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## Local energy markets as a solution for increased energy efficiency and flexibility

To cite this article: Ilieva *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **352** 012036

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# Local energy markets as a solution for increased energy efficiency and flexibility

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**Abstract.** With increasing share of distributed renewable energy resources in the grid and arising energy consumer awareness on environmental challenges new market models are sought where energy can be traded in an efficient and end-user centric way. This trend, together with the increasing consciousness on the benefits of local consumption and production has given rise to an increased focus on local energy market structures. Within the E-REGIO project, funded through the ERA-Net Smart Grid Plus initiative, local energy markets have been paid particular attention. This paper discusses opportunities associated with local energy trading, as verified through the E-REGIO local energy system pilot - Skagerak EnergiLab in Norway. Embracing, among others, local loads, energy storage system, PV generation and a large consumer (stadium facility), the pilot-based simulations have produced some useful insights on the implementation of local energy markets and have helped collect learnings that can be of benefit for future local energy market establishments.

## 1. Introduction

Local energy markets can be considered as a good solution to pending challenges in the local grid. Recent research indicates increased interest towards local markets, giving visibility to the ambition to move electricity trade closer to the end-user [1], [2], [3]. Utilizing a trading platform that can match supply and demand on a local level, thus creating a marketplace for flexible loads, distributed generation and storage, local markets can effectively alleviate problems in the local grid, at the same time as they facilitate a more efficient use of local energy resources. Not less important is the fact that local markets often engage market participants through innovative business models, encouraging them to install technology solutions for local production, distributed storage and demand response [4].

As “local” markets can be considered markets that facilitate trade within a smaller town or a neighbourhood. A precondition for the realization of local trade is the existence of demand that needs to be covered by some form of supply. With the accelerating spread out of distributed energy resources (DER) in the grid, it becomes increasingly attractive to utilize locally produced or stored energy.

The local market envisioned in this work incorporates two types of trade – in energy and in flexibility – which are facilitated by means of a market pool manager. The use of a market platform to facilitate the exchange among independent local suppliers (providers of energy and flexibility) and buyers (in demand of energy and flexibility) can, from economic viewpoint, bring optimal resource distribution and remuneration for trading parties. Yet, in the context of existing grid constraints, some major benefits can be associated with improved operation of the distribution grid (e.g., better quality of supply and



avoidance of local congestions) and increased self-consumption on an individual (prosumer) or collective level. In particular, from a grid operator point of view, local markets for energy and flexibility can have a highly positive effect due to the possibility to effectively manage and aggregate local assets by means of market rules. Thus, grid challenges associated with rapidly increasing capacity needs (e.g., as related to higher penetration of distributed generation and electrical vehicles) can be to a large extent mitigated.

Further, the current work considers the presence of distributed storage as highly beneficial for a well-functioning local market structure and this attitude is well documented within the following chapters. More specifically, the availability of distributed storage can be of particular importance as it can be utilized as an energy bank for both commercial and technical purposes.

The above topics are being met with growing interest as they concern a wide range of actors in the electricity value chain – end users (consumers/prosumers), distribution system operators (DSOs), energy retailers, transmission system operators (TSOs), regulators, technology providers and others. Providing reference towards a unique market design and supporting it by specific real-case implementation with a consequent simulation results, the current scientific contribution helps fill in the research gap associated with the variety of possible cases for operational local market establishments.

To start with, this research work represents the local energy market design as envisioned in the E-REGIO project and reflects on the specific case-based implementation, as valid for the Skagerak pilot. The discussion continues with a description of the pilot site and how it is used to test new and innovative energy-solutions for local energy balance and flexibility that benefit both electricity end users and the grid. Thus, the possible contributions of local market structures to improved grid operations, as experienced by the grid operator Skagerak Nett, are exposed. Finally, this paper provides a conclusive part that reflects on the experiences gained so far from the local energy market implementation and builds the basis for the creation of guidelines directed towards best practices and regulatory recommendations as associated with local energy trading.

