Decentralized Energy Networks based on Blockchain: Background, Overview and Concept Discussion

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Abstract. This paper provides a snapshot of the globally ongoing decentralization of (business) relations in the energy sector. This tendency can be observed in other domains as well and is accompanied by new digital technological developments. Blockchain technology is assigned disruptive potential when it comes to realize those decentralization ideas. This hype about Blockchain is mainly company-driven without a solid academic basis yet. The authors are currently involved in several research efforts for utilizing distributed energy resources like photovoltaic systems, batteries and electric cars for the setup of energy communities and marketplaces. The paper, therefore, presents detailed investigations of background and motivations for decentralization and the building of (local) energy communities and (peer-to-peer) marketplaces for sustainable utilization of renewable energies. An overview of recent related Blockchain-based works is presented, and the current state and feasibility for the realization of the envisioned decentralized solutions are discussed. In this way, the work aimed at contributing to a research-based decision foundation for upcoming Blockchain-based decentralization efforts.

Keywords: Energy Decentralization, (Local) Renewable Energy Communities, Blockchain-based Energy Networks.

1 Introduction

In 2008, Bitcoin was invented with the aim of creating a peer-to-peer (P2P) currency that removes the need for trusted third parties like banks [1]. Especially Bitcoin’s underlying technology – Blockchain – caught the attention of several domains. Even in the energy sector, where disruption is currently underway, in which (private) owners of renewable energy sources, e.g., photovoltaic (PV) systems, could directly sell their surplus energy to others. Traditional energy consumers are becoming producers, which are referred to as prosumers, and represent equal peers in the energy system.

As a consequence of these disruptions, todays energy systems, in particular, regional and local distribution networks are facing increasingly complex challenges. A main driver are high numbers of private, decentralized, fluctuating generators, combined with electricity storages, a rising share of e-mobility, and the increasing electrification of building heating systems, as well as the selfish use of private flexibilities opposed to grid and system-friendly behaviors. From today's perspective, these developments will escalate driven by flexible tariffs, the increasingly active and unregulated market participation of prosumers, and new business models this paper tries to investigate.

The following structure explains the logical flow of arguments throughout the paper: Sec. 2 introduces the background of the ongoing energy decentralization efforts heading towards enabling (local) renewable energy communities. The subsections highlight concrete opportunities and challenges of these decentralization tendencies, by already having in mind Blockchain as supportive technology. Sec. 3 presents an overview of identified active, recent Blockchain initiatives for decentralized energy solutions. Preparatory for this overview, the first subsection refers to and shortly presents a scheme for distinguishing different types of hitherto Blockchain applications in the energy sector. Subsequent to the overview of Blockchain-based energy networks, a mapping of the investigated systems to these application types is done in the last subsection. Sec. 4 discusses gained experiences concerning Blockchain potential to support aforementioned opportunities and challenges, together with limitations and open issues. Sec. 5 concludes the paper and presents a short outlook on further activities.

2 Decentralization in the Energy Sector

Decentralization in the energy sector is currently a highly relevant topic, also in Europe. A lot of initiatives, new laws and directives on European and national levels have been recently elaborated. The Strategic Energy Technology (SET) Plan [2] is putting energy research & innovation at the heart of the Energy Union in Europe, aligned with the Energy Union research and innovation priorities.

2.1 (Local) Renewable Energy Communities

The “Winter Package” [3] introduces the concept of energy cooperatives or “Energy Communities”, as they are called in Annex1 [4] and Annex2 [5]. They empower active consumers of the Energy Union to participate (generate, consume, store, share, trade, and sell back renewably generated energy) in energy markets. This includes incentives for self-consumption of locally and regionally produced energy as well as for activation of flexibility to help stabilize the overall energy system.

