Exploring the Potential of Blockchain as an Enabler for Three Types of Energy Communities

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Abstract— **We focus on exploring the opportunities related to blockchain in regard to three different types of energy communities i.e., industrial microgrid, apartment building and virtual community, as seen by a group of Finnish energy sector experts. To address the research problem, we first summarize results from literature for blockchain as an enabler for energy communities, discuss the technical aspects of blockchain and summarize the status of ongoing pilots and demonstrations around blockchain. Our results from empirical study among energy industry experts show that there clearly is potential for blockchain as an enabler especially of energy efficient use of resources, trading without intermediaries, load balancing, new business, automated functions and long-range in system valuable resources. Despite this potential, multiple gaps exist and future research on blockchain is still called for.**

Index Terms— **Energy, communities, microgrid, peer-to-peer computing**

I. Introduction

Blockchain has its origins in Bitcoin and is closely associated to crypto currencies. However, its application to other use cases has been recently identified [1]. One of these potential applications areas is distribution and trade of electrical energy. With the decentralization, digitalization and decarbonization [2] of the electricity system, new models for producing, storing and selling energy are becoming feasible. Blockchain as a decentralized transaction system could enable consumers and prosumers, i.e. the producers and consumers of energy, or energy communities to share energy and other exchangeables.

Blockchain potential in energy has been recognized in recent research (e.g., [1], [3], [4]). For example, Casino et al.[1] did a systematic literature review and recognized several application areas for blockchain in energy:

- Cost reduction and new business models and marketplaces
- Manage complexity, data security, and ownership in grids,
- Engage prosumers in the energy market
- Act as enabler for the creation of energy communities
- Enhance the transparency and trust
- Handle demand response and provide a framework for more efficient utility billing processes
- Be used for issuing certificates of origin
- Peer-to-peer energy transactions schemes
- Energy management schemes for electric vehicles
- Enabler for the decarbonisation

However, the applicability of blockchains in energy markets is still under scrutiny. The different use cases would prefer a different variation of a blockchain, but the use cases are not understood thoroughly, yet. It has also been found that the mainstream blockchain technologies, like Bitcoin, use a growing amount of energy per transaction, even more that was actually sold in that transaction (e.g. [5]). Due to the excessive power consumption, sustainability of blockchain as an enabler for energy can be questioned.

Furthermore, many open questions however remain on how, e.g., energy sales shall and should be organized in the future. For example, will the current centralized energy market structure be able to offer solution to the more decentralized energy system based more and more on small-scale production? Or will the market be based on a decentralized model managed by third-party aggregators? Or will there be fully decentralized and independently organized communities that produce and share energy? The latter examples could be potentially enabled by blockchain technology. Likely multiple models will apply, at least in the interim. However, blockchain could provide one option for organizing either an aggregator led or independently operated decentralized market place for energy communities.

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Despite the growing academic and practical interest toward blockchain for energy, many research gaps still exist. For example, Andoni et al. [3] acknowledge in their systematic literature review that: "In terms of academic research, blockchains in energy markets form a new research area that has just been started to be explored".

In this paper we set to explore the opportunities of blockchain for different types of energy communities. Our research question is: What kind of opportunities could blockchain enable in energy communities such as virtual communities, apartment buildings or industrial microgrids?

From here on, the paper is structured as follows. First, we give a short introduction to blockchain as a technology enabler. Second, we review the state-of-the art of energy community, flexibility and electric mobility related blockchain pilots and demonstrations. Third, we describe the method and results of our empirical inquiry on blockchain opportunities in energy communities. And fourth, we conclude the paper by discussing the limitations and proposing avenues for future research.

II. BLOCKCHAIN TECHNOLOGY

Blockchain is novel technology for distributed and decentralized transactions. In its pure form blockchains, i.e. permissionless blockchains, enable trusted business transactions without a need for a centralized authority. Although the original use of blockchains was to implement crypto currency Bitcoin [6] blockchains can have several other use cases.

