D 1.1: Review on existing local energy market projects in the world

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Blockchain based ElectricitY trading for the integration Of National and Decentralized local markets

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Authors Shafi Khadem; Aziz Un Nur Ibn Saif (IERC-Tyndall)
Contributors

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1. Introduction

Depletion of hydrocarbon energy resources and associated environmental impacts are driving the rapid integration of renewable energy resources into the existing electrical power network. In addition to the large-scale renewable generation plants connected to the transmission network, there is also growing trend of distributed energy resources, predominantly renewable generation, located on-site or near to the consumers. Besides the integration of DERs, the possibility of demand side management, due to the deployment of storage devices, electric vehicles, smart meters and energy management systems, are promoting transformation of increasing number of passive consumers to prosumers who can actively control their generation, consumption and storage facilities. This opens new opportunity and challenges in the existing power system which are traditionally designed to accommodate large-scale centralized power stations and passive consumers [1].

Present-day electricity market structure does not allow the participation of pro-/consumers to energy, ancillary service market directly. It is because the control, coordination and communication infrastructure that are required to incorporate individual DERs and prosumers into the market are complex and expensive which preponderates the associated potential benefits. Pro-/consumers connected to low voltage distribution networks are commonly represented through energy suppliers into the energy market. The intermediary role of large energy suppliers ensures small scale pro-/consumers are not exposed to the volatility of electricity market price. Nevertheless, countries across the world introduced several indirect market mechanisms to incentivise the prosumers having DERs and flexible resources which successfully resulted in the growth of number of prosumers [2]. Net metering and feed-in-tariff are two widely popular incentive mechanisms being used to involve prosumers with DERs to sell their surplus energy back to the grid [3] [4]. However, the disparity between incentives under net-metering and feed-in-tariff, and wholesale electricity market price leads to suboptimal market clearing which is not beneficial to any of the stakeholders. Another disadvantage of previously stated market incentive mechanisms is that incentivizing injection of surplus energy to the grid at times, when generation is expected to be more than demand, stresses the grid stability. Prosumers having flexible resources are only incentivized by shifting their consumption to hours of the day where the price of electricity is low. Currently, it is done by sending price based indirect control signal though the response of the prosumer to such indirect control signal is uncertain.

To address the transformation taking place in the power system, the centralized, top-down market structure also needs to be transformed into decentralized, bottom-up consumer-centric market model which will better suit the distributed nature of prosumers [5]. With the state-of-art communication technologies and advancement in optimization and control techniques, such automated, decentralized, consumer-centric market model is appearing to be more realistic and potential [6]. Consumer-centric electricity market will not only enable prosumers taking price-maker role, but also creates an energy management platform to control and coordinate a cluster of DERs and prosumers in autonomous way.

2. Local energy market

Local Energy market is the heart of the consumer-centric electricity market approach. Local Energy Market (LEM) is a market platform provided to participants under a local energy community (LEC) to involve in localized energy trading engaging generation, flexible demand and storage resources located at participant's premises. Aforementioned market place under LEM empowers the community by allowing prosumers and consumers to interact among each other with/without central intermediary as well as helps better integration of distributed RES incentivizing RES effectively at end-user stage compared to central support scheme. Depending upon the structure of LEM, it may also deliver opportunities to a small-scale participant in LEC to participate in regional / national electricity market or to offer system services through aggregators. In order to achieve the consumer-centric approach of LEM, energy management mechanism under LEM requires to be decentralized and automated in nature. Peer-to-Peer (P2P) and community based trading framework are suitable, effective energy management schemes that enable the pro-/consumers to participate in trading in localized level and also to other stakeholders [7]. One of the key challenges in implementing Peer-to-Peer (P2P) and community-based trading is the need of a technology that enables the decentralized, automated trading respecting the user's anonymity and privacy. Blockchain emerges as a promising technology serving the previously mentioned features LEM [8]. Digitalized marketplace created by blockchain offers benefits not only to central market players in terms of re-structuring the traditional infrastructures in efficient manner but also to the energy end-users who are confronting rise in energy bills and removal of market incentives to prosumers.

The bottom-up nature of P2P and community-based energy trading eliminates the need of top-down approach of electrical energy market. Collaborative principle underlying the P2P and community-based energy trading permits the direct communication and exchange of energy among market participants avoiding the centralized market players. Therefore, formerly mentioned trading structures are entirely compatible with the decentralized and localized nature of prosumers with DERs within a community. Through such market mechanism, interested customers are allowed to purchase surplus renewable energy from neighbours in the local community which results in maximization of green energy usage, reduction on grid dependency, increase in prosumer's revenue and also reduction in consumer's electricity bill. Apart from previously mentioned benefits, these market structures also aid aggregation of excess energy of LEC to participate in regional/national market and/or to offer flexibility, by altering generation and consumption activated by direct and indirect control signal, from small scale participants in LEC to contribute to different services. LEM can be classified into three categories based on underlying P2P framework: i) full P2P market, ii) community-based market and iii) Hybrid P2P market combining the previous two categories [9].