## **2. E-REGIO's local energy market design**

The E-REGIO project explores the role of local system operator (LSO) as a facilitator of grid and community services based on an innovative platform that manages local trade [5]. The platform considers the available energy and flexibility resources in the grid to find an optimal market-based match that satisfies the ambitions of local prosumers, consumers and storage owners at the same time as it supports the local grid in its operation.

### *2.1. Overview*

The local market defined within E-REGIO is considered attractive for community members due to its ability to cater for more efficient utilization of renewable and local energy, facilitate smart mobility services and contribute to service diversity and economic benefits for the end users. The design of the local market considers roles, responsibilities and rights associated with local market participation, as well as such that relate to the activities which can be carried out in the market. The activities are to deliver values to different customers of the LSO and within the E-REGIO project this value is investigated through different business cases. The discussion provided in this paper is centred around a business case for the DSO, where increased flexibility utilization by means of local market mechanism enables a more efficient distribution grid operation at the same time as benefits (both direct economic and from value added services) are brought to the end users (providers of flexibility).

From a technology perspective, the efficient local market trading is facilitated by means of an ICT platform that exploits advanced algorithms to find optimal utilization of local energy resources considering both the grid's needs and the preferences of local market participants. Thus, the digitization uptake associate with the utilization of big data, machine learning, and artificial intelligence is well presented into the local market processes. This also helps to accommodate new or amplified business opportunities for the local market participants, bringing increased interest in attaining market membership.

## 2.2. Actors and roles

As a facilitator of the local trading (by means of the platform functionalities), the LSO is a most central local market actor. Within the E-REGIO project the LSO's roles are defined in more detail as: aggregator, market maker, intermediary (between the external electricity markets and the local market), local energy retailer (which caters for attractive, clear and concise energy contracts), energy storage manager, EV operator and local service provider. Considering the preferences of its customers, the LSO carries out a joint optimization of the flexibility loads. In the process the delivery of either grid or community service, or both can be prioritized. Finally, the contracts offered by the LSO can be referred to as flexibility contracts, energy contracts and contracts for various services (e.g., related to community storage, smart mobility or complementary ones).

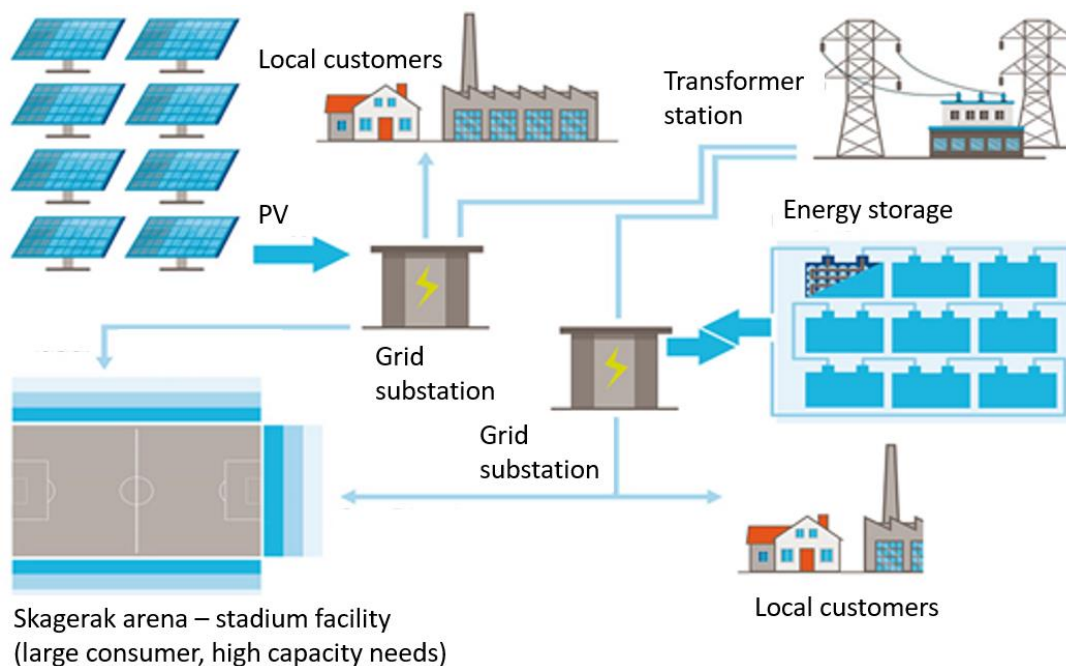
When it comes to the specific LSO customers, these have been divided into two groups. The first group encompasses the end users which are considered the smaller (internal) customers of the LSO. Thus, the end users' group contains the local consumers, prosumers, producers, as well as storage owners and neighbourhood managers, the last being defined as legal entities that manage the neighbourhood community's energy resources. In the second group of LSO customers are classified the external (middle voltage (MV) or high-voltage (HV) level) actors such as DSOs, TSOs, balancing responsible parties (BRPs) or distribute generation facilities of a larger scale (as compared to the local prosumer/producer).