At the moment, the primary drivers for such communities are a potential increase of self-consumption and energy self-sufficiency for prosumers as well as the enhanced use of local energy generation, reinforced by new opportunities brought by digitalization and new smart technologies. For example, the Energy Package provides the appropriate collaborative environment for the implementation of Smart Grids and roll-out of smart metering systems across Europe. In the proposal for the internal electricity market, a specific role is given to "Energy Communities." Hence, it is crucial to think beyond the currently existing regulatory framework and to create a new regulatory space regarding local energy communities.

Several EU member states have prepared legislative changes to allow for more onsite self-consumption of electricity coming from PV. Belgium, for example, recently announced to allow direct lines between companies that consume renewable electricity in the area of another company. Greece, as one of the first EU countries in this regard, has adopted a new energy law in 2017, allowing energy communities to lease corresponding parts of the grid from the distribution system operator (DSO). In Germany, the so-called “Mieterstrom” – where tenants are buying electricity produced on site – is regulated within the Renewable Energy Sources Act (EEG) and since 2017 projects implementing such solutions are being subsided.

The legislative change of the energy law in Switzerland (Energiegesetz EnG, 30.09.2016) allowed for so-called “Eigenverbrauchsgemeinschaften” (EVG), i.e., self-consumption communities) in which pro-/consumers in spatial proximity are allowed to form a decentralized electricity production facility for self-consumption.

2.2 User Centered Business Models

While the centralized energy market structure has a limited number of decision makers, decentralized structures may involve a large number of actors, among which specific market and business models need to be coordinated, requiring specialized methods. Within the given regulatory framework, mainly two general types of energy communities have been established. In company organized energy communities, such as sonnenCommunity [6] or EnBWsolar+ [7], energy providers manage the community of prosumers as their customers and offer tariffs and trading options. Their customers remain in contractual relationship with the energy provider or utility. On the other hand, there are bottom-up, community-organized projects, legal forms of associations that allow prosumers to be co-owners or investors. In Germany, for example, an energy trading community in Bammental [8] sets precedence on how a community with about 80% of prosumers owns and organizes the local energy system. In energy systems of the future, new players and stakeholders are gaining in importance: households, municipalities, business holders producing, and consuming energy at the same time will become prosumers. Full-service providers will be offering the whole service beginning with planning, installation and ending up with operations and maintenance. New business models can be based on cooperative models, where users and stakeholders are deeply involved or “carefree” solutions, where customers just click a join button and the service behind takes care of all organizational and legal processes. The challenge for new market participants, established utilities, and grid operators is to find their place in the competitive value chain. Following questions are still unsolved:

1. Identification of stakeholders, assignment of roles (e.g., customers, stakeholders)
2. Deep understanding of stakeholders and customers motivations
3. Designing attractive value propositions for all involved stakeholders
4. Conceptual work on new revenue streams, applying successful business model patterns on current topics based on new technologies (e.g., platforms, Blockchain)
5. Search for profitable and scalable business models where all stakeholders benefit.

The integration of users and stakeholders into research and development processes and users active participation in early stages of projects is crucial for understanding the customer perspective. The implementation and market acceptance depends on the approval of solutions being supportive to underlying values and needs and the general willingness of users to integrate solutions into their practices and everyday life.

The Austrian Living Lab Act4Energy [9], founded in 2018, is currently forming a user community in the energy region of southern Burgenland which supports R&D projects to develop and test new decentralized energy networks, including PV, storage, e-mobility, and Blockchain applications. An analysis of three case studies in Austrian Climate and Energy Model (CEM) regions conducted by IIASA [10] on participatory governance and existing possibilities for inhabitants to engage into decision-making processes regarding energy transition in their communities shows that decision-making within projects is usually assigned to informed and organized public. However, inhabitants are mostly excluded from decisions on the project definitions, needs of the project or the implementation process.

2.3 (Decentralized) Control Strategies for Energy Optimization

With the continuously growing renewable energy generation, users need to be flexible in adjusting their energy consumption, giving rise to demand response mechanisms.

