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Local Flexibility Markets in Smart Cities: Interactions between Positive Energy Blocks

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Adoption of solar PV and other distributed generation sources are becoming widespread and affordable across Europe. Local on-site energy production raises the chance to manage surplus energy (especially for variable renewable sources, solar or wind) and exploiting possible local flexibility sources (e.g. storage, load shifting, and others). These local energy system features has translated into the rise of positive energy buildings which form a cluster labeled as the Positive Energy Block (PEB). In this concept paper and as part of the H2020 project +CityXChange, we discuss the creation of local flexibility markets for PEBs. We propose the electricity trading within the block and the exchange of flexibility locally and externally to other PEBs. This creates added value and incentives for the consumer to exploit energy products and services. As local flexibility markets carry different definitions and connotations in the literature, we propose ideas for a local market based on PEBs. We discuss the value they provide, such as: 1) smoothing and balancing locally solar PV surplus, 2) defer distribution grid investmens and 3) utilizing local energy products.

Key words: Local market design; smart grid; renewable; distributed generation; microgrid; buildings

1. Introduction

As the numbers of prosumers (i.e. consumers producing energy) and local distributed energy resources (DERs) increases, potential power grid problems from the regional scale, i.e., high and medium voltage network, might arise on the local scale, i.e., low voltage network. Developments including electrification of transport (Dyke et al. 2010) and heating systems (Veldman et al. 2011) will alter load profiles in the low voltage network. Technological options to deal with the increased local load variations are many and promising (Lund et al. 2015), but several of these DERs have characteristics hindering them to be fully utilized in current electricity markets. These DERs include small-scale electricity generation at consumer locations (e.g. solar photovoltaics), flexible loads (e.g. charging of electric vehicles), electricity-to-heat converters (e.g. heat pumps) and energy storage (e.g. batteries and hot water storage tanks). End-user flexibility products based on DERs properties could be used as underlying assets for distribution system operator services. This is in

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line with the flexibility markets concept discussed in the literature: technical properties that can be traded in local markets (Eid et al. 2016, Pérez-Arriaga and Knittle 2016). Local flexibility markets can incentivize full or partial control (based on trading) on appliances and DERs. Utilizing local flexibility for multiple purposes is envisioned as a promising resource to integrate RES by the EU energy strategy (European Commission 2016).

This paper elaborates on the design of local markets to facilitate activation of DERs in smart cities. We propose a categorization of assets in a local energy market, including both electricity and heat as energy carriers, and we discuss how different asset characteristics, technological opportunities, objectives and goals will shape the local market design. Section 2 presents different strengths and weaknesses of local market design in smart cities and related research. Section 3 presents our proposed categorization of assets in a local market modelling framework and discusses such a modelling framework can be used to shape the operation of assets. Finally, Section 4 concludes our paper.

2. Local electricity markets and Positive Energy Blocks (PEBs)

Affordable real-time communication technologies is leading a digital transformation in the power system that can bring new opportunities to challenge traditional ideas in electricity market designs. For example, access to the electricity market for agents controlling many small energy assets is yet very limited. As a consequence, research and demonstration projects are exploring the idea of local electricity markets that provide a trading place for energy assets in buildings, districts and cities (Noor et al. 2018, Liu et al. 2019, Morstyn et al. 2018, Mengelkamp et al. 2017, Sousa et al. 2019a, Bremdal et al. 2017). Local electricity markets are defined as the exchange between prosumers and consumers to balance locally and to trade energy surplus (e.g. excess wind or solar), manage load peaks, optimize the use of RES, and maximize the use of flexibility assets.

The literature in local markets is in its early stages. In the last years many concepts and ideas have emerged, which have defined different type of local markets, such as: peer-to-peer (P2P) markets, community based market, hybrid P2P market, and aggregators. These primarily rely on P2P collaboration in a local market: the prosumers and consumers first share their generation and consumption in a local market at internal prices, and then trade with a retailer to cover the remaining electricity deficit or surplus. In this regard, Sousa et al. (2019b) has performed a comprehensive review of P2P and community-based markets, including an analysis of opportunities and challenges. Table 1 presents a summary from a SWOT analysis presented in the review.

All in all, local markets benefits can be summarized in four main services: 1) deferring grid investments and congestion management for the local grid, 2) facilitate local RES integration, 3) preserve power quality (voltage, reactive power and frequency), 4) citizen engagement, and 5)

Table 1 Summary of key potential strengths, weaknesses, opportunities and threats of P2P trading in local markets, from a SWOT analysis performed by Sousa et al. (2019a) in a comprehensive review.