In order to maintain a reliable power supply and ensure grid balancing, external LSO customers may be willing to buy flexibility services. The scope of flexibility services that the LSO can offer is substantiated by its own portfolio of end users. The overview of trading actors and contracting regimes within the E-REGIO project has been provided previously in [6]. While the LSO plays the role of market pool manager, DSO, TSO, energy retailers and producers and the existing electricity market are considered predominantly buyers of energy/flexibility services. These parties are bounded with the LSO through the so called "external contracts". On the other hand, "internal contracts" are meant to define the trading premises of smaller-scale energy and flexibility traders. These are consumers, prosumers, ESS and local producers, as representative for the LSO's market portfolio.

## 3. The Skagerak pilot

The Skagerak pilot (Skagerak EnergiLab) is owned by Skagerak Nett which is one of the largest distribution grid owners in Norway and a part of Skagerak Energi Group. Skagerak Energi Group also includes Skagerak Kraft (dealing with power generation), Skagerak Varme (dealing with district heating) and parts of other businesses such as natural gas and electricity retail. Skagerak Energi has a partnership with Odds ballklubb, Norway's oldest and most environmentally friendly soccer club. Their home stadium, which has the name Skagerak Arena, is used as a pilot site to test new and innovative energy solutions for local energy balance and flexibility that benefits both the customers and the grid.

More specifically, the Skagerak pilot, as shown in figure 1, consists of three large PV installations covering the east, south and west roofs of the tribunes adding up to approximately 5000m<sup>2</sup> in addition to a large energy storage battery. The PV panels and the battery are connected to the local grid supplying the stadium in two different locations. The pilot aims to demonstrate how the PV generation, different usage of the battery and the local consumption can efficiently interact.



**Figure 1.** Overview of the E-REGIO pilot at Skagerak, Norway.

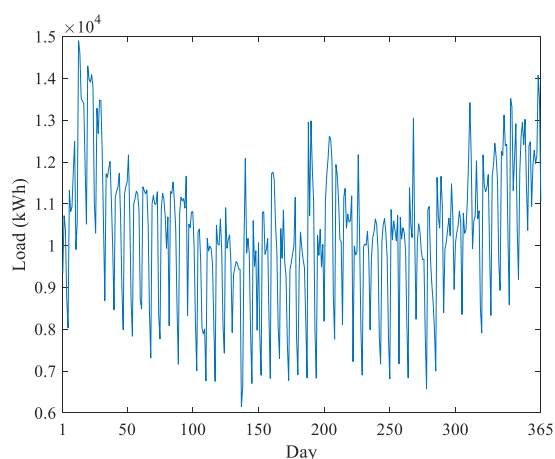
The pilot's PV and energy storage installations will be used to test different use cases for the three actors, subgroups of the described above LSO customer types – end users, power generator and DSO. The energy storage is used by all three actors for each use case isolated but also in combination. In this regard the pilot's ambition is to demonstrate how surplus storage, peak shaving, congestion management, voltage support, frequency support and arbitrage can be successfully achieved through the E-REGIO platform for local trade.