Demand response refers to the ability of each user to respond to specific requests reported by the network operator by changing its load [11, 12]. This response may be performed either in the form of a commitment of the consumer to reduce electricity during peak hours [13], or by introducing financial incentives that affect prices during peak hours [14, 15]. Some examples of currently implemented demand-response programs are the SLRP (“Scheduled Load Reduction

Program (SLRP)") and PJM ("PJM - Demand Response") programs in the USA. In these programs, a demand-response aggregator announces an electricity deficit to customers and schedules a demand-response plan in the day ahead. Customers join the demand response plan voluntarily for monetary credits (rewards).

The problem of optimally defining the amount of flexibility requested by each user (in a commitment-based approach) or the amount of financial incentives provided to each user (in an incentive-based approach) is currently drawn significant attention due to its computational complexity. Examples of commitment-based approaches have been presented in [16, 17], while examples of incentive-based approaches include [15, 18]. Incentives or own interests are also present under such framework, given the ability of the end-users to vary their electricity use patterns given the current conditions (e.g., the price of electricity, PV generation, state of the storage equipment).

Several challenges naturally emerge, including a) accurately predicting the flexibility of the end-users, b) optimally and equitably utilizing the provided flexibility subject to user-defined constraints, and c) exploiting local coordination mechanisms to guarantee efficiency for the global (operator's) objectives.

2.4 Trust, Privacy, Security and Interoperability

Through the excessive use of intelligent distribution algorithms in smart grids, the proliferation of the Internet Protocol (IP) is expected to rise in the power grid significantly. This factor has a severe impact from a security perspective, for it both makes control devices susceptible to the broad range of security vulnerabilities of IP networks and also potentially makes these devices (through misconfigurations) accessible to threats from the Internet [19]. Ukraine, for example, was struck by large-scale cyber-attacks on their power distribution network, causing complete blackout events [20]. Typically, attacks within the distribution grid aim at the Advanced Metering Infrastructure (AMI), the Distributions Automation (DA), and monitoring feeders. These attacks can cause malfunctions, trip distribution network feeders, distort power grid data, or violate user privacy by extraction of sensitive information [21].

Necessary protection actions are, therefore, essential to be in place to reduce the attack surface of the overall system against cyber threats. These include measures for device security, identity management, communication line and data storage security.

A further important issue is a compliance with the General Data Protection Regulation [22], which has to be addressed by carefully selecting which data will be collected or processed and which data will be transmitted. Data and all communication channels need to be protected from unauthorized access and also its integrity and authenticity need to be ensured. Therefore, technologies which exploit or combine different key-exchange methods, consisting of signature, encryption algorithm and key length, cipher mode, as well as hash-algorithm, which are considered secure for the foreseeable future [23] need to be found.

In general terms, trust, privacy, security and interoperability issues are currently huge challenges, even though, if traditionally centralized business models will be increasingly decentralized. To ensure that data remains in the exclusive possession of the respective user, a secure architecture by introducing Blockchain building blocks seems to be a viable solution to guarantee cybersecurity, interoperability, provenance, privacy and, therefore, ensuring also GDPR compliance [24, 25].

3 The Case of Blockchain for Decentralized Energy Solutions

Blockchain and decentralized business models and applications built on top of it are recognized as some of the most significant disruptions since the invention of the Internet. However, a thorough overview of available Blockchain implementation flavors that provides a research-based decision foundation for other interested parties to follow is still missing. A systematic review on Blockchain technology research until 2016 showed that most work (~80%) is related to Bitcoin systems, while other relevant topics suffer from detailed investigations [26].

In the following paragraphs, we will explore the continuously evolving Blockchain-based business models and proposed solutions in the energy domain. As this is currently a very active field, for identifying and selecting, we will concentrate on finding active, recent initiatives for developing new decentrally organized energy business models. An overview of Blockchain applications in microgrids until mid of 2017 is given in [27].

The current state of knowledge regarding development and exploitation of Blockchain technology and applications in the energy sector is heavily driven by start-ups and initiatives at municipal, local, and regional levels.

