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Designing microgrid energy markets A case study: The Brooklyn Microgrid

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HIGHLIGHTS

- State-of-the-art overview of blockchain-based local energy trading.
- 7 required components are derived for the design of microgrid energy markets.
- A case study, the Brooklyn Microgrid, is evaluated according to the 7 components.

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ABSTRACT

Generation from distributed renewable energy sources is constantly increasing. Due to its volatility, the integration of this non-controllable generation poses severe challenges to the current energy system. Thus, ensuring a reliable balance of energy generation and consumption becomes increasingly demanding. In our approach to tackle these challenges, we suggest that consumers and prosumers can trade self-produced energy in a peer-to-peer fashion on microgrid energy markets. Thus, consumers and prosumers can keep profits from energy trading within their community. This provides incentives for investments in renewable generation plants and for locally balancing supply and demand. Hence, both financial as well as socio-economic incentives for the integration and expansion of locally produced renewable energy are provided. The efficient operation of these microgrid energy markets requires innovative information systems for integrating the market participants in a user-friendly and comprehensive way. To this end, we present the concept of a blockchain-based microgrid energy market without the need for central intermediaries. We derive seven market components as a framework for building efficient microgrid energy markets. Then, we evaluate the Brooklyn Microgrid project as a case study of such a market according to the required components. We show that the Brooklyn Microgrid fully satisfies three and partially fulfills an additional three of the seven components. Furthermore, the case study demonstrates that blockchains are an eligible technology to operate decentralized microgrid energy markets. However, current regulation does not allow to run local peer-to-peer energy markets in most countries and, hence, the seventh component cannot be satisfied yet.

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1. Introduction

To date, power has mainly been generated by large centralized power plants run by non-renewable fossil fuels [1]. This directly causes environmental degeneration and energy losses in power transmission due to long physical distances between generation and consumption sites [2]. The increasing integration of renewable energy sources (RES) into the energy system provides a solution to this environmental energy dilemma [3]. Nevertheless, uncertainty and fluctuation in renewable generation need to be taken into account [4]. Existing wholesale markets lack the ability to react in (near) real time to the volatile and intermittent generation from RES [5]. Furthermore, market prices are often determined on a national level which does not reflect (local) energy scarcity or surplus of supply. However, to support the integration of distributed RES into the energy system, new market approaches should mirror the locality of their services [6].

Microgrid energy markets allow small-scale participants, i.e. consumers and prosumers (consumers that also produce energy),

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to actively trade energy within their community in (near) real time. Thus, they facilitate a sustainable, reliable, and local balance of generation and consumption. Hence, this represents a viable option for integrating distributed RES into the current energy system in an economic way [7,8]. Furthermore, this empowers small-scale energy consumers and prosumers, incentivizes investments in local generation, and helps to develop self-sustainable microgrid communities [9]. The implementation of microgrid markets requires innovative, secure, and smart information systems [10], which are an essential factor for their successful operation [11].

Blockchains [12], as emerging information technology, offer new opportunities for decentralized market designs and provide transparent and user-friendly applications [13] that allow energy consumers to participate in the decision on who produces their energy and by which technology it is generated. Microgrids, which are a geographically limited group of multiple generation loads and energy resources [14], can also increase the reliability of supply as they offer the potential to provide energy in case of power outages of the superordinate grid [15].

The conceptualization and implementation of blockchain-based microgrid energy markets have recently gained the attention of several researchers. Sikorski et al. [16] present a proof-of-concept implementation of a small blockchain-based machine-to-machine electricity market with two producers and one consumer in the chemical industry. Their work demonstrates that blockchain technology can establish (very) small-scale electricity markets. Green and Newman [17] analyze the development of local communities into self-sufficient, local generation utilities (so called citizen utilities). They investigate the opportunity of blockchain-based microgrid energy markets to the growth of distributed solar systems and the corresponding challenges for the traditional energy grid in Australia. They specifically state that the use of blockchain technology for electricity transactions makes microgrids more resilient by creating trust between the involved agents, especially with respect to financial payments and electricity delivery.