Strengths	Weaknesses	Opportunities	Threats
– Consumers have better choice of supply and possibility to produce and sell their own energy. – Increase resilience and reliability of the system. – Remove potential market power from some players in the wholesale market.	– Sub-optimal energy price of all energy systems. – Potentially overwhelming transition to this consumer-centric market. – Heaviness of negotiation and clearing mechanisms.	– Democratization of energy. – Increase consumers awareness and cooperation towards environmental energy consumption. – Create new business models. – Boost retailer market, since lacks competition. – Postpone grid investments from system operators.	– Legal and regulatory obstacles, which influence the transition to these markets. – Energy poverty for some groups of consumers. – Co-existence with existing electricity markets. – Security and privacy with data. – Potential failure of these markets if poorly structured.

energy savings (increase efficiency in distribution grid operations). These benefits will vary based on the stakeholder perspective, such as distribution system operators, prosumer/consumers or aggregators/retailers.

Local Markets and Smart Cities

A natural replicability and scability setting for local markets concept is its application at the city level. Henceforth, the +CityxChange project (+CityxChange 2019) is demonstrating the utilization of existing potential of end-users with energy assets to ensure efficient development of local energy systems. The objective is to analyze how utilization of existing energy assets motivates the development of Positive Energy Blocks (PEBs). The definition of PEBs based on +CityxChange Project and the European Innovation Partnership on Smart Cities and Communities (EIP-SCC) (European Union 2019) is as follows:

Definition 1 *A Positive Energy Block (PEB) is a group of at least three connected neighbouring buildings producing on a yearly basis more primary energy than what they use. These buildings must serve different purposes [...] to take advantage of complementary energy consumption curves and optimise local renewable energy production, consumption and storage.*

Additionally, asset load levels within buildings in PEBs can be adjusted thorough participation in a local energy market. Buildings within the PEB are able to actively manage their energy consumption and the energy flow between them and the wider energy system. Eventually, the goal is that interaction between PEBs and the neighbouring district will lead to a positive energy district (PED), where PEBs are smaller components of the PED. A PED requires interaction between a

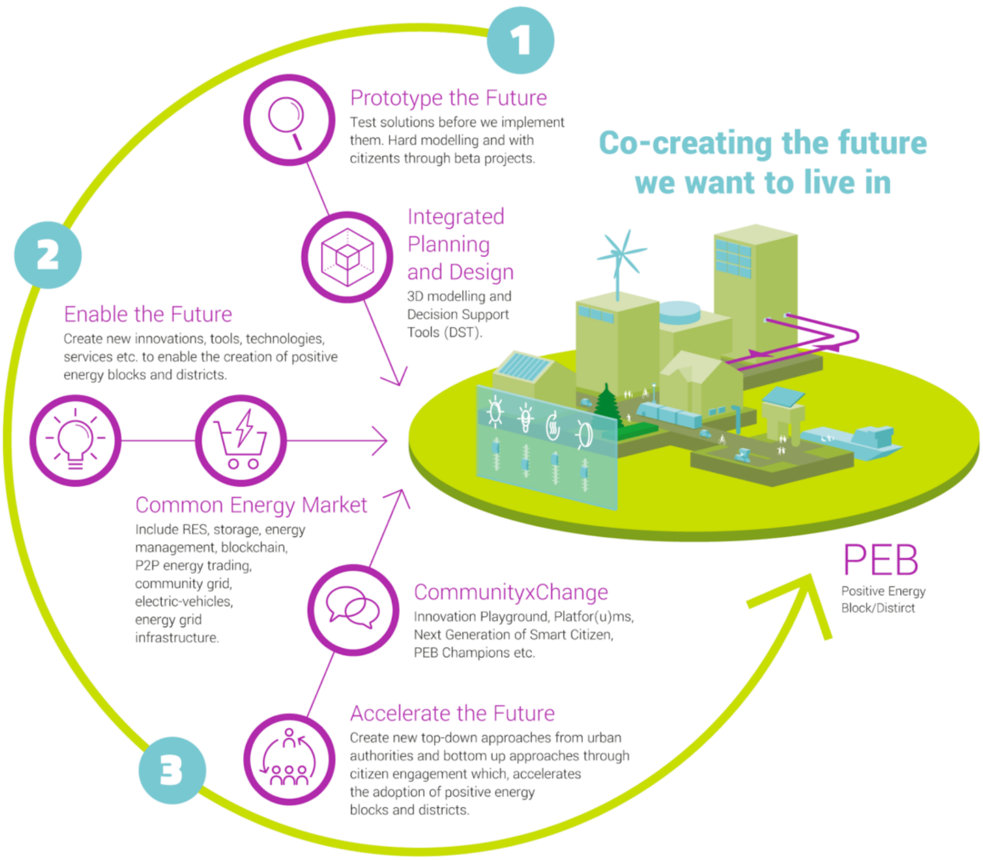

Figure 1 +CityxChange vision process for local energy markets with P2P trading, extracted from +CityxChange (2019).

larger group of buildings, users and the regional energy, mobility and ICT system in an holistic approach (EU-SETIS 2018).