3.1 Types of Blockchain Applications in the Energy Sector

Energy Cities, a European association of local authorities in energy transition for over 30 years with over 1,000 member cities through 30 countries, in [28] distinguished the following types of Blockchain applications, covering current use, needs, and near-future trends of the energy sector: transaction processing, document asset ownership and management, energy certification and verification, real-time monitoring and analysis of energy use, invoicing and allocation processes, remuneration in a real or virtual currency, creation of an online marketplace for (local/regional) energy, peer-to-peer renewable energy transactions in a decentralized system, offsetting CO_2 emissions and rewarding the implementation of sustainable measures, facilitating the development of e-Mobility as a service.

While this list of different application types helps in classifying existing Blockchain energy applications, in most cases, the started initiatives are aiming at the creation of an online marketplace for (local/regional/global) energy and/or peer-to-peer renewable energy transactions in a decentralized system. This means, the other listed types are more or less partly included in those kinds of projects as well.

3.2 Overview of Blockchain-based Energy Networks

According to a news-message at bitcoinist.com [29], the UK based company *Verv* has facilitated the first Blockchain energy trade transaction in the U.K. with its P2P energy trade pilot project in the Banister House Estate. The developed technology consists of two parts: 1) the Verv Home energy assistant that identifies the power usage of individual appliances in a household using artificial intelligence. And 2) the Blockchain-based P2P energy trading solution that allows households to trade generated excess electricity with a neighbor who has a higher demand. With this technology, one kWh of solar power generated from an array of solar panels on one of the roofs of an apartment block was sent to another residential building on April 11, 2018.

WePower [30] aims at changing how energy is developed and distributed, and provides a Blockchain-based green energy trading platform. When a renewable energy producer requires capital to finance the initial cost of a renewable energy project, he may sell a portion of the energy to be produced in the future, on the WePower platform. The buyer/investor acquires this energy in the form of internal energy tokens. One internal energy token represents 1 kWh to be produced at a particular future time. Each energy token acts as smart contract indicating: 1) type of energy, 2) time of energy production and delivery, and 3) price tag. This smart contract represents a standard power purchase agreement between the renewable energy producer and energy buyer. As a result, energy producers can trade directly with the green energy buyers (consumers and investors). The platform is connected to the energy grid, the local energy exchange market and energy end users. It receives data about the produced and consumed energy and about the energy price from the energy grid, and energy exchange markets.

Hive Power [31] aims at developing a solution for the creation and management of local energy communities on the Ethereum blockchain. All participants are guaranteed to benefit from their participation, and at the same time achieve a technical and financial optimum for the entire community. This optimum shall be reached through a market mechanism that incentivizes the participants to collaborate with each other by coordinating their energy production and consumption.

Thereby, the Hive Power platform also takes into account technical aspects, such as cables, power rating, and voltage limits to provide an optimal solution for multiple objectives. It also provides an energy trading mechanism for energy communities. The so-called HONEY algorithm exploits customers' flexibility to match production and consumption optimally, such that the community's welfare is maximized and grid technical constraints are satisfied. This selling of flexibility as a service helps system operators balancing the grid.

In collaboration with meter producers, Hive Power is building a Blockchain-ready energy meter, which allows tokenizing energy safely. The developed and used Hive Token (HVT) is a standard Ethereum ERC20 token managed by a smart contract which gives access to the Hive Power platform and its management.

For the realization of its P2P distributed green energy market, the *Pylon Network* [32] created its Ethereum-based blockchain that solves specific challenges of the energy sector, like the need for high rate transaction speed and storage and processing of vast amounts of data as well as scalability and versatility requirements. The Pylon Network targets renewable energy cooperatives (RECs) and aims at helping energy sellers having better knowledge of energy flows. Similar to Hive Power, it combines a smart meter (Metron) and Blockchain technology to certify energy flows and enable virtual transactions using tokens (green kW production units/coins). This technology allows the renewable energy community to manage demand and optimize the energy flows in real-time. For certification and payments, the Pylon coin is used which enables micro-payments in real-time and traces by whom, when, and where each kWh of energy in the community was produced and consumed. A full-scale pilot for the Spanish market is expected in 2018 and shall later be expanded to other countries like the United Kingdom and Germany.