Blockchains have two important technical properties. First, the information about transactions, the ledger, is distributed to the users. This means that the information is not lost even if one party disappears. Second, all transactions are validated so that they cannot be disputed in the future. This validation system is often called *consensus mechanism* in blockchains.

Blockchains can be either permissioned or permissionless. In permissionless blockchains all users can act as validators of the transactions while in permissioned blockchains only some authorized subset of users can validate transactions. Blockchains can also be divided to public and private. Public blockchains are open to anybody while private blockchains are for internal use of the organization, such as an energy community, only.

There are several cryptographic technologies to implement the validation of the transactions. In Bitcoin and many other public blockchains a technology called proof-of-work is used. This suits well for public and permissionless blockchains but requires a lot of computing power and energy. Proof-of-work was the first consensus mechanism for blockchains, but since then other mechanisms like proof-of-stake and Byzantine fault tolerant mechanism have been proposed.

The aspect of energy consumption in blockchain has indeed raised questions. Fully open Ethereum aims to move from proof of work to the less energy-intensive proof of stake, meaning that even a technically large block chain can be rotated without consuming much energy. Assuming, of course, that the transition can be made successfully. In the case of a proof of authority that has certain known contributors or technically specific private cryptographic keys that can validate blocks, the community should be more closed. Indeed, an interesting and not yet well-addressed topic, is how open or close should the community or the grid be to allow for these low energy consumption consensus mechanisms.

Blockchains may be just a distributed storage for the transaction data, like in Bitcoin, or they may implement a simple distributed computing platform. Ethereum is an example of such platforms [7]. Ethereum enables smart contracts that are user-defined programs that lay out the rules of writing in the ledger. For instance the UK Government Office for Science [8] states that "the real potential of blockchain technologies can be only realized when combined with smart contracts" [3].

Technically the ledger is implemented as a chain of blocks (thus the name blockchain) that contains the approved contracts. When a new contract is done, it is sent to all participants, jointly approved, and finally added to the chain. The previously described proving methods add a cryptographic hash to each block. All blocks are validated and all participants can easily check the validity by checking the hash. Creation of the hash is either resource consuming (proof-of-work) or based on secret (proof-of-stake). Figure 1 depicts the basic logic of blockchain.

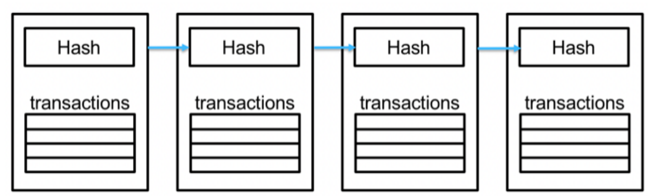

Figure 1. Basic logic of blockchain

III. EXISTING BLOCKCHAIN PILOTS

Blockchain has been used in numerous different applications in the energy sector and Andoni et al. [3] offer thorough review of blockchain pilots in the whole energy sector level. In this paper, we concentrate on pilots related to energy communities. Because of the character of disruptiveness of peer-to-peer (p2p) -market models, these pilots have gained perhaps the most attention in the energy field. Such pilots are defined under concepts of distributed energy systems, microgrids and local energy markets. In addition, electric vehicle management is included in the pilot examination because it is so closely linked to functioning of future energy communities. In fact, most papers on energy-related blockchain pilots are related to these topic areas [9].

A. Peer-to-peer energy trading

The most common function enabled by blockchain is p2p trading. In these p2p pilots, blockchain technology enables a robust, efficient and low-cost trading system. Its irreversibility of transactions and distributed and transparent data basis are seen as a way to increase trust, reliability, information symmetry and safety between actors [10], [11]. Blockchain is seen as an exchange mechanisms that can mitigate costly and time-consuming involvement of third-party actors [9]. Tokenisation helps in managing different transactions and scalability of the system.

LO3 Energy's Brooklyn microgrid pilot is built around private Ethereum-based blockchain that forms a transparent market platform for consumers and prosumers. It uses tokens for trading excess local production for peers who can set their price preferences for selling and buying electricity [11]. Exergy, a project that continues commercialisation of the p2p-market platform, argues that blockchain is necessary to manage the future energy ecosystem with untrusted third parties' control over smart contracts and transaction settlement [12].

