021: 4.584, CiteScore 2021: 28.8

Research Paper 4

Surmann, A., Chantrel, S. P., Utz, M., Kohrs, R., & Strüker, J. (2022). Empowering Consumers within Energy Communities to Acquire PV Assets through Self-Consumption. Electricity, 3(1), 108-130.

DOI: 10.3390/electricity3010007

Research Paper 5

Roth, Tamara; Rieger, Alexander; Utz, Manuel; and Young, Amber Grace, "The Role of Cultural Fit in the Adoption of Fashionable IT: A Blockchain Case Study" (2022). ICIS 2022 Proceedings. 17.

https://aisel.aisnet.org/icis2022/blockchain/blockchain/17

During my dissertation, I have been a contributor to other publications. Please note that these are not included in my doctoral thesis.

Research papers and reports

- Lockl, J., Thanner, N., Utz, M., & Röglinger, M. (2023). The Paradoxical Impact of Information Privacy on Privacy Preserving Technology: The Case of Self-Sovereign Identities. International Journal of Innovation and Technology Management (IJITM), 20(04), 1-39. https://doi.org/10.1142/S0219877023500256
- Strüker, J., Albrecht, S., Schmid, J., Utz, M., & Mohr, R. (2019). A Digital Real-time Energy Economy: Building Blocks for a market-based Target Model. https://eref.uni-bayreuth.de/id/eprint/61175/

6.2 Declaration of Co-authorship and Individual Contribution

This dissertation is cumulative and consists of five research papers. All of them have been written in collaboration with numerous co-authors. My individual contribution to each of the five papers is described in this section.

Research Paper 1:

I co-authored this research paper with Tamara Roth, Felix Baumgarte, Alexander Rieger, Johannes Sedlmeir and Jens Strüker. Tamara Roth and I acted as lead authors. I contributed significantly by its conceptualization and formal analysis. Moreover, I have substantially been involved in the conceptual development of the paper’s methodological approach and its data curation. Additionally, I was co-responsible for data visualization and the validation of the results of the analysis for their generalizability. Finally, I reviewed and edited the original draft of the paper.

Research Paper 2:

I co-authored this research paper with Simon Albrecht, Thorsten Zörner and Jens Strüker. I acted as the lead author and contributed substantially regarding its conceptualization, development of the methodological approach and formal analysis. Moreover, I participated in the data curation and was responsible for validating the analysis results and transferability.

Research Paper 3:

I co-authored this research paper with Simon Johanning, Tamara Roth, Thomas Bruckner and Jens Strüker. I am the lead author of this research paper and contributed substantially by its conceptualization and formal analysis. I have been involved in the conceptual development of the paper’s methodological approach as well as data curation and wrote the original draft of the paper. Additionally, I was responsible for validating the results of the analysis.

Research Paper 4:

I co-authored this research paper with Arne Surmann, Stefan P.M. Chantrel, Robert Kohrs, and Jens Strüker. Arne Surmann, Stefan P.M. Chantrel and I contributed equally to this paper and jointly developed the framework for the Renewable Energy Community. I contributed to the conceptualization and formal analysis of the research paper. Moreover, I was involved in the development of the paper's methodological approach, writing and data validation. Finally, I have been co-administering of the research paper and edited the original draft.

Research Paper 5:

I co-authored this research paper with Tamara Roth, Alexander Rieger and Amber Grace Young, with Tamara Roth acting as the lead author. I provided feedback on the conceptual and methodological approach and substantially engaged in the formal analysis. Moreover, I validated the results of the initial analysis regarding their generalizability and reviewed as well as edited the original draft of the paper.

6.3 Research Paper 1 — Electricity powered by blockchain: A review with a European perspective.

Authors: Roth, Tamara; Utz, Manuel; Baumgarte, Felix; Rieger, Alexander; Sedlmeir, Johannes; Strüker, Jens

Published in: *Applied Energy (2022)*

Abstract: Blockchain is no longer just a hype technology, and effective blockchain applications exist in many industries. Yet, few blockchain projects have been successful in Europe's energy systems. To identify the reasons for this slow progress, we reviewed the recent energy literature regarding the use of blockchain, analyzed industry reports, and interviewed experts who have conducted blockchain projects in Europe's energy systems. Our analysis reveals eight common use cases, their expected benefits, and the challenges encountered. We find that the expected benefits are often little more than generic hopes, largely outweighed by technological, organizational, and regulatory challenges. The identified challenges are significant and numerous, especially for peer-to-peer trading and microgrid use cases. The fact that few projects have yet provided robust evidence for profitable use suggests there is still a rocky road ahead. Moreover, many use cases appear to require more than just blockchain technology to succeed. In particular, privacy and scalability requirements often call for systems in which blockchains only take a backseat. This realization may be essential for the future use of blockchain technology in energy systems – in Europe and beyond.

