A Review on Local Energy Markets and Peer-to-Peer Energy Trading

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ABSTRACT: Traditional energy systems rely on large centralized energy producers (e.g., power stations) and many distributed passive consumers. However, to successfully tackle the challenge of transforming these energy systems into more sustainable and climate-friendly systems an increasing number of renewable energy systems (RESs) are included into the existing power systems. Furthermore, the installation of RESs, for example, photovoltaics, change more and more passive consumers into actively participating prosumers. Subsequently, this poses new challenges for the existing systems like the need for additional monitoring infrastructure or adapted forecasting methods. To overcome these challenges several different strategies have been implemented resulting in so-called local energy markets (LEMs). LEMs present the core of a consumer-centric system providing a platform to exchange energy between the different participants of a so-called local energy community (LEC). Furthermore, additional services from the individual participants in a LEC can be shared with others, such as energy storage systems to provide flexibility inside a LEC. Additionally, LEMs enable the individual market participants to aggregate their RESs as well as flexibility options in order to provide services for the regional or national market. In order to meet the demands of LEMs and LECs a decentralized and automated bottom-up approach is required in contrast to the traditional top-down centralized energy systems. So-called Peer-to-Peer (P2P) and community-based energy trading approaches allow, for example, for a direct consumption of locally produced surplus renewable energy from neighbors. Therefore, this work presents an overview on the state-of-the art of LEMs/LECs as well as P2P- and community trading approaches and methods. As in general, a LEM consists of market design, business model development, control architecture, ICT infrastructure, a particular focus of the study is on the specifically implemented market designs and their consequences. Additionally, an overview is given on the advantages and disadvantages of different LEM/LEC design and which questions remain open and thus require further research in the future.

1. INTRODUCTION

Traditional top-down centralized energy systems are undergoing a rapid transformation due to the increasing number of renewable energy resources (RESs) (e.g., photovoltaics and wind) being installed. Subsequently, the passive consumers become actively participating prosumers in the energy system. A prosumer usually has three different choices for using the locally produced energy: 1) self-consumption, 2) feeding into the grid at a fixed tariff, and 3) storing energy using different technologies. However, prosumers cannot actively participate in the wholesale market. This is due to their unreliability and inefficiency regarding energy production and consumption (Mengelkamp et al. 2017). Local Energy Markets (LEMs) and in particular Local Energy Communities (LECs) enable the integration of individual prosumers with highly fluctuating renewable energy generation into the existing energy systems.

However, novel strategies and methods regarding the trading of renewable energy have to be devised to create a market environment with potentially lower costs for locally produced energy. Hence, the local consumers benefit from lower energy prices. In addition, in a LEC the actively participating prosumers can obtain extra revenues for selling their energy locally using the existing energy grid, because they are able to directly sell their surplus to individual consumers instead of selling at a fixed feed-in tariff. Following this approach both, the prosumer and the consumer, benefit by higher selling and lower buying prices, respectively (Lilla et al. 2020). Such a market design is, for example, realized in so-called Peer-to-Peer (P2P) trading approaches (Alam et al. 2017). Additionally, prosumers and consumers in a LEC can be aggregated and eventually providing additional flexibilities for the overall energy system (Jin et al. 2020).

All new approaches as LECs and P2P trading rely on a structural change of the existing energy systems. A fact that is also true for the underlying technologies, like market and trading platforms, or smart meters (as accurate price signals are highly important for P2P trading). Consequently, besides the structural change also adaptations and new approaches on the technological level are necessary. Digitization plays a major role in pursuing the goal of a successful transformation to an intelligent and decentralized energy system. This can be observed, for example, by the advent of more and more blockchain-based LEMs and LECs (Mengelkamp et al. 2018). Furthermore, smart meters offer the possibility to provide near real-time data for both, demand and production. This is key information required for determining price signals, which serve as basis for most local or community based energy trading platforms (Van Aubel & Poll 2019).

This work is organized as follows: Section 2 is dedicated to the definition of LEMs and LECs as well as to P2P trading and community trading. This is followed in Section 3 by a discussion of different market designs and potentially enabling technologies. Finally, the study is concluded in Section 4.

2. LOCAL ENERGY MARKETS AND COMMUNITIES

To overcome some of the challenges that traditional energy systems are facing nowadays (e.g., high penetration of RESs with volatile production characteristics), the concept of LEMs was introduced. A LEM usually consists of numerous consumers and prosumers, but can also include different industrial market participants. The latter can, for example, provide their surplus energy for the consumers in addition to the local production of the prosumers (Mengelkamp et al. 2017).