PowerLedger is piloting a similar solution as LO3 Energy but they have included a permissionless blockchain layer, which allows everybody to invest in the platform through POWR tokens. According to the CEO of PowerLedger, blockchain enables faster monetary transactions between prosumers and retailers. She sees that blockchain mitigating the risk of having central data repository enables cross-retailer p2p trading and settlement system. Blockchain also facilitates automation through smart contracts and reduce human errors in accounting. Related to energy communities, PowerLedger has also used blockchain as an asset and income register for fractionalised ownership of larger renewable energy assets.[13] Similar frontrunner projects are listed in [3].

B. *Flexibility services and grid management*

As the distribution system is becoming more complex due to increasing amount of distributed energy resources, secure and efficient data management has become more important. Real-time verification through high transaction speed is still a challenge in blockchain implementation. For instance, energy communities can be controlled by aggregators and participate in demand response markets. Implementing and validating these operations is a rather complex issue when there are many different actors participating.

Blockchain can be used recording resource availability and automating demand response [14]. The Transmission System Operator (TSO) TenneT, Sonnen and IBM have implemented several pilots using blockchain. They have a pilot project in Germany where the aim is to control local grid congestions by using battery storage. Blockchain is used for verifying and documenting the performance of the assets participating to demand response. It uses a Hyperledger Fabric, which is a private blockchain developed by the Linux Foundation. They also use blockchain technology in deploying electric vehicles for balancing purposes.[15]

C. *Electric vehicle charging*

Blockchain is seen as a promising technology for mobility in general and also electric vehicle (EV) smart charging is a function that has been developed under several different projects [16]. Fragmented nature of the EV market including many parties supports blockchain capabilities. Verification and communication capabilities can help to increase transparency and overcome security concerns [3]. They are closely related to the incentives and governance of energy communities but also coordination challenges they aim to solve. The German start-up Share & Charge implemented an "AirBnb" of EV charging stations in 2017. It run on public Ethereum blockchain and had about 1250 public and private charging points. They stopped serving that platform in 2018 and shifted from public blockchain to a consortium blockchain as fees and network congestion of the public Ethereum network caused challenges [17]. As a next step, Share&Charge created a foundation for cooperation with various companies and developing a decentralised open-source protocol for EV charging transactions. Another EV-related pilot project is PowerLedgr's and Silicon Valley Power's blockchain-based automated accounting system for tracking carbon credits under Low Carbon Fuel Standard in California [18].

IV. EMPIRICAL STUDY

Our research question explores the applicability of blockchain in energy communities. Technology enablers, such as blockchain, make both centralized and decentralized markets possible but current business models and regulations set practical limits to these options, at least in the shorter run. We now set to explore, how both incumbent and emerging energy sector experts see the fit of the blockchain in energy communities.

Our empirical data was collected in a workshop held at the Tampere University as part of Social Energy - Prosumer Centric Energy Ecosystem (ProCem) [19] -project in 2018. In the ProCem –project Internet-of-Things (IoT) based technology platform was carried out for the exploitation of various distributed energy resources, considering both the electricity market and power system management perspectives. The technology platform enabled to study roles, behavior, needs and requirements of prosumers and new kind of business models and ecosystems in a new operational environment. Realization of the research project called for interdisciplinary approach and it was carried out in collaboration of research groups of four units at Tampere University (i.e Electrical Engineering, Computing Sciences, Automation Science and Engineering, and Industrial Management) and co-operation with 15 industrial partners. Main funding come from Business Finland.

Group of 20 energy sector experts were divided into three groups to discuss the potential as well as the strengths and weaknesses of each type of community, namely virtual communities, apartment buildings or industrial microgrids, in regard to blockchain as the central solution for energy sales. The experts represent a broad range of Finnish energy stakeholders: transmission operator, distribution system operators, electricity retailers, service providers and energy consultants, and ICT companies. In addition, a multi-disciplinary academic research group participated the workshop as facilitators. In terms of the selected methodology, using the expert opinion method is well suited, when there's limited amount of historical data, modelling is difficult or in case of a completely new product or technology [20].