3. Existing local energy market projects

There are several finished and ongoing projects that exist across the world. From the perspective of product value-streams, LEM projects can be categorized largely into following: First, LEM projects with focus on only energy trading among participants within local energy community where electricity is traded as energy content, Secondly, LEM projects having focus on acquiring, trading flexibility from market participants in local community to provide system services to local DSO, balance responsible party (BRP) and TSO. Lastly, few of the LEM projects go beyond the aforementioned single product value-streams to several where trading of electricity has both energy and flexibility value-streams. The electrical boundary of the LEM projects is usually limited within the low voltage (LV) distribution grid, however often it scarcely, transcends to medium voltage sub-transmission grid and high voltage transmission grid depending upon system size associated with the project. Overall framework of LEM consists of market design, business model development, control architecture, ICT infrastructure. The emphasis put into each constituent of LEM also varies with project goal. Undergone/existing projects on LEM differentiate from each other based on their product offering, system size, and specific focus on certain process of the LEM framework. The rest of the section describes different projects in detail with a summary presented in Table *1* .

1.1. Quartierstrom

This is a LEM project funded by Swiss Federal office of Energy. The real-life pilot site of the project was built in Walenstadt, Switzerland where 37 households are involved in P2P trading aimed at local consumption of locally produced solar energy [10] [11]. The implementation phase of the project has undergone throughout the 2018 and the local market has been in operation since January 2019. A blockchain based platform incorporating double auction algorithm has been developed. To encourage the local consumption of locally produced electricity economical, a locational grid tariff has been introduced which is competitively lower than usual grid tariff taking into account that a small portion of grid is being used for transferring energy. The project does not have any special incentive mechanism to sell the surplus energy of the community to the grid. In future, the project is also planning to have seven households with combined storage and PV facilities along with a virtually connected charging station for electric vehicles.

1.2. LAMP

LAMP is a German industry-academia collaborative project supported by Federal government which implements a prototype blockchain based LEM. A merit-order based market mechanism is implemented with trading happening every 15 minutes in LEM. This project currently consists 20 residential consumers and two producers (having PV and CHP in portfolio) located at Hospital garden in Landau, Germany where they participate in trading for buying/selling of local generated electricity within the community. The project targets to increase the number of participants in LEM to 100 households residing in the community. The purpose of the project is to design a LEM that encourages consumption of local, green energy. In addition, the project investigates market price resulted from locally produced electricity and observes the interaction of market participants within LEM [12].

1.3. EnerChain

EnerChain project delivers a P2P energy trading infrastructure for wholesale market players. It allows energy traders in the wholesale market to engage in P2P trading without any need of central exchange. EnerChain supports trading of spectrum of products ranging from wholesale products, e.g. electrical energy, gas, or flexibility products needed for system services or regional products, energy trading among energy communities. In the proof of concept phase conducted between June 2017 and March 2018, around 40 European trading entities jointly involved in P2P trading using the Enerchain platform. Enerchain trading platform is based on blockchain technology which takes transactions to be finalized within one second [13].

1.4. NRGcoin

NRGcoin project develops bitcoin-like digital currency which incentivizes the local balancing within a community by consumption of local, green energy [14]. This market mechanism is based on blockchain and smart contract and is capable of operating in parallel with the existing centralized electricity market. In the proposed market structure, injection of green energy is only incentivized when consumed locally near to real time, otherwise the excess injection is not remunerated. This market mechanism helps local balancing of energy within the community and therefore contributes grid stability. The provision of virtual currency, generated through blockchain based smart contract, offers the market participants to trade green energy without being exposed to volatility of electricity market and to be paid instantly.

1.5. The Energy Collective

The Energy Collective project is the first Danish demonstration site, situated in Svalin, Denmark, hosting consumer-centric, local energy market. Svalin community is a co-housing community having 20 households, equipped with solar PV and EV charging facilities, and shared infrastructure of solar heater and heat pump. The community is annually energy positive. The project intends to investigate consumer-centric market design where pro-/consumers are allowed trading and exchanging energy inside the community with the possibility of providing system services to DSO through aggregation [15].

