Decentralizing Energy Systems Through Local Energy Markets: The LAMP-Project

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Abstract. The increasing amount and volatile generation from renewable energy sources causes challenges for its integration into the German energy system. Furthermore, the rise of smart prosumers and energy aware consumers results in new energy users and small-scale producers that are currently excluded from the energy market. We conduct the decentralization of the energy system into local energy markets on which consumers and prosumers can trade locally generated energy within their community. We present the ongoing implementation of a local energy market project in Germany, the LAMP-project. To give an impression of the project's results, we simulate the LAMP market in a multi-agent simulation and evaluate the projected market prices and level of self-consumption. Local energy markets as new concepts of energy systems call for innovative information technologies to support the decentralization of the formerly centralized energy system. Therefore, we use the innovative blockchain technology to sustain the implemented LAMP market.

Keywords: decentralization, local energy market, renewable energy, blockchain.

1 Introduction

A main objective of the German government's *Energiewende* is to increase the share of renewable energy sources (RES) in the electricity generation to 60% by 2050 [1]. At the same time, criticism of the current centralized electricity system in terms of its costs, environmental impact, transmission losses and security vulnerabilities has been constantly growing [2]. A change from the formerly linear energy value chain to a complex and multidirectional system seems inevitable [3]. Due to the distributed nature of RES, a decentralization of the German energy system into localized energy balances seems natural. Adding the roles of active prosumers (consumers, who also produce energy) and energy aware consumers leads to the idea of local energy markets. A local energy market (LEM) is a market platform, that offers local producers, prosumers and consumers the opportunity to trade energy locally at prices of their own valuation [4].

To validate current LEM research, we implement a prototypical LEM between up to 20 household residents in Landau, Germany (Landau Microgrid Project (LAMP))[1]. We

[1] http://www.energie-suedwest.de/unternehmen/projekte/lamp/

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measure the market development and participation as well as the participants' acceptance of the project. Firstly, we conduct a literature overview of current LEM research as an introduction into the topic. As the project is currently ongoing, we then focus on an agent-based simulation of the project's setup to show insights into the predicted market results.

2 State-of-the-Art: Local Energy Markets

LEM aim at maximizing the utilization of distributed RES in a specific region [5] by offering a local marketplace for prosumers and consumers. LEM are often community-oriented and put emphasis on empowering their community, decreasing electricity costs and reducing electricity production by conventional sources through encouraging local RES [6]. The idea of using LEM to integrate RES into existing energy systems has been around for several years [7]. [8] argue that LEM can be used for integrating large amounts of fluctuating RES into the energy system and will incentivize RES more efficiently on a prosumer level than the current centralized energy market. [9] give a short overview of energy auction mechanisms in local energy markets ranging from double-sided auction models to continuous double auctions, that give insights into LEM efficiency. [10] also focus on a stock exchange model. However, they put emphasis on the decentralized nature of LEM and give public access to the entire order book.

The compatibility of LEM designs with current regulation is a critical topic that is not sufficiently addressed yet. [11] draw attention to the importance of European regulation by discussing how LEM can be implemented in different ways. New regulation needs to be able to cover several market types as long as no superior LEM framework emerges. Furthermore, the transaction object of LEM is not yet clearly defined. While several authors focus on energy demand and generation for trading on LEM, e.g. [12], others focus on balancing and reserve energy trading, e.g. [13].

A large drawback of LEM is their limited number of potential market participants and tradable volume, which may result in limited market liquidity [13]. Thus, LEM need to be well adaptable to low liquidity markets or participation needs to be ensured.

Recently, LEM are often associated with being the ideal scenario for combining the innovative blockchain technology and the energy sector [14]. Blockchains consist of a secure chain of data blocks. The content of a block is unchangeable once it is confirmed. The chain is ordered chronologically and distributed to all participating nodes. The addition of new data is protected by a decentralized consensus mechanism and cryptographic security measures. Thus, blockchains are a distributed software architecture that may enable agents to interact amongst each other without the need of a central intermediary [15]. The distributed software architecture as well as the absence of need for a central intermediary and the secure transaction platform are the main reasons why blockchain-based energy trading is currently being actively discussed.

