RESEARCH REPORT

VTT-R-00545-20

Local flexibility markets
Smart Otaniemi D4.1

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Confidentiality: Public

Report's title	
Local flexibility markets - Smart Otaniemi D4.1	
Customer, contact person, address Business Finland	**Order reference**
Project name Smart Otaniemi Pilot (Phase 1)	**Project number/Short name** 118621/BF_Smart Otaniemi first pilots
Author(s) Koreneff, G., Similä, L., Forsström, J., Rinne, E., Schöpper, C., Segerstam, J., Repo, S., Kilkki, O.	**Pages** 70
Keywords Smart Otaniemi, local flexibility market, local energy market, smart grid, demand response	**Report identification code** VTT-R-00545-20

Summary

This report is part of the results of Smart Otaniemi WP 4, Local flexibility market. Smart Otaniemi is a smart energy piloting area and ecosystem in Otaniemi, Espoo.

This report includes a state-of-the-art analysis of local markets, especially in Germany and the UK, and of the system wide markets in Finland, in which demand response can almost conclusively participate, aggregated or not. The notion of local flexibility markets hits the first snag with the question of who will buy the local flexibility in Finland: analysis shows that it is not other end-users, not the seller per se, nor the local generator unless it is a clearly better solution than selling to the energy market. For example, although a small end-user does not participate in the spot market directly, she can use her flexibility via market price based contracts. The main answer is the DSO. The DSO's demand for flexibility might have different reasons such as local ancillary service needs or fighting bottlenecks. However, in general, flexibility should be available for multiple uses in order to enable value stacking.

Local energy markets could be practical for reasons other than the utilization of flexibility for the management of the local network. Local markets could enable more specialised or granular trading, especially if trading is not possible on existing markets for the interested stakeholders. In addition, the local markets could act as an aggregation platform for existing markets.

The more markets and interested parties, including independent aggregators, are involved, the more important and complicated balance settlement will become. One option of simplifying things that this research came up with is to elevate all end-users to the status of balance responsible. To better understand the balance implications for different parties under various conditions, a balance model was created.

The report presents a general framework for flexibility markets (Smart Otaniemi logic) consisting of considerations for balance responsibility and product design. The framework could be implemented in Otaniemi and beyond.

Confidentiality	Public

Espoo 30.4.2020

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Distribution (customer and VTT)

No printed versions. Public by VTT report site.

Preface

Smart Otaniemi is an innovation ecosystem for smart energy solutions. It is part of Business Finland's Smart Energy program, and aims at being an internationally recognised and impactful smart energy innovation platform. The ecosystem and the testbeds are built modularly through business-driven pilots: the target is to become a showroom and gateway for Finnish energy excellence. Smart Otaniemi integrates co-operation, digitalisation, energy and users and forms a platform where business and research can work in tight collaboration accelerating new technology, services, business models and systemic solutions.

Steering group of Smart Otaniemi Pilot Phase 1 was comprised of following professionals: Tuula Mäkinen, VTT Technical Research Centre of Finland Ltd., Matti Lehtonen, Aalto University Foundation sr., Antti Säynäjoki, Aalto-yliopistokiinteistöt Oy, Harri Vesa, E2M Voimakauppa Oy, Jan Segerstam, Empower IM Oy, Chairman of steering group, Davor Stjelja, Granlund Oy, Jyri Öörni, Merus Power Dynamics Oy, Jarno Halme, Nokia solutions and networks Oy, Heikki Suonsivu, Parkkisähkö Oy / Parking Energy Ltd and Jussi Puranen, Väre Energia Oy. Ismo Heimonen from VTT acted as the Project Manager and secretary of the steering group.

This report *D4.1 Local flexibility markets*, is part of Smart Otaniemi Pilot phase 1, the pilot for, Local Flexibility Market (Work package 4). The WP4 seeked to establish a framework for local flexibility markets and to study new local market enabled business models suitable for Smart Otaniemi.