1.6. P2P SmartTest

This project is a R&D collaborative project involving academia and industry started on 2015. The project explored P2P approach among microgrids to better incorporate the demand-side flexibility and DERs in the distribution network. In the proposed project, a hierarchical structure has been considered with microgrids, cells (consists of several microgrids) and multi-cells. P2P operation among the microgrids facilitates energy trading within a particular cell or with neighbouring cells or wholesale market through aggregator [16]. Different system services required by DSO or TSO have also been considered. It is also examined that overall P2P design enhances the reliability of the distribution network. The project especially focuses on control architecture and ICT infrastructure necessary to implement the proposed P2P approach.

1.7. EMPOWER

EMPOWER project worked with the development and validation of cloud based ICT platform and user app. The cloud-based ICT platform is designed to accommodate a local energy market managing local renewable energy resources, active participation of prosumer. A new, central role has been created for local energy market named “Smart Energy Service Provider (SESP)” which manages necessary operation, within the community and outside as well, through developed cloud-based ICT platform [17]. Three business models, based on three different value streams: electricity trading, flexibility trading and other services, have been investigated as use cases.

1.8. INVADE

This project investigates a cloud-based flexibility management system implemented to manage wide range of storage facilities: mobile-electric vehicles, centralized - central battery energy storage in substation, distributed-batteries in prosumer premises. The central cloud management system manages storage resources to aggregate flexibilities for the benefit of DSO, e.g. network congestion management, voltage regulation, and BRP, self-optimization of portfolio to mitigate imbalance. Throughout 2019, several use cases have been tested in large-scale pilot site situated in Norway, Germany, Spain, The Netherlands and Bulgaria [18].

1.9. DOMINOES

The project investigated a scalable local energy market platform that allows energy trading among prosumers in the community and also facilitates trading of energy and flexibility with other market players: DSO, TSO, retailer and aggregator [19] [20]. A central entity named ‘Energy Community Service provider (ECSP)’ acts as an intermediary to trade energy/flexibility outside of the community and enables LEM solutions. Use cases planned to demonstrate in the project are based on different LEM solutions serving different stakeholders e.g. DSO in local grid management, energy community to maximize its economic benefit, retailer to self-optimize its portfolio and DSO/TSO to mitigate imbalance. The project plans to validate the use cases in three types of sites: microgrid environment in university laboratory, distribution grid environment in pilot site and VPP demonstration in commercial sites.

1.10. PEBBLE

PEBBLE project is a R&D project supported by Federal Ministry of Economic Affairs and Energy in Germany started from March, 2018. The project aims to design, develop and validate a prototypical, blockchain based digital platform which will establish a LEM for decentralized energy trading within market participants in the community without violating grid constraints [21]. The energy trading is performed with an objective of utilizing expected flexibility to support local balancing and to provide grid services if necessary. Provision of energy trading is present for both DA market and intra-day market to reduce the effect of forecasting error to possible extent. Market matching algorithm in the project is auctioned based and blockchain based P2P strategy will be implemented in settling contractual agreements. The project plans to demonstrate for validation in simulation and in a pilot site in Southern Germany.

Table 1: Overview of key local energy market projects

Project Name (Start year)	**Country**	**Types of product/ value chain stream**	**Grid status**	**Focus participant**	**Market design**	**Implementation status**	**Objective/ Outcomes**
Quartierstrom (2017)	Switzerland	Energy	LV network	Consumer, prosumer in community	P2P trading confined local community (Blockchain-Tendermint)	Field level demonstration	P2P trading of locally produced solar energy for local consumption
LAMP (2017)	Germany	Energy	LV network	Consumer, prosumer in microgrid	P2P trading confined within microgrid (Blockchain - Ethereum)	Field level demonstration, live simulation of blockchain based market platform	P2P trading of local solar energy within neighbours in microgrid
Enerchain (2017)	Europe	Different form of energy (electricity, gas), flexibility	Not network restricted	Wholesale market players e.g. suppliers, utility companies	P2P trading among suppliers in a wholesale market (Blockchain - Tendermint)	Proof of concept,	Generalized P2P trading platform to replicate trading in wholesale market level for any product
NRGcoin (2013)	Belgium, Spain	Energy	LV network	Consumer, prosumer in microgrid	P2P trading confined within microgrid (Blockchain)	Proof-of-concept , Lab based prototypical demonstration	Virtual currency based trading platform, that co-exists with current wholesale market structure, also incentivizes the consumption of local, green energy