Implementations of LEM have developed very recently. German companies (e.g. Lumenaza GmbH[2] and sonnen GmbH[3]) develop concepts to buy and sell locally

[2] https://www.lumenaza.de/
[3] https://www.sonnen-batterie.com/de/home

produced electricity on a residential level. These projects give residential customers the chance to become more active in their energy procurement. However, the introduction of blockchain technology promises a real-time market place without supervision by a central intermediary. Such markets are not yet implemented in real world scenarios. The worldwide first project implementing a (near) real-time, blockchain-based LEM with active traders is the Brooklyn Microgrid [14]. However, the project is not yet market-ready and its academic evaluation is just beginning.

There exists a considerable gap in academic literature discussing blockchain-based LEM, and industry actually implementing projects of blockchain-based LEM. We address this research gap and conduct a comprehensive approach towards the implementation of a blockchain-based LEM by leading and shaping LAMP from an academic point of view. We conduct a rigorous project management and research approach in terms of replicability and control over the project's and participants' degrees of freedom. Thus, we are first to implement a pilot project of a blockchain-based LEM and to evaluate the pilot according to strict academic guidelines.

3 The Landau Microgrid Project (LAMP)

The LEM in LAMP is being implemented between up to 20 residential households on an area grid in Southern Germany. The residential consumers and prosumers (photovoltaic (PV) systems operated by the local utility) access the LEM within their community via a specialized smartphone application (app). They can set maximum prices for buying local electricity as well as minimum prices for selling their PV production within the community. The local energy retailer provides the payment system, while an energy service company provides the market place and blockchain infrastructure. Every market participant can propose one order (bid or ask) for local electricity every 15 minutes. These orders are matched by a central market mechanism at one market price per time slot. Orders are generated automatically based on the price preferences the market participants provide via the app.

Thus, LAMP provides its participants with the chance to buy locally produced electricity at prices of their own valuation. Thereby, they can support their community through keeping the profits within the vicinity. Furthermore, reinvestments in RES are encouraged as projected market prices (see Figure 1) are expected to settle above the current feed-in tariff for PV energy in Germany. The objectives of LAMP are:

1. Design and implementation of a prototype blockchain-based LEM abiding by German regulation
2. Evaluation of market and agent behavior, motivation, acceptance and participation of German residential energy customers to participate in a LEM
3. Evaluation of reached autarky, simulated vs. real local electricity prices and comparison to the existing green electricity tariffs

3.1 Simulation of LAMP

During the project-planning phase, several LAMP simulations were conducted. We extend the market model from [4] that already focuses on small-scale LEM and specify it to the exact planned LAMP setup to project LAMP's market behavior. Thus, we simulate 20 residential German households based on randomized H0 consumption profiles as well as five 5 kWp PV systems based on measured data from German PV panels over one year. Hence, 15 consumers and 5 prosumers are simulated that trade electricity every 15 minutes for the next time slot. The simulation results yield a necessary understanding of the project before implementation and a direct transmission of [4]'s theoretical market model to a practical implementation.

Based on a time discrete double auction mechanism [4] the 20 households trade for the locally produced PV electricity. Based on a price descending (ascending) order for bid (ask) orders, the lowest priced bid order still served by the aggregated local generation sets the market price for local electricity in the current time slot. In LAMP, we only auction local PV electricity in addition to the still existing German electricity tariffs. This means, that electricity supply, balancing energy and grid stability are always ensured by the existing connection of the area grid to the public grid. Thus, the LAMP marketplace is an addition to the current energy market and an experimental project in which we determine the market behavior of the typical German electricity customer without changing the level of service security to which he is accustomed.

Assuming the typical energy customer has little knowledge about strategic bidding in energy markets and is risk-averse [16], it is natural to assume that he will bid prices between the current feed-in tariff for PV electricity (0,1231 €/kWh) and his current variable electricity price (0,2549 €/kWh) in the LAMP region. Provided a basic understanding of markets, we assume the LAMP participants (or agents) to be able to learn from their past trades and adjust their bidding strategies accordingly. Thus, we implement a basic, continuous learning algorithm for electricity agents [17] which adapts the probability to choose a certain price for local electricity on the LAMP market according to [4]. We assume a perfect forecast for generation in the next time slot.