#### 4. Simulation-based studies

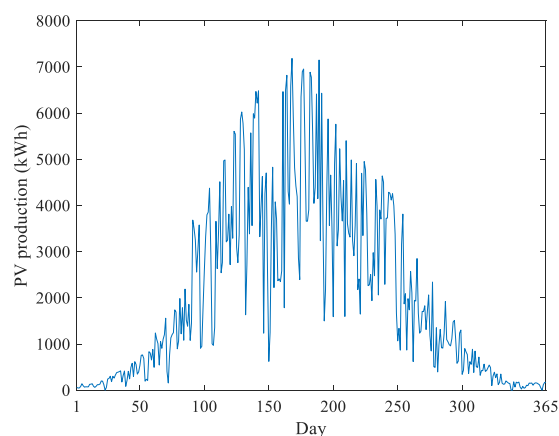
As a background to the simulation studies performed, it should be clarified that the optimal usage of PV and energy storage system (ESS) is assumed achievable by means of local market trade. Thus, the simulation results presented hereby indicate the impact that efficient trade with local energy and flexibility will have on the overall local system operation, with associated profits and costs.

In order to evaluate the E-REGIO concept within a real environment, a simulation effort has been carried out with focus on the above described Skagerak pilot. The simulations address two grid services relevant for the local grid area – dealing with energy surplus and peak shaving. These two services are facilitated based on the local resources available at the Skagerak pilot. In particular, the Skagerak pilot is equipped with a local PV power plant of 800kWp and a local energy storage system of 1000kWh/800kW. Further, the pilot is characterized by a certain local consumption and a connection to the distribution network.

To show the local profiles of PV and load, figures 2 and 3 portray the local aggregate daily consumption and the aggregate daily PV production. Considering the exhibited consumption and production profiles, utilization of a local storage facility becomes of high relevance.



**Figure 2.** Local aggregate daily consumption.



**Figure 3.** Local aggregate daily PV production.

#### 4.1. Description of the simulations

From a conceptual point of view the achievement of maximum self-consumption, from which the grid also benefits, has a first priority. However, within the simulation effort described below some assumptions are made to simplify the modelling work and which may to some extent be limiting the wider range of possibilities for local market trading. Yet, the E-REGIO local market platform to be running towards the project end will cater for increased number of options, as associated with e.g., the ownership of local resources, order of priorities in the optimization process and others.

To develop the simulations, the LSO is considered as the owner of the local resources such as the PV and the ESS. The LSO also manages the resources, maximizing profits but subject to power limits. The simulations reflect a local market concept, but as previously mentioned, involve some model-specific assumptions that are further referred to in the following paragraphs.

Within the simulations, optimization is related to maximizing incomes from injecting energy into the network, minimizing costs of the energy delivered through the distribution network, and minimizing the maximum power limit (kWh/h) per month. The mathematical model allows modelling the services of the Skagerak pilot. The objective of the mathematical model, as mentioned earlier, is to maximize the profits of the local system operator. These profits come from managing all the resources involved in the local energy system as well as from minimizing the energy delivered per hour from the distribution network (peak shaving). The mathematical model maximizes the profits because the local market has an income and costs. The income comes from selling the locally produced surplus energy, while the costs are associated with all resources utilized to satisfy the local consumption needs. The end users are the ones to pay the costs for the local market's operation. For this reason, the local market's optimization should aim to reduce those costs as well as the power limit cost. In parallel, the local market helps with congestion management through the limit of maximum power from the distribution network.