The operational group guiding the pilot consisted of Markus Talka from Caruna, Harri Vesa and Carina Schöpper from e2m, Jan Segerstam, Sirpa Repo and Olli Kilkki from Empower IM, Jukka Rinta-Luoma from Fingrid, Elahe Doroudchi from Aalto and Hannele Holttinen (WP4 Leader until end 2018), Göran Koreneff (WP4 Leader March 2019 onwards), Lassi Similä, Juha Forsström, Erkka Rinne and Jussi Ikäheimo from VTT.

Espoo 30.4.2020

Authors

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1. Introduction

Local market for flexibility, in cooperation with existing market structures: who needs it, and why, and what are the alternatives. The backbone of the electricity market is the spot market and the balance settlement. Will it be broken? An unfair balance settlement arrangement can have severe repercussions if the imbalances for some parties are let to grow. In Smart Otaniemi, what kind of local flexibility market type could be piloted?

1.1 Background

Before the planning of any local market pilot, we need to know what different kinds of local flexibility markets could entail in practice. This includes framework definition (local market models, need for and buyer of flexibility, tradable resources, and interaction mechanisms) and product definition (what are the local products).

1.2 Goal

The work will start by writing down the local market hypotheses: who will buy the local flexibility and for what local purposes. That will define the product type that is relevant, the market structure (e.g.one or two-way market), and how it relates to the wholesale market and the balance responsibility and settlement. Local market models may include network, electricity and heat, and definition should be flexible enough not to leave out new possibilities and be open for upscaling. Possibility to pilot advanced market models, like power in addition to or instead of energy, is the final goal of market demonstration. The local flexibility could also fit in the wholesale or ancillary markets, so there is the question of where the flexibility is best used and to what extent the local flexibility market products could be purchased from or traded to the outside.

We shall look at the current market products in the Nordic markets (day-ahead and intra-day for energy as well as markets run by TSOs for ancillary services) and also look at future harmonisation and developments planned at Nordic and EU (ENTSO-E) level. New energy market rules will be considered as part of this Task with a special focus on energy communities. Joint use of energy resources as well as methods for its facilitation will be explored. Various options for balance responsibility will be evaluated.

The task will explore and collaborate with the H2020 project DOMINOES to establish viable local flexibility market hypotheses that can be scaled beyond the Otaniemi region and local Nordic conditions. The collaboration will be facilitated by Empower IM as the coordinator of the DOMINOES project.

The discussions to enable changes in regulation in the pilots are also conducted - jointly with other WPs. These can be the regulation changes needed for energy communities, as well as for the use of storage (avoiding taxation for both charging and discharging). Possibilities for the distribution system operator Caruna to test new tariffs will also be discussed. Possibility to use Otaniemi for testing area of new tariff structures, like optimising for power in addition to energy, will be explored.

1.3 Limitations

Otaniemi is a quite robust distribution network area with only a limited amount of distributed generation. Several aspects of why local flexibility would be needed cannot be established in Otaniemi, and, in addition, active local participants might be sparse, which severely impact the rationale for a real local flexibility market. More than not, local flexibility markets are in the danger of having to be only simulated in Smart Otaniemi.

However, there are other potential uses for local markets in currently resilient grids, such as for the purposes of aggregation, consumer empowerment, and local resource sharing and trading. Furthermore, in the following the aim is to also investigate flexibility markets more generally for application in other locations and in future grid conditions.

Market descriptions are basically written in the winter of 2018/2019. Due to the speed with which the market is changing, they were updated in the summer 2019, for the planned publication of the deliverable. The project plan was, however, subsequently changed, deliverables were merged and the deadline for this merged report set to end of April 2020. Market changes since summer of 2019 have to a certain extent been added, but knowing the fast development taking place, some are unavoidably not included.

2. Who will locally buy the flexibility and why

The starting point was the idea of having a local flexibility market to where flexibility would be offered and from where flexibility would be bought for use in TSO or DSO ancillary markets, BRP’s local balancing, intraday (and day ahead) market, for network peak load management etc., see Figure 1. These markets and needs are studied in this Chapter, and we take the first peaks at the benefits and disadvantages of local flexibility markets as opposed to system wide markets.