In the LAMP simulation, we arrive at a mean self-consumption of local PV electricity in LAMP of 42% of the aggregated generation over one year. The agents directly consume 26% and trade 16% of the locally produced PV energy. Consequently, the market place increases the self-consumption by 16%. Figure 1 shows the typical course of the PV price on a winter and summer day. It differentiates between the local market price and the overall electricity price, which includes the weighted local prices as well as the weighted energy prices at standard electricity tariffs.

Obviously, the local electricity price during a typical winter day only decreases during midday, when the solar irradiation and the corresponding PV production is high. During summer, due to long hours of solar irradiation, local prices begin to drop as early as sunrise and stay low until evening.

It is interesting to note that local price levels always drop to approximately 0.16 €/kWh once PV production is high. This is due to the very similar production of the 5 PV systems in the simulation (in a local scenario irradiation can be expected to be similar). Thus, all prosumers sell excess energy simultaneously during the day when consumer demand is low compared to local supply. Hence, local prices decrease in the competitive environment. Accordingly, less PV production increases price levels. Figure 1 also shows that the overall electricity price approximately follows the local price. Thus, once local electricity is produced, it amounts for a high percentage of the local demand. Hence, the market participants' overall electricity price is only slightly higher than the local price during generation hours. However, as PV only produces during daylight hours and mostly in summer, the mean yearly overall price for all electricity procured converges at approximately 0.24 €/kWh which is 94% of the original electricity tariff. Yet, the mean yearly price for only local electricity is 0.20 €/kWh. This shows the potential for significantly lower local prices. However, it cannot be exploited due to the temporal discrepancy between demand and PV production. Energy storage or another source of local generation could reduce this issue.

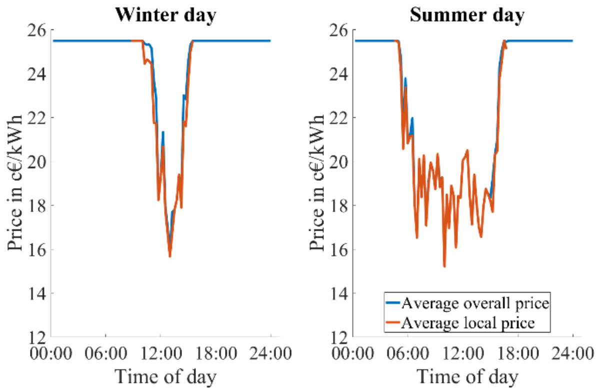

Figure 1. Local PV electricity price (red) and average overall electricity price (blue) during a typical winter and summer day.

3.2 Discussion of LAMP Setup and Evaluation

The conducted simulation can partly project the expected market behavior of LAMP. Yet, especially the agent behavior, which we assumed to be rational, is difficult to project and highly influences the implementation results. Thus, we need to be careful to directly transfer the simulation evaluation to the implementation. Consequently, we only draw broad conclusions. Specially, we do not deem the simulated electricity prices to be reliable enough for an in-depth conclusion and expect differing prices in the implementation as the agent behavior is largely untested yet.

One conclusion we can draw from the simulation is that to reach a high autarky of the community, a second source of energy generation and/or energy storages should be added to the project. A thorough evaluation should document changed bidding behavior and community self-consumption through these additions. The simulation runs of LAMP show that self-consumption can be increased by approximately 16% through solely PV generation. The combined 42% of autarky do not represent the aspired high level of autarky for which the project was designed. Thus, we decided to further include controllable local generation. Due to usual implementation challenges (regulation, budget) we decided on a combined heat and power (CHP) plant with a maximum of 80 kWh to be incorporated in LAMP. Thus, the project setup will be as follows.

- 20 residential market participants
- 25 kWh residential PV production

- 80 kWh CHP
- Blockchain-based market trading platform in 15 minute time slots

In addition to the market and participation evaluation of LAMP, we will also provide a pilot implementation and feasibility study of a private blockchain protocol sustaining a LEM. A technological evaluation study of the suitability and adequacy of using a private blockchain as information and communication system of a LEM will be conducted during the project. We will focus on data consistency, transaction rates and resource consumption of the blockchain as well as susceptibility of errors.

From an LEM perspective, we use LAMP to evaluate real market and agent behavior, and validate and adapt our simulation. Simultaneously, we focus on participation and acceptance of LEM as well as activity on the market.