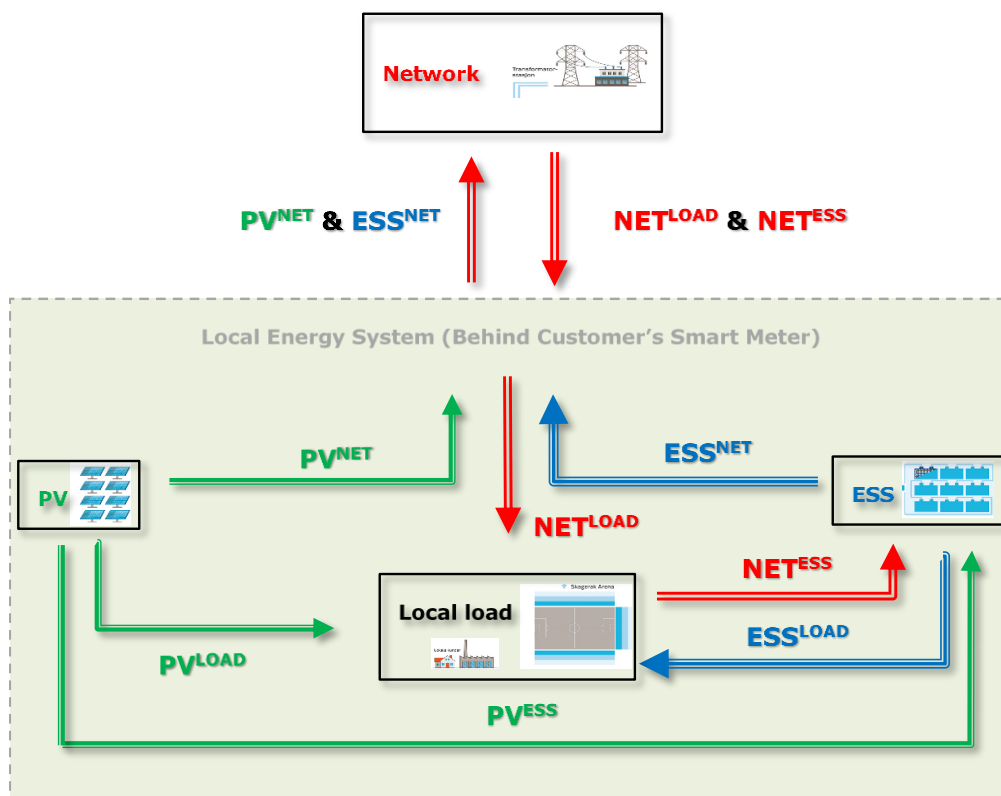
To understand how the local energy system behind the customer's smart meter has been modelled, figure 4 shows an illustration of its different participants. The participants are the network (distribution network), PV (PV production), ESS (energy storage system), and local load (the local consumption). As it was mentioned above, the network, PV and ESS are managed by the LSO, which is, in these specific simulations, considered as their owner. Moreover, the LSO tries to reduce the costs and consume locally the local resources. The local use of the resources is supported by the utilization of PV and ESS, which is considered free of cost. An exception arises in the case when the ESS is charged with energy generated outside the local system.

To model the local market, energy flows among participants are needed. Four local market participants with energy flows between them have been considered, as shown in table 1. Network-delivered energy can be delegated to the ESS and local load ( $NET^{ESS}$  and  $NET^{LOAD}$ ), the PV has energy flows to the three other components ( $PV^{ESS}$ ,  $PV^{NET}$ ,  $PV^{LOAD}$ ), the ESS can charge from the network and PV ( $NET^{ESS}$  and  $PV^{ESS}$ ) and discharge to the local load and network ( $ESS^{LOAD}$  and  $ESS^{NET}$ ), while the local load can only receive energy ( $ESS^{LOAD}$ ,  $PV^{LOAD}$ ,  $NET^{LOAD}$ ).