Building on current literature, we focus on the required components for a holistic market design and implementation of a microgrid electricity market between a significant number of residential households. Thus, we expand current literature by providing the first structured evaluation of an implemented case study on a blockchain-based microgrid energy market. The new contribution of this paper can be summarized as follows:

1. Introduction of a market design framework consisting of 7 fundamental components for designing a microgrid energy market.
2. Introduction and evaluation of blockchain technology as an information system for microgrid energy markets between residential households.
3. Presentation of the Brooklyn Microgrid (BMG), an implemented case study of a blockchain-based microgrid energy market
4. Discussion and evaluation of the case study according to the outlined 7 required market components.
5. Demonstration that a private blockchain can sustain and operate a microgrid energy market.

Subsequent to a comprehensive literature review of microgrid energy markets, blockchain technology, and their combination (i.e. blockchain-based microgrid energy markets) in Section 2, we propose a framework for designing microgrid energy markets in terms of the required components for the successful market operation in Section 3. Then, in Section 4 we present the BMG in Brooklyn, New York as an implemented case study for microgrid energy markets. We evaluate and discuss the case study according to the required market components from Section 3. Finally, Section 5 provides the conclusion of our work. Fig. 1 presents a schematic overview of this paper.

2. Literature review

2.1. Microgrid energy markets

Sustainability and an efficient use of our planet's resources are inherently linked to taking advantage of (decentralized) RES. RES use the huge energy potential of sunlight, wind, water, geothermal resources, and gravitational forces [18]. The efficient integration of RES and the restructuring of the energy system into several interconnected microgrids can improve the reliability and environmental sustainability of the energy system and, simultaneously, provide economic benefits [3].

Traditional centralized energy systems can be characterized by a large number of customers located within a wide area, e.g. a country. Energy is supplied by large power plants that operate according to a centralized coordination mechanism [19]. Decentralized energy systems, one the other hand, are the opposite of centralized energy system: They consist of small-scale energy generators (up to 200 kW) "(...) that are placed in the same location with an energy consumption point and that are used by a small number of people" [19]. Microgrids can aid in ensuring this reliable supply. They operate in both grid-connected or island-mode [14]. Microgrid energy markets provide small-scale prosumers and consumers with a market platform to trade locally generated energy within their community. Hence, they promote the consumption of energy close to its generation and, therefore, foster sustainability and the efficient use of local resources. An exemplary microgrid energy market scenario of residential consumers and prosumers (consumers with photovoltaic (PV) systems) is shown in Fig. 2. Note, that market participants do not necessarily have to be physically connected. Virtual microgrids are the aggregated control of multiple energy producers, prosumers, and consumers in a virtual community. By expanding a physical microgrid to include virtual participants, its revenue potential can increase substantially.

Microgrid markets can reduce the need for expensive and inefficient energy transportation with substantial losses [20] by satisfying demand from local energy resources. Furthermore, the latency for managing congestion and distribution faults can be decreased [21]. Microgrid markets strengthen the local community in terms of self-sufficiency and provide the possibility of energy cost reduction. Local transactions keep profits within the community and encourage reinvestments in additional renewable generation [22]. Thus, microgrid energy markets provide members of a community with a new asset class as well as a previously nonexistent direct access to locally generated energy from their neighbors. Consequently, they can be linked to the recently emerging sharing economy [23].

Combining the virtual power plant approach and the community aspect, Franke et al. [24] consider the economic and ecological efficiency of peer-to-peer (P2P) microgrid energy markets. Additionally, they point out the importance of social factors. The public acceptance of local compared to national renewable generation is discussed in the empirical study of Bertsch et al. [25]. Increasing the public's acceptance of microgrid energy markets can be done by developing a shared vision with the affected community about the objectives and operation of the market [26].

The optimal operation of a microgrid regarding its energy generation has already been addressed extensively, e.g. Pascual et al. [27] and Montuori et al. [28]. Furthermore, feasible connections between multiple microgrids are recently being investigated with the aim to facilitate a more reliable balance of supply and demand than in individual microgrids [8,11]. However, research in the field of microgrid energy markets is just gaining momentum. Our paper extends the market design research by deriving and discussing required components of microgrid energy markets and by presenting and evaluating a case study, i.e. the BMG.

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