Tal.Markt [33] is a digital marketplace for local renewable energy trading, which is based on a private blockchain. It was developed for the Wuppertal area by Wuppertal Stadtwerke Energie & Wasser AG (WSW) in cooperation with Elbox. On one hand, energy producers can sell their surplus energy from renewable energy sources and thereby earn an additional income. On the other hand, energy consumers can create a personal electricity mix by choosing energy producers and energy sources, e.g., solar system, biogas plant or wind turbine. Thereby, the consumer gets a guarantee of the origin of the consumed energy. If no energy from these sources is available, e.g., no solar energy when the sun is not shining, WSW supplies the energy consumer with energy from a combined heat and power plant. Tal.Markt especially targets energy producers, which will lose support by the Erneuerbare Energien Gesetz (EEG), which expires in 2020. Currently, a requirement for participation is that the energy producer’s installation is above 30kW.

The *Inuk* [34] application, developed by the French start-up Inuk, focuses on carbon emission offsetting. Users can calculate their carbon footprint based on their daily activities, like getting food delivered or traveling. Inuk offers the user to offset their carbon emissions by investing in solar energy production. The Inuk model enables small solar energy producers to obtain higher prices for generated energy, thus contributing to the development of local clean energy. Inuk cooperates with solar energy producers, mainly in France, whose plants must comply with specific quality criteria and be equipped with sensors for real-time monitoring of energy production. Based on the UN Framework Convention on Climate Change (UNFCCC), the equivalent of the carbon emissions in green electricity is calculated. Thereby, the public Ethereum blockchain is used to guarantee transparent emission offsetting.

The pilot project *Power-ID* [28], led by the Swiss Federal Institute of Technology ETH in Zurich, aims to create a local peer-to-peer energy marketplace in Walenstadt (canton St. Gallen). Thereby, the marketplace focuses on solar energy and energy storage systems, like batteries. For energy payments, matchmaking and allocation of network costs, the Ethereum blockchain is utilized. The network costs are calculated according to the actual degree of self-sufficiency, which means that if external energy sources, like other networks, are used, the network costs include costs for their usage.

The TECSOL spin-off *Sunchain* [35] wants to realize self-consumption of solar energy independent of the production point. Therefore, a virtual network of solar energy producers and consumers using the Blockchain is created. It utilizes its private blockchain, based on Hyperledger Fabric, to store encrypted and signed energy production and consumption data. The distribution system operator is involved in this process and receives allocation coefficients for energy distribution between the self-consuming network participants. Possible applications based on the network are, besides off-site self-consumption, collective-self consumption, e.g., in multi-apartment buildings, and power exchange between buildings.

A further notable international initiative is *Restart Energy* [36], which is developing a decentralized energy trading platform based on Blockchain that will enable anyone to trade energy in any deregulated energy market in the world. *Enosi* [37], *SunContract* [38], and *Green Power Exchange* [39] are developing platforms to support self-sufficient energy communities and P2P energy trading between their members. *EnergiMine* [42] aims at building a decentralized global energy market by rewarding energy efficient behavior. The Energy Web Foundation is developing a Blockchain-based transactive energy implementation framework that includes *EW Origin* [40], a customizable, open-source decentralized application for renewable energy and carbon markets, and a decentralized autonomous area agent *(D3A) market model* [41].