The European Union (EU) proposed a definition of a specific type of LEM, namely LEC. One key aspect of a LEC is the collective ownership or control of assets (e.g., photovoltaic systems) as well as an energy management system, which enables the interaction of the LEC as a single entity with other entities of the existing energy system. However, the proposed EU laws still have to be implemented into national legislation (European Commission 2019).

Although LEMs and LECs are comprised of significantly fewer market participants than a traditional centralized energy system, several challenges have to be tackled to guarantee a safe operation of the local energy system. These challenges include the balancing of demand and supply in a LEM or LEC, obeying distribution constraints, manage congestions and providing incentives for the participants to join, stay, and invest in the local market (Jin et al. 2020).

A key aspect in the new decentralized energy systems is the concept of P2P trading. A major advantage of the P2P concept is the fact that market participants, i.e., prosumers and consumers, are able to buy and sell energy locally to other consumers. On the one hand, this is particularly attractive as the need for a central authority is circumvented yielding higher revenues for the prosumers selling their surplus energy to local consumers. The latter, on the other hand, benefit from lower energy costs in a LEM or LEC compared to the electricity prices from the "outside" grid. However, the P2P trading leaves prosumers in a weak position when negotiating energy prices with large stakeholders (Zia et al. 2020).

3. MARKET DESIGNS AND TECHNOLOGICAL/SOCIAL ASPECTS

Economic benefit seems to be the main motivator to participate in these new forms of energy trading (Mengelkamp et al. 2019, Pumphrey et al. 2020). Other reasons are related to gaining independence and protecting the environment (Dukovska et al. 2018). Participants in a P2P energy market are on the one hand buyers, who demand energy from local generators, and on the other hand, sellers, who generate own energy and sell the produced surplus in the local market (Khorasany et al. 2018). The heterogeneity of preferences need to be considered - those can differ, but also overlap (Dukovska et al. 2018). Additional participants are independent mediators, like, for example, a Distributed System Operator (DSO), who delivers electricity to customers in a cost-effective and sustainable way and who is responsible for congestion management, voltage control, loss minimization, and planning. There can also be a Balance Responsible Party (BRP), who balances consumption and supply and who is responsible for imbalances and deviation of prognoses. Aggregators are service providers, which manage groups of consumers and connects them with prosumers. Finally, a Local Flexibility Market Operator, who could be an energy supplier or has an independent role, provides the trading platform and runs the market (Jin et al. 2020). Fig. 1 shows an exemplary LEM (or LEC) consisting of a DSO, a BRP, and several aggregators who manage prosumers and consumers. The LEM is utilized as a competitive trading platform for trading energy and flexibility. For example, the DSO is responsible for voltage control and congestion management whereas the BRP aims at reducing imbalanced energy volumes thus reducing its imbalancing charges. The aggregators sell their flexibility earning profits (Jin et al. 2020).

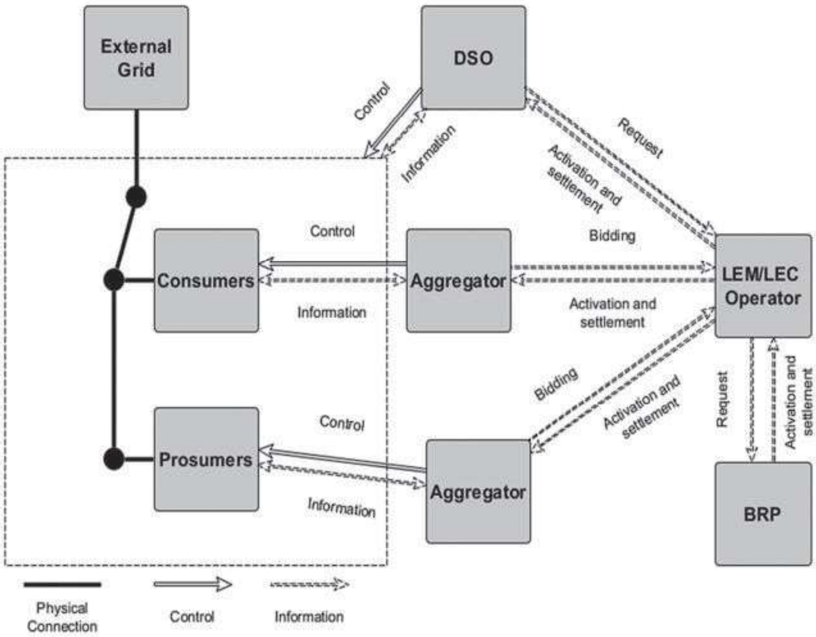

Fig. 1: An overview of a possible design for a LEM or LEC (adopted from Jin et al. 2020).