The experts were asked to address the questions of “What opportunities could blockchain enable in the case of the three different communities?”. Group 1 was asked to focus on virtual energy community in which the participants are physically located in different parts of the electricity grid but sharing and trading energy resources within the energy community. The Group 2 focused on an apartment building microgrid and Group 3 on industrial microgrid. An apartment building forms a natural energy community format and a microgrid that has, e.g., PV panels on the roof, EVs in the field, electrical energy storages, heat pumps, lifts and other common loads, and the loads of apartments as one entity to be used together in an optimal way. This type of microgrid may also include buildings sited in the same quarter. An industrial microgrid may consists of a large area with various energy resources and a medium voltage network. The microgrid, in this case, is considered as a separate network, e.g. a pulp and paper factory area or a shopping center with its own electricity network and production units.

The workshop discussions were recorded and the groups also documented and summarized their results at the end of the session. As a result, the experts identified multiple opportunities that can apply to the three types of communities. These results are summarized based on the workshop materials in Table 1.

TABLE I. BLOCKCHAIN OPPORTUNIES FOR DIFFERENT TYPES OF ENERGY COMMUNITIES

Virtual community	Apartment microgrid	Industrial microgrid
Two-way energy trading within the Community alongside retail markets.	Combining and sharing resources between business premises and residents.	Sharing resources and efficient use of resources inside a community and between several communities
Community model without aggregator	New sources of revenue: for example, billing for parking spaces or billing for services	Internal trading regardless of traditional operators
Combining of energy forms (heat, electricity) and their efficient use	Virtual currency simplifies transactions within the community: No bank needed	Combines the functions of different grids (production / consumption)
Validating resources before trading	Balancing consumption and production between customers. Equalizing the power peak, also utilizing electric car batteries	Flexibility for managing overloading situations
Allocating customer resources for wholesale market and network support.	Participation in the electricity market as a property	The regional energy market e.g. for an internal flexibility market

In the case of virtual community, blockchain was seen as a way to introduce p2p energy sharing that would function as complement to the retail markets, even without an aggregator. This would in many markets require changes to the regulation before becoming feasible. It was also seen that efficient use of different energy types, such as heat and electricity, could be improved by enhancing interoperability and making their prices more comparable. Blockchain would be a way to validate the origin of resources in a reliable way and hence would enable “local and clean energy produced here” type of choices to the consumers. By adding aggregation on top of the virtual community energy sharing, blockchain was seen as an enabler for efficient allocation of the prosumer resources that would benefit also the electricity grid operators as well as by providing flexible resources to the market place.

Blockchain opportunities in an apartment building were related to an easily accessible internal market place not only limited to trading energy, but also other goods and services using virtual currency. This was seen potentially leading toward new business opportunities that the housing association and the inhabitants could innovate. For example, means for letting EV charging stations to external EV owners could be charged using blockchain based market place. Efficient use of both shared and private resources, e.g. solar panels, water tanks and geothermal energy, could be increased as the loads could be automatically optimized introducing cost reductions to the whole community. Additionally, social benefits of being a member of a community were seen as benefit to the inhabitants.

In the industrial micro-grid case, blockchain could support sharing of resources between stakeholders in the micro-grid and provide energy trading without traditional operators. This could facilitate a regional energy markets to emerge and provide more independence for regional energy communities and enhance the competitive advantage of regional firms. Blockchain was also seen as supporting different grid functions in production and consumption and provide flexibility (e.g. internal flexibility market) and help in optimizing energy flows.

In addition, the experts identified multiple similarities between the different micro-grid communities (see Figure 2).