6.4 Research Paper 2 — Blockchain-Based Management of Shared Energy Assets Using a Smart Contract Ecosystem.

Authors: Utz, Manuel; Albrecht, Simon; Zoerner, Thorsten; Strüker, Jens

Published in: *Lecture Notes in Business Information Processing (2019)*

Abstract: Energy markets are facing challenges regarding a changing energy generation and consumption structure, as well as the coordination of an increasing number of assets, devices and stakeholders. We address these challenges by introducing a blockchain-based smart contract ecosystem as our contribution to extant research. Apart from blockchain-specific benefits (e.g. data integrity and smart contract execution), the ecosystem fosters energy-blockchain research through the creation of digital assets. Doing so, we address research gaps identified by previous authors. From our work, we can derive economic implications regarding the foundation of local energy markets, the incentivization of grid-stabilizing behavior and the settlement of collective action problems.

6.5 Research Paper 3 — From ambivalence to trust: Using blockchain in customer loyalty programs.

Authors: Utz, Manuel; Johanning, Simon; Roth, Tamara; Bruckner, Thomas; Strüker, Jens

Published in: *International Journal of Information Management (2022)*

Abstract: Global initiatives on climate protection and national sustainability policies are accelerating the replacement of fossil fuels with renewable energy sources. Many electricity suppliers are engaged in efforts to monetize this transition with 'green' services and products, such as Green Electricity Tariffs. These promise customers that their supply includes a specific share of green electricity, yet since electricity suppliers often fail to deliver on those promises, many customers have lost trust in their suppliers. Further information asymmetries may not only exacerbate this loss of trust, but also spark distrust and lead to an overall feeling of ambivalence. Eventually, ambivalent customers may feel inclined to switch suppliers. To prevent this domino effect, electricity suppliers must eliminate ambivalence by increasing customer trust and reducing customer distrust. Here, we discuss how these challenges can be met with a customer loyalty program built on blockchain technology. We developed the program following a Design Science Research approach that facilitated refinement in four iteration and evaluation cycles. Our results indicate that the developed customer loyalty program restores trust, reduces distrust, and resolves customer ambivalence by providing four features: improved customer agency, sufficient and verifiable information, appropriate levels of usability, and unobstructed data access.

6.6 Research Paper 4 — Empowering Consumers within Energy Communities to Acquire PV Assets through Self-Consumption.

Authors: Surmann, Arne; Chantrel, Stefan P.M.; Utz, Manuel; Kohrs, Robert; Strüker, Jens

Published in: *Electricity (2022)*

Abstract: The use of photovoltaic energy (PV) and the involvement of residents within energy communities are becoming increasingly important elements of decentralized energy systems. However, ownership structures are still too complex to empower electricity consumers to become prosumers. We developed a token-based system of the gradual transfer of PV ownership rights, from the initial investor to residential and small-scale commercial consumers. To demonstrate the system, we set up a simulation of a 27-party mixed usage building with different load profiles, ranging from single student apartments to office units with battery electric vehicles, in a German energy community. As a result, we show that the proposed system design is economically viable for all involved stakeholders over the simulation horizon from 2022 to 2036, with a payback time of <5 years, 4 years to distribute 50% of the PV tokens, and an overall self-consumption share of 69%.

6.7 Research Paper 5 — The Role of Cultural Fit in the Adoption of Fashionable IT: A Blockchain Case Study.

Authors: Roth, Tamara; Rieger, Alexander; Utz, Manuel; Young, Amber Grace

Published in: *International Conference on Information Systems (ICIS) (2022)*

Abstract: Investments in fashionable IT do not make organizations more successful than investments in less fashionable alternatives. Many organizations nevertheless associate with fashionable IT to signal compliance with norms of progress and rationality. These decisions can be risky as they require the ability to navigate hype narratives and fit the new technology into the adopting organization. In this paper, we explore a so far understudied fit perspective: cultural fit between the values attributed to the fashionable IT and those of the recipient organizational context. Through an interpretivist case study of two blockchain projects, we find that cultural sensemaking and dissonance reduction can be important determinants for successful adoption of fashionable IT. Moreover, we identify two recursive paths for how organizations can reduce cultural dissonance. They can adapt their implementation and the narratives surrounding the fashionable IT or they can transform their local or overarching organizational culture.