Project Name (Start year)	Country	Types of product/ value chain stream	Grid status	Focus participant	Market design	Implementation status	Objective/ Outcomes
The Energy Collective	Denmark	Energy	LV Network	Consumer, prosumer in microgrid	P2P trading confined local community (Blockchain - tbd)	Proof of concept	Deployment of P2P trading based consumer-centric electricity market in Denmark
P2P SmartTest (2015)	Spain, Belgium, UK and Finland	Energy, flexibility	LV, MV network	Microgrid in distribution grid level	P2P trading between microgrids (Blockchain not implemented)	Proof of concept	Investigates control and ICT architecture to facilitate P2P trading between microgrids for energy market and system services.
EMPOWER (2015)	Europe	Flexibility	LV network	Distribution grid level	Centralized optimization by local central community manager	Proof of concept	Development and validation of cloud based ICT platform and user app to facilitate local energy market
INVADE	Europe	Flexibility	LV network	Storage units in the distribution grid	Centralized optimization by local central flexibility manager	Proof of concept: large project site demonstration	Cloud-based flexibility management systems to empower distributed storage, to provide range of support services to distribution grid and BRPs

Project Name (Start year)	Country	Types of product/ value chain stream	Grid status	Focus participant	Market design	Implementation status	Objective/ Outcomes
DOMINOES	Europe	Energy, Flexibility	LV network	Prosumer, consumer in the community	P2P approach for energy trading within community, centralized optimization for gathering flexibility to offer external stakeholders	Proof of concept	Development of a market platform that enables prosumer to engage with other prosumer and also with different market players: retailer, DSO, TSO, aggregator.
PEBBELS	Germany	Energy, Flexibility	LV network	Prosumer, consumer, DSO	Blockchain based decentralized market structure within community	Proof of concept, Lab based simulation and pilot site demonstration	Development of prototypical blockchain based grid-compliant energy trading platform to establish local energy market.

4. Take-away for BEYOND

BEYOND project aims to design, demonstrate novel electricity market and business models which will integrate local energy market to regional-national electricity market using P2P model. The projects mentioned in this report can be classified broadly into the following categories, **Category 1:** LEM projects only focusing on local utilization of energy, **Category 2:** LEM projects focusing on providing services to DSO, BRP by exploiting the flexibility in the LEM and **Category 3:** LEM projects having characteristics of both categories formerly mentioned to an extent. Considering the objective of the BEYOND project, it is imperative that projects falling under above categories should be taken into account for further use in BEYOND project LEM design.

Quartierstrom, LAMP, NRGCoin and energy collective projects are under category 1 implementing the local usage of locally produced energy. Majority of the projects are real-life demonstration in pilot sites and do not have arrangements of providing services to grid or other external stakeholders. The interaction of LEM with grid is mostly business as usual. INVADE project is designed to create LEM offering services to DSO or BRP similar to category 2. This category does not prioritize the local consumptions rather focuses on using flexibility present in the local community to offer services to DSO and BRP. P2P SmartTest, EMPOWER, DOMINOES and PEBBLES emphasizes on creating LEM offering both services: local balancing of energy and participating in providing services to other stakeholders: DSO, BRP, TSO and other wholesale market players. Few of the projects solely consider trading of energy among market participants whereas other projects are based on either flexibility or energy and flexibility both. LEM Projects offering flexibility, are mostly focused on developing marketplace to provide services to different external stakeholders with an intent of maximizing benefit to prosumer/ local community. Market participants of all the LEM projects (except EnerChain), local DER owners, consumers and prosumers, are predominantly connected to low voltage distribution network, very often in the medium voltage grid.

Proof-of-concept phase/ live demonstration considers that the local market community is connected to the public electricity grid and interacts with external local community/ stakeholders through grid to exchange excess/deficit power. Market platforms of eight of the projects involve P2P approach whereas EMPOWER and INVADE both use centralized optimization approach. Among eight of the projects using P2P approach, all of these deploy blockchain technology except P2P SmartTest, which implemented P2P using dual decomposition technique.

The outcome of the project also varied on different projects: Quartierstrom, LAMP, NRGCoin, energy collective, DOMINOES and PEBBLES projects are more focused on creating market platform associated trading mechanism, business models, P2P SmartTest was having emphasis on ICT and control architecture and research of EMPOWER and INVADE projects are having more attention on developing cloud-based ICT platform facilitating the LEM. EnerChain project is different from all the projects mentioned in the Table *1* and eventually is not related with LEM. However, the capability of P2P trading within wholesale market players demonstrated in the EnerChain project provides useful insights in market designs where LEMs trade among each other and with other wholesale market players.

5. Conclusions

After reviewing the ongoing research projects on LEM, it is found out that research work in LEM projects are yet in their nascent phase considering their participation in regional/national electricity market. LEM projects are usually focused on specific goals where different LEM designs are directed towards either local consumption of locally generated electricity or providing different services, using flexibility present in the user's end, to external stakeholders outside of the energy community through the grid. Research work, integrating the above-mentioned approaches, requires to be investigated for full-fledged, wide-scale implementation of LEM and identify necessary changes in the current structure to accommodate LEM. Progress on such research is still a long way to go. Therefore, the outcome of the BEYOND project will pave the way for future development.

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