4 Conclusion

We present the project setup of the ongoing implementation of a LEM in Landau, Germany in the LAMP project. LAMP will sustain a local electricity market place for up to 20 residential households and is based on a private blockchain protocol. We present a research agenda for energy market analysis, social participation and acceptance of LEM evaluation, and technological consideration of blockchain characteristics. Through simulations of the LAMP energy market we show that solely local PV production is insufficient for a high level of autarky. Thus, a CHP plant is added to the project. This is expected to result in a higher level of autarky and should lower the overall electricity prices in LAMP as the CHP energy will be priced below current electricity tariffs. The LAMP project runs from September of 2017 to December 2018. It is one of the very first pilot and research projects of an implementation of a blockchain-based LEM and abides by German regulation.

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References

1. Maubach, K.-D.: 2050. Energiewende. In: Energiewende: Wege zu einer bezahlbaren Energieversorgung, pp. 167–176. Springer Fachmedien Wiesbaden, Wiesbaden (2014)
2. Carley, S.: Distributed generation. An empirical analysis of primary motivators. Energy policy 37, 1648–1659 (2009)
3. Gordijn, J., Akkermans, H.: Business models for distributed generation in a liberalized market environment. Electric power systems research 77, 1178–1188 (2007)
4. Mengelkamp, E., Staudt, P., Gärttner, J., Weinhardt, C.: Trading on local energy markets. A comparison of market designs and bidding strategies. In: 14th International Conference on the European Energy Market (EEM), 2017, pp. 1–6. IEEE (2017)

5. Marzband, M., Yousefnejad, E., Sumper, A., Domínguez-García, J.L.: Real time experimental implementation of optimum energy management system in standalone microgrid by using multi-layer ant colony optimization. International Journal of Electrical Power & Energy Systems 75, 265–274 (2016)
6. Teotia, F., Bhakar, R.: Local energy markets: Concept, design and operation. In: 2016 National Power Systems Conference (NPSC). IEEE (2016)
7. Hochschulte, D., Erlangga, A.S., Ortjohann, E., Kortenbruck, J., Leksawat, S., Schmelter, A., Premgamone, T., Morton, D.: Local energy markets in clustering power system approach for smart prosumers. In: 2017 6th International Conference on Clean Electrical Power (ICCEP). IEEE (2017)
8. Hvelplund, F.: Renewable energy and the need for local energy markets. Energy 31, 2293–2302 (2006)
9. Buchmann, E., Kessler, S., Jochem, Patrick, Böhm, Klemens: The costs of privacy in local energy markets. In: 2013 IEEE 15th Conference on Business Informatics (CBI). IEEE (2013)
10. Blouin, M.R., Serrano, R.: A decentralized market with common values uncertainty. Non-steady states. The Review of Economic Studies 68, 323–346 (2001)
11. Eid, C., Bollinger, L.A., Koirala, B., Scholten, D., Facchinetti, E., Lilliestam, J., Hakvoort, R.: Market integration of local energy systems. Is local energy management compatible with European regulation for retail competition? Energy 114, 913–922 (2016)
12. Ilic, D., Da Silva, P.G., Karnouskos, S., Griesemer, M.: An energy market for trading electricity in smart grid neighbourhoods. In: International Conference on Digital Ecosystems and Technologies (2012)
13. Rosen, C., Madlener, R.: An auction design for local reserve energy markets. Decision Support Systems 56, 168–179 (2013)
14. Mengelkamp, E., Gärttner, J., Rock, K., Kessler, S., Orsini, L., Weinhardt, C.: Designing microgrid energy markets. A case study: The Brooklyn Microgrid. Applied Energy (2017)
15. Sikorski, J.J., Haughton, J., Kraft, M.: Blockchain technology in the chemical industry. Machine-to-machine electricity market. Applied Energy 195, 234–246 (2017)
16. Frederiks, E.R., Stenner, K., Hobman, E.V.: Household energy use. Applying behavioural economics to understand consumer decision-making and behaviour. Renewable and Sustainable Energy Reviews 41, 1385–1394 (2015)
17. Nicolaisen, J., Petrov, V., Tesfatsion, L.: Market power and efficiency in a computational electricity market with discriminatory double-auction pricing. IEEE transactions on Evolutionary Computation 5, 504–523 (2001)