**Table 1.** Energy flows (start/finish) between participants.

Energy flows (start/finish)	NET	PV	ESS	LOAD
NET	No	No	Yes	Yes
PV	Yes	No	Yes	Yes
ESS	Yes	No	No	Yes
LOAD	No	No	No	No

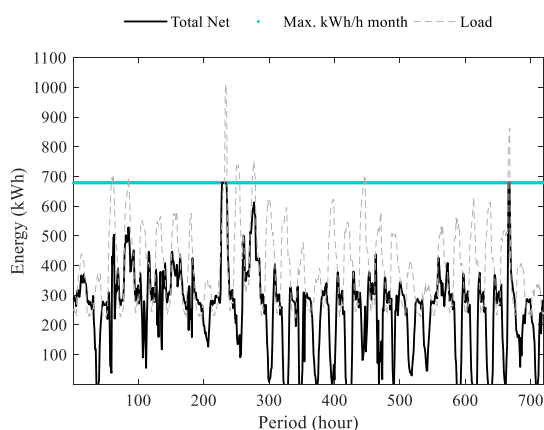
Once the energy flows in the local system are introduced, the costs are only for  $C^{NET^{LOAD}} = C^{NET^{ESS}} = 0,02048$  €/kWh from the 9th month to 4th month and 0,01858 €/kWh from the 5th month to the 8th month (the one-year period September 2017 to August 2018 has been considered for simulation purposes). The tariff for  $PV^{NET}$  and  $ESS^{NET}$  as a prosumer is 0,0039 €/kWh. Besides, the energy per hour imported from the network is a cost equal to 5,54 €/kWh/h per month.

**Figure 4.** Illustration of the local energy system and its energy flows.

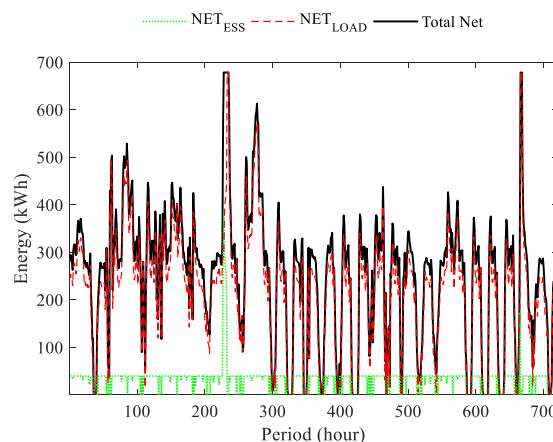
#### 4.2. Results

The volatility of the local PV production and consumption as shown in figures 2 and 3 plays an essential role for the flexibility utilization and for how the local system can mitigate this volatility. In this relation, figure 5 displays the results for the optimal profile of the total energy flow from the network, the limit of peak shaving that is the maximum energy per hour kWh/h from the network and the load. Figure 6 shows how the total energy flow from the network is divided into the ESS ( $NET^{ESS}$ ), and the load ( $NET^{LOAD}$ ). As it can be observed in figure 5, the energy from the network is lower than the load and the flexibility stemming from the local energy system is higher. Thus, the more local resources as PV and ESS are being utilized, the higher the efficiency of local flexibility in matching the local power balance. This higher rate of flexibility utilization is associated with the increase in local resources to

satisfy the local load. In particular, the local system can exploit the ESS for balancing purposes after integrating the PV production locally.



**Figure 5.** Total energy imported from the network (Total Net), maximum kWh/h per month and the load.



**Figure 6.** Energy flow from the network to the ESS ( $NET_{ESS}$ ), from the network to the load ( $NET_{LOAD}$ ), and the total energy imported from the network (Total Net).

Table 2 shows the annual profits of the local energy system behind the customer's smart meter and maximum kWh/h for two local market cases: i) a system without PV and ESS, and ii) a system that includes the local resources PV and ESS, with a round trip efficiency of the ESS equal to 80 % during a one-year period. Thus, table 2 indicates that case ii) has more flexibility because maximum kWh/h is reduced by 24,3 %. This lower maximum kWh/h (peak shaving) reduces the cost (negative profit) of the local system. The energy imported from the DSO network goes from 3.703.454,03 kWh without PV and ESS to 3.313.817,76 kWh with PV and ESS for the whole year.