In literature, two different methods to establish a P2P energy market are mentioned: A centralized market design and a distributed/decentralized market design. While centralized markets are managed by an independent coordinator/mediator, in decentralized markets the interaction happens directly among the peers (Khorasany et al. 2018; Jin et al. 2020). The implementation of a centralized market design is less complicated compared to the decentralized design, as it is similar to conventional power systems and the control lies with a single central aggregator. However, it is more difficult to scale up such a model in case more participants enter the market at a later stage (Zia et al. 2020). In contrast to decentralized markets, in which appearing problems are divided into sub-problems which are easier to identify and solve, communication systems in centralized markets are not able to cope with the computing and communication requirements in the event of a market enlargement (Khorasany et al. 2018). Furthermore, transparency and reliability of centralized markets are lower, whereas computational and communication cost are higher than in a decentralized market. Another factor in favour of the decentralized market is the high customer centricity as different objectives based on consumers' preferences can be addressed (Zia et al. 2020). However, a decentralized market requires a sophisticated architecture with several market layers (e.g., user layer, network layer, system operator layer, market layer, distributed ledger layer, communication layer, and regulation layer) and a two-way communication system to ensure accurate communication flows among the participants, which makes its establishment more complex (Zia et al. 2020, Khorasany et al. 2018). Another issue that only occurs in decentralized markets, due to the lack of a mediator, is a competition among market participants that occasionally results in price peaks (Jin et al. 2020). Tab. 1 summarizes these differences.

Tab. 1: Comparison of centralized and distributed/decentralized markets

Market design	Centralized	Distributed/decentralized
Management	Independent coordinator	Directly among peers
Complexity	Similar to conventional power systems	Higher than conventional power systems
Market implementation	Less complex	More complex
Control	Single central aggregator	No aggregators required
Market scalability	Low	High
Transparency	Low	High
Reliability	Low	High
Computational cost	High	Low
Communication cost	High	Low
Market objectives	Operator-centric	Customer-centric
Communication system	One-way	Two-way

A compromise between centralized and fully decentralized market design is a partially decentralized market, in which the control is divided among more than one aggregator, which naturally leads to a competition among them and additionally among different power producers (Zia et al. 2020). To overcome issues concerning the competition or communication failure among participants, both in centralized and decentralized markets, Khorasany et al. (2019) refers to market segmentation based on participants' preferences, which could concern, for instance, economic benefits or environmental protection aspects. By segmentation of consumers and prosumers, communities can be created under the control of a community manager. This has the advantage that the single members are more involved in the LEM/LEC due to a social cooperation, resulting in the maximization of local energy sharing, prediction of participants' behaviour is possible and therefore a better handling with demand peaks and finally, customer centricity can be set to an even higher level (Zia et al. 2020).

Another distinguishing factor of energy markets is the timescale of energy transactions. These can be processed either in a day-ahead timescale (1 hour intervals) or in real-time (5 to 15 minutes intervals). Real-time markets may provide a lower average price of energy; however, real-time processing leads to a higher volatility of prices (Dowling et al., 2017). This could cause uncertainty for consumers. According to Alam et al. (2017) involatile prices in real-time markets lead to an imbalance of demand and supply as naturally the demand for energy increases if the price is low.

4. CONCLUSION

With the advent of the modern concepts of LECs and LEMs new opportunities arise while pursuing the path to sustainable and renewable energy systems. Especially the role of the individual market participants gains more and more importance as with the possibility of P2P energy trading the classical passive consumer can now actively participate in the energy trading system. Furthermore, the ongoing transformation of more and more of these passive consumers into active prosumers yields additional opportunities and challenges for the existing infrastructure. On the one hand, additional revenues can be obtained by prosumers together with an active participation in the course of energy transition. On the other hand, for example, a DSO has to overcome new difficulties with the increasing penetration of RESs in the existing systems, by monitoring and balancing the volatile energy production (e.g., from photovoltaics or wind turbines). However, LEMs and LECs are a key development for achieving the goal of climate friendly energy systems and thus will play a major part in the short- and long-term future.

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