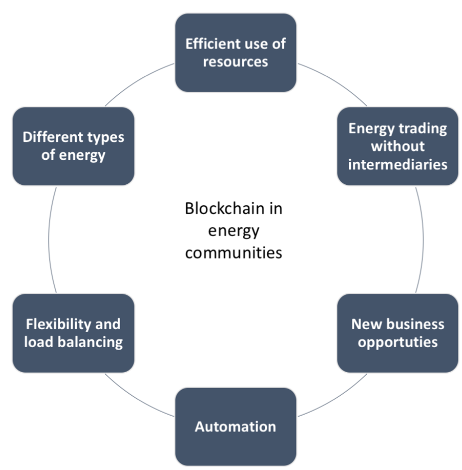

Figure 2. Shared benefits of blockchain in energy communities as seen by the energy industry experts.

Among the findings were, regardless of the community type, that the use of blockchain could, for example, enable efficient use of resources, provide an internal market place without middle men, support load balancing and flexibility, bring new business opportunities, automate functions, as well as help combining and using multiple forms of energy.

V. Discussion and implications

While multiple opportunities for blockchain in energy communities were identified, there are many open questions related to the feasibility of introducing blockchain for energy trading. Our experts found that introduction of decentralized energy trading with blockchain threatens the position of current energy incumbents by for example weakening the position of the retailers. Therefore, incumbents have very little incentive to forward implementation of these solutions. But at the same time blockchain can indeed bring a competitive system to the market that challenges the existing systems beyond energy, such as billing. It also might bring totally new opportunities for innovative new products and services that incumbents could be offering alongside with new entrants.

Issues related to access to energy production and consumption data was also raised as blockchain was seen as increasing the information within energy communities but allowing less information to be passed out to other stakeholders. Furthermore, the freedom of choice for individuals in the communities was also questioned. These issues are directly related to political and regulatory discussions how the resiliency of future energy system is to be designed.

Implication to use blockchain technology in p2p energy sharing also extend to social values of communities, people join communities not just for the monetary but also for social belonging and for other reasons. These present important part of the value for community members. Furthermore, "local and clean energy produced here" type of choices to the consumers have already been found to influence consumers and prosumers behavior. Blockchain implementations could boost this behavioral change towards sustainable energy production and use of renewables.

Easily accessible internal market place not only limited to trading energy but would also engage community members on innovating new solutions. This could spark new wave of grassroot innovations for e.g. apartment buildings or superblocks in smart city implementations. Blockchains could support sharing of various resources between stakeholders in the micro-grid with clear advantages.

VI. Conclusions

Blockchain as a platform for energy trading, flexibility services and electric vehicle charging has been recognized and multiple pilots are ongoing to test the real-life feasibility of the technology. There is however need for more research and demonstrations before definitive feasibility of blockchain can be concluded. Our research contributes to the blockchain for energy –related studies. Our results suggest that multiple opportunities for blockchain in energy communities can be identified already at this early stage of piloting.

The ideas and opinions expressed in the workshop were partly similar as the pilots introduced. Excluding intermediaries by automating transactions, validating resources, p2p-markets and managing flexibility were some functions that were discussed but are also piloted. Extending community's resource sharing outside energy to housekeeping and other services and integration of different heating systems were things that have not been widely implemented.

The early pilots and studying their impacts are crucial for gaining knowledge and experience on effects of implementation on industry, individuals and dynamics of markets. Regulatory frameworks and practices in industry and communities can evolve through experiments like this.

Our research is limited to a small sample size and restricted geographic coverage. Furthermore, the focus group session was limited in time and hence participants' views could not be elaborated further. This means that new, more innovative effects of using blockchains were not dealt with. All this leaves ample room for future research. One example of an important aspect to be explored is how blockchain implementation would change the use of available resources and the actual behavior of the resource user. Take for example EV and dynamic charging price with blockchain: Would this discourage use of EV charging stations all together or actually direct charging to off-peak hours? Our own research continues to explore these new avenues with the blockchain in microgrids and energy communities. We have, for instance, built a pilot implementation of blockchain for a university campus energy trading and are further evaluating its usage. We encourage similar research projects and pilots to share their findings as well as academic research to continue to focus on these issues.

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