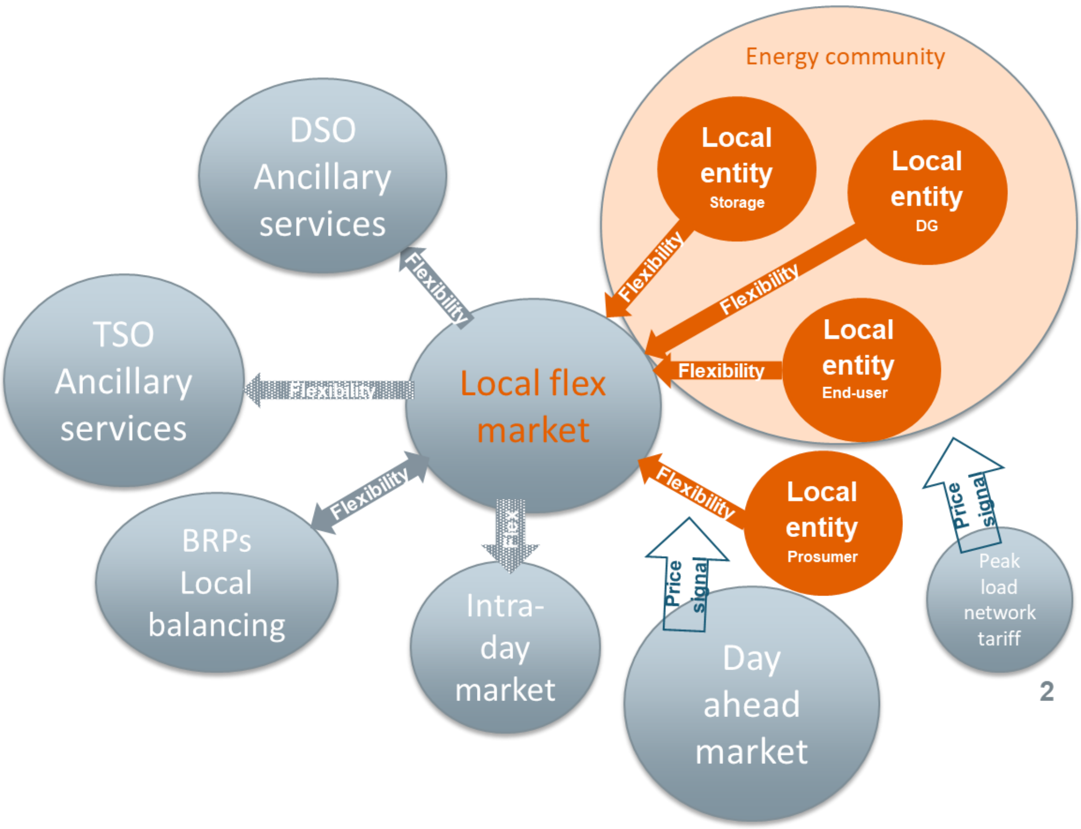

Figure 1. The Smart Otaniemi local flexibility market approach.

2.1 System wide markets in Finland and in the Nordic system

The project plan of Smart Otaniemi calls for definition work for what local flexibility markets (LFM) could entail in practice before defining the pilots. The task includes framework definition (local market models, tradable resources, and interaction mechanisms) and product definition (what are the local products). In this section, an overview of **system wide markets** (day-ahead spot markets, intraday markets, and system operational markets such as frequency containment reserve and frequency restoring reserves markets), is taken to help the definition work.