The power outtake with increasing amount of DERs in Europe is expected to increase for the future (Ruiz-Romero et al. 2013). Consequently, low voltage grid problems, such as voltage problems and congestion existence, will increase (Kechroud et al. 2014). These problems will occur due to the variable and uncontrollable nature of DERs. However, if low voltage grid problem are solved by the system operator through use of local resources (Villar et al. 2018), a delay in grid investments and reduction in operational costs could occur. Therefore, geographical location of the resource providing the energy service is important. In addition, the power amount, activation time and duration of the energy service are key characteristics.

On this purpose a local market design should give incentives for end-users and prosumers for their participation in demand response programs (Albadi and El-Saadany 2008) to motivate expansion of local generation plans and participate in dealing with power quality issues. The cost of participation, revenue from the market, degree of competition, trading horizon (day-ahead or shorter), dispatch intervals, and characteristics of stakeholders are all elements of the market design (Ampatzis et al. 2014). In the case of CityXChange project, peer-to-peer (P2P) trading (e.g. as proposed in Zepter et al. (2019)) among PEB participants and PEBs are subject to consideration.

3. A modelling framework for PEBs

We propose a linear programming model to assess local flexibility markets and represent PEBs interactions. We follow local market designs models based on the seminal papers in (Lüth et al. 2018) and (Zepter et al. 2019), but it is tailored and extended to the PEB concept. That is, a smart grid based interaction concept of PEBs that trade through the DSO and a local trading platform. The model minimizes the operational costs for a set of local participants. These can be a mix of PEBs, regular buildings, microgrids and others. In other words, a mix of prosumers and consumers that trade surplus energy or manage local flexibility assets (e.g. storage or demand response). The objective is to minimize the consumption from the main grid by optimally using local flexibility assets and promoting trading among PEBs.

In the linear programming model, we categorize energy asset types in PEBs that can participate in the local energy market. An asset is defined as any component (or collection of components necessarily operating together) producing or consuming energy where there is a possibility to alter operations to balance inflexible load, i.e. both inflexible demand (e.g. occupant controlled appliances) and inflexible supply (e.g. solar PV). We define each asset in the market with an operational cost and capacity dependent availability which could be time varying. Further, we define three different types of assets:

- Flexible Supply Assets (FSA), e.g. dispatchable micro-generators.
- Flexible Demand Assets (FDA), e.g. electric vehicle charging and hot water storage tanks.
- Energy Converter Assets (ECA), e.g. heat pumps and electric boilers.

As an output from the linear programming model, an operational schedule will be given for all the assets. This includes when and how much energy to supply for the FSA, when and how much energy to charge, store and discharge from the FDA and when and how much energy to convert with the ECA to maximize achievement of the objective subject to operational constraints.

The modelling framework will be useful for three purposes: (1) to provide short term operational decisions and propose daily schedules based on daily updated forecasts, (2) to define longer time horizons and analyze long-term operations and support strategic asset procurement based on long-term forecasts, and (3) simulate and analyze different local based market designs alternatives that stimulate (or helps to understand the role of) PEBs trading interactions.

4. Conclusion and outlook

In this conceptual paper, we have outlined a vision and ideas on bringing PEBs to be active actors in the energy transition. Incentivizing trading and active interaction between PEBs will deliver smart grid services that can: 1) provide local supply-demand balance needs, 2) optimize the use of flexibility assets within the PEB, 3) provide flexibility services to the local system operator. But more importantly, it will accelerate the adoption of RES in buildings, improve energy efficiency and operations of distribution grids, and explore new dimensions and ideas for local electricity market designs. Demonstrating PEBs viability within the +CityxChange project will showcase these possibilities under real life conditions and users. At the moment, the city of Limerick (Ireland) and Trondheim (Norway) are preparing a full fledged implementation of PEBs in each city. In Trondheim, around four PEBs will be fully operational by the end of 2020 to demonstrate a local flexibility market between them.

As part of our contribution to the 16th IAEE European Conference, this short conceptual paper provided a short overview on state-of-the-art in local electricity markets: benefits, challenges and opportunities. This focused on examples and ideas surrounding P2P and local market studies to manage peak demands and trade flexibility. This lead to discuss and present the concept of local markets at the city level. The key take away is the notion of modelling the city of Trondheim in order to represent and simulate a local flexibility market for PEBs.

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