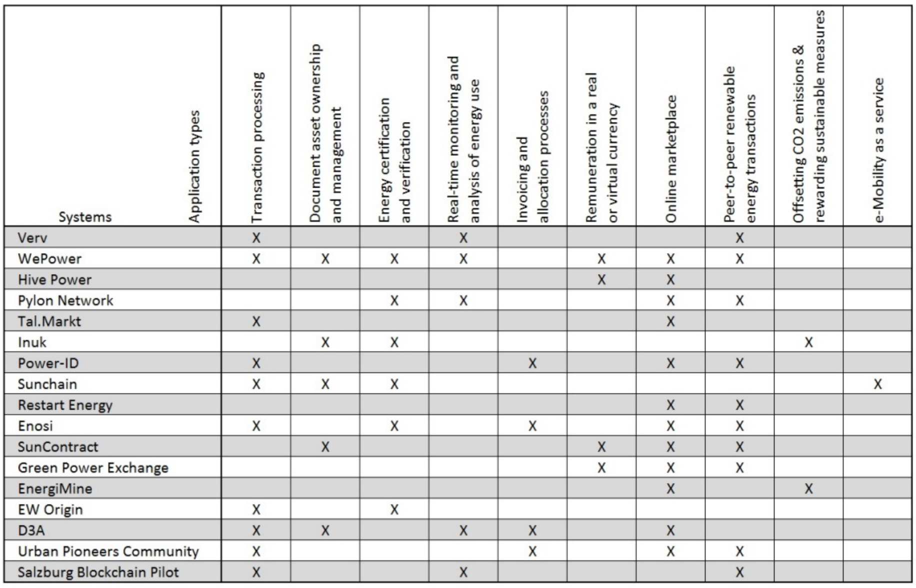
In Austria, just a few projects are focusing on Blockchain applications for the energy sector so far. The *Urban Pioneers Community* project [43], carried out by Wien Energie and Riddle & Code, is a pilot project on cross-property electricity trading infrastructures based on Blockchain technology in Vienna. The project explores how new energy pricing models based on Blockchain and smart meters could work. In that way, energy transactions can be carried out autonomously by the system.

A similar approach has been developed in a project (*Salzburg Blockchain Pilot*) by the Austrian consortium consisting – amongst others – of the Center for Safe Energy Informatics (ZSE), University of Applied Sciences Salzburg, Salzburg AG and Verbund AG. In their project, the Blockchain technology is used to enable residents of a multi-party residential building to transfer their shares of PV electricity to their neighbors within the same building – thus, allowing for higher energy self-consumption rates and increasing the overall efficiency of the building's electricity consumption. [44]

3.3 Summary: Mapping of Investigated Systems and Application Types

Table 1 summarizes the investigated systems and assigns them to the Blockchain application types introduced in Sec. 3.1. It reveals that lots of recent effort is spent for online energy marketplaces and P2P energy transactions, which are both supportive for (local) renewable energy communities as motivated in Sec. 2.

Table 1. Mapping of investigated Blockchain-based energy systems and Blockchain application types in the energy sector



Application types Systems	Transaction processing	Document asset ownership and management	Energy certification and verification	Real-time monitoring and analysis of energy use	Invoicing and allocation processes	Remuneration in a real or virtual currency	Online marketplace	Peer-to-peer renewable energy transactions	Offsetting CO2 emissions & rewarding sustainable measures	e-Mobility as a service
Verv	X			X				X		
WePower	X	X	X	X		X	X	X		
Hive Power						X	X			
Pylon Network			X	X			X	X		
Tal.Markt	X						X			
Inuk		X	X						X	
Power-ID	X				X		X	X		
Sunchain	X	X	X							X
Restart Energy							X	X		
Enosi	X		X		X		X	X		
SunContract		X				X	X	X		
Green Power Exchange						X	X	X		
EnergiMine							X		X	
EW Origin	X		X							
D3A	X	X		X	X		X			
Urban Pioneers Community	X				X		X	X		
Salzburg Blockchain Pilot	X			X				X		

4 Discussion

In the following, the gained experiences concerning Blockchain potential to support the opportunities and challenges of the ongoing decentralization tendencies in the energy sector introduced in Sec. 2, together with limitations and open issues, are discussed.

4.1 Blockchain Support for (Local) Renewable Energy Communities and User Centered Business Models

The presented overview in Sec. 3 revealed that a bigger part of ongoing Blockchain initiatives in the energy domain is aiming at realizing (local) renewable energy communities.