System wide markets for electricity refer in this report to the utilization of market to its full extent in matching the supply and demand of flexibility resources, whatever the exact product might be. Thus, aiming at locally restricted solution, following geographical location or other infrastructure-based characteristic, is not the primary driver in their development. Often, on the contrary, maximal amount of integration is aimed at in the developments of system-wide markets to achieve the efficiency benefits of market-based solutions. Particularly, as the Smart Otaniemi innovation ecosystem is strongly connected to Finland and Nordic electricity markets, we study the characteristics of existing and evolving system-wide markets to identify the need for local markets. That is, in defining the requirements for pilots, it is essential to identify to which extent current market mechanisms in place for Smart Otaniemi can cope with the foreseen developments and, therefore, define the value-adding niche for local flexibility markets, if any. Hence, at least the following characteristics are of interest for the review of system-wide markets in Finland.

- Product definition and its flexibility properties (activation times, etc.)
- Local elements (e.g. market areas)
- Minimum size for bids
- Gate closures
- Incentive mechanism / Financial penalties on non-compliance with the market signals
- Demand Response participation (Yes/No)

System wide markets in Finland and in the Nordic system offer possibilities for flexibility in both day-ahead spot markets and intraday markets, as well as in system operational markets. System operation reserves in Finland are maintained by the national System Operator, Fingrid, who uses several market mechanisms operating in different timeframes to maintain power balance in Finland in such a manner that frequency quality criteria are filled. In the market mechanisms for reserves, there are also products that be traded internationally with neighbouring TSOs, and there is a clear tendency based on European initiatives to integrate and develop the markets further.

The needs for system operation reserves are calculated for the Nordic system as a whole and then allocated to individual countries. The Nordic reserve demands are allocated to each country according to their loads. The TSO of each Nordic country procures its share of reserves as it considers best. The reserve types are divided *in Frequency Containment Reserve for Normal operation (FCR-N) Frequency Containment Reserve for Disturbances (FCR-D),* and *Automatic Frequency Restoration Reserve (FRR-A)*, as well *as Manual Frequency Restoration Reserve (FRR-M a.k.a mFRR),* of which there are several types (*Balancing energy market, Balancing capacity market, Reserve power*). The mechanisms to procure these reserves include different channels such as tailored yearly and hourly markets for each reserve type, international connections, and balancing markets. (Ritter et al. 2017)

We discuss these markets separately in the aforementioned context in the following sections. The flexibility characteristic of the markets from Finnish perspective are thoroughly discussed in earlier work included in Ritter et al. (2017), who analysed different electricity markets from the viewpoint of Smart Electric Thermal Storage (SETS), a household-scale electric heating device with smart storage functionalities. In the following review, in addition to *flexibility* we pay special attention to *local* elements in existing system-wide market mechanisms to reflect the discussion in Ritter et al. (2017) efficiently feeding this report. For example, if generator's or consumption unit's location in the power grid is not included in the market system, it is clear that part of the market cannot be utilised in any congestion management.

In addition to the market mechanisms in place, the foreseen developments in Europe are relevant for the case of Smart Otaniemi, as there is a lot of on-going activity. Interestingly, in a Nordic perspective, where we have an all-embracing market and flexibility system, the flexibility subsystems in the individual Nordic countries and/or the price areas within them can as such be seen as local flexibility markets.

2.1.1 Day-ahead and intraday markets

2.1.1.1 Flexibility

The Nordic power exchange Nord Pool nowadays consists of the Nordic and Baltic countries as the main spot market participants. Participants from Germany-Luxembourg, Austria, Belgium, France and the Netherlands, can also participate in the spot market. Participation in power exchanges is voluntary, and the exchanges are privately owned for-profit market institutions.

The day-ahead market, Nord Pool Spot, uses an hour as a basic unit of time resolution. The Nordic electricity exchange Nord Pool operates the hourly-based day-ahead market Elspot that is opened 36 hours before delivery and is closed at 12:00 CET on the day previous to delivery. Almost all energy sold in the Nordic countries goes through the spot market. The spot price forms the basic corner stone of the well-functioning Nordic market mechanism.

Intraday markets offer continuous trading to complete the day-ahead markets. In these markets, for example adjustments to trades done in the day-ahead market, can be made closer to delivery. Typically, the intra