**Table 2.** Annual profits, maximum kWh/h from the network and differences between cases i) and ii).

Case	Profits (€)	Maximum (kWh/h) per month from the network
1. Without PV and ESS (i)	-135.306,0	11.133,3
2. With PV and ESS with an RTE 80 % (ii)	-113.044,2	8.431,3
3. $\Delta$ (1. - 2.)	-22.261,8	2.702,0
4. $\Delta$ (1. - 2.) %	16,5	24,3

As indicated by the simulation results, utilization of the local flexibility resources will have a positive impact on the local system operation. In E-REGIO this is to be achieved through well-designed flexibility contracts that ensure the optimal solution is attained. The local market trading facilitated within E-REGIO caters for reduced energy import and for mitigated local congestions. In addition, accommodating for the utilization of local PV generation and storage, the local market contributes towards increased local system efficiency and decreased CO<sub>2</sub> emissions. More specifically, the simulation results point out that the local energy market would be able to efficiently reduce the CO<sub>2</sub> footprint with approximately 9.351.270 gCO<sub>2</sub>eq, given that the ESS losses are equal to 20 %.

## 5. Conclusions

This paper addresses central topics in the E-REGIO project related to the creation of local markets. A prerequisite for any form of trade is that there is a demand that seeks some form of supply to cover the request for energy. With the advent of energy prosumers and energy production within or close to the vicinity of where it will be consumed a business case for "short travelled" energy arises. Provided that separate economies are involved the prerequisites for commercially based exchanges arise. Within E-



REGIO, the practical implementation of such exchanges is to be carried by means of an advanced ICT platform for local trade.

Two basic forms of exchanges are possible - energy trade and flexibility trade. The former can be in the form of direct peer-to-peer exchanges or through entity in the middle, a broker or pool manager, which in the case of E-REGIO refers to the role of the Local System Operator (LSO). The latter accounts for up and down regulations to maintain local energy balance.

Local energy balance can be attractive for several parties as illustrated by the pilot case of Skagerak and the simulations. First of all, it can be an instrument to maintain positive and negative peak loads within certain upper and lower limits. As shown this can be highly beneficial for the local grid owner, which wants to maintain high quality of supply in its grid and to avoid local congestions. At the same time, it creates an impetus for prosumers to increase self-consumption on an individual or collective level. As illustrated by the simulations, an ESS will be quite essential in order to maximize self-consumption and the economic yield. In the case of Skagerak this is currently possible since the pilot case represents a simplified model of a local market with a minimum of economic entities within the market boundary. A practical consequence is that the ESS can be operated “behind the meter”. The meter represents a single point of coupling and defines a separate economic zone for the PV and ESS owner as well as the load. The local market can then exploit the differences in tariffs and prices to achieve desired economic ends.

However, with the existing regulations, it is generally not possible to place multiple prosumers and multiple consumers within a single economic zone and to achieve a form of internal trade with a common ESS and increase self-consumption as each entity of this kind would require a meter. Thus, each new entity would appear in the form described here. But the relevance of the presented approach could still be relevant for multiple entities under prevailing regulatory conditions. That is, for buildings and areas where there is one meter and multiple economies (such as in the case where there are several tenants within the realm of one property). As supported by the ERA-Net community the E-Regio project is obliged to contribute to new standards and policies. In this role the project has made recommendations in line with the knowledge gained and the work that has been done and remains to be undertaken. In particular, the parties involved in the project have actively provided input to the EU Commission regarding the forthcoming directives on energy communities.

### Acknowledgments

The E-REGIO project (2017-2020) has received funding from the ERA-Net Smart Grids Plus initiative, with support from the European Union’s Horizon 2020 research and innovation program. The authors are grateful for working on the important topic of local energy markets, as part of the project’s scope.

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