Further research efforts are needed to investigate new value chains, including new actors relevant in energy communities such as municipalities, energy cooperatives, aggregators, and citizens. The concepts of local energy and grid communities, based on the ongoing decentralization movement in the energy domain, create opportunities for new market players to enter the energy market and to build up new value chains. New entrants like startups or IT-companies will take over the role of full-service providers. Everyone in the new value chain has to define their new business model.

However, besides offering new possibilities, the complexity of Blockchain might even expose "small" consumers participating in a local energy marketplaces to unacceptable price risks, as argued in [27].

4.2 Blockchain Support for Decentralized Control Strategies for Energy Optimization

The realization of advanced decentralized control strategies utilizing Blockchain technology is partly addressed by some of the investigated works. An important related issue concerns the exploitation of energy transaction histories captured on a blockchain for the prediction of future energy transactions.

In [45, 46], the authors reported about the conceptualization of a decentralized battery energy storage network to compensate for schedule deviations. Thereby, Blockchain was already identified as potential enabling technology. In an ongoing and proposed follow-up effort [47, 48], this concept will be extended to 1) include further kinds of flexibilities like heat pumps, boilers, and electric vehicles, and 2) develop user-centered, grid- and system-friendly integrated, local and regional energy systems including local and regional markets based on Blockchain technology. Parts of the introduced Hive Power system [31] are closely related to these conceptualizations and will, therefore, be further investigated and observed.

4.3 Blockchain Support for Trust, Privacy, Security and Interoperability

Blockchain technology claims to solve fundamental trust problems in decentralized applications. A considerable challenge for the future, however, is to provide trustworthiness among different blockchains and establish secure and transparent mechanisms to settle apart drifted statements, which do not match to the interrelated ecosystem but were supplied by these blockchains. For example who has the authority and what happens when the reported CO_2 certificates do not fit energy transfer reported by the sensor values at different grid monitoring points?

4.4 Limitations and Open Issues

Alongside the development of Blockchain-based solutions for energy markets and economics, which represent the primary objectives with the works presented in the overview of Blockchain-based energy networks (cf. Sec. 3.2 and Sec. 3.3), further potential applications of Blockchain technology need to be investigated. There are many attempts for promising applications, but implementations often lack a holistic, customer-centered, cyber-physical system considering point of view. According to [28], some of these initiatives exclusively focus on the technological aspects, leaving aside further essential elements, in the light of the envisioned disruptions in the energy sector.

While the presented international initiatives are quite ambitious in their goals, it is not yet clear, except Verv, how far the developments of these experimental and pilot activities, as sketched in the development timelines of the corresponding white papers, have gone already. The amount of different white papers and the lack of feasible applications is a success story for openly shared research. The Austrian projects are quite focused but of comparably limited scope.

To reach a readiness technology level, Blockchain needs to be thoroughly understood by a broad array of stakeholders, involving everyone from customers to producers, from technologists to economists etc. Blockchain, as of today, is not a ready to use off the shelf technology but needs to be made measurable by technology experts on each application scenario. A thorough overview of available Blockchain implementations providing a research-based decision foundation is currently missing. The work at hand represents one step for improving this situation.

5 Conclusion and Outlook

Blockchain technology bears the potential to disrupt whole economic sectors by decentralizing traditional business relations. The energy sector is one of the early adopters, but as the presented mapping of investigated applications and types shows, in early stages as well. These disruptions are just starting with potentially far-reaching social and socio-economic consequences [49]. It is therefore necessary – also for Austria – to keep up with, and even shape these developments, especially from a scientific point of view as this (technology) domain is currently heavily driven by technology start-ups. Therefore, the authors are currently participating in and initiating activities for building an Austrian Energy Blockchain Experts Group/Cluster to tackle open issues, limitations, and also strengthening Austria's international position. An essential building block in doing so is "Smart Grid Control", a flagship project recently proposed with the Austrian Green Energy Lab – a global testbed for the integrated energy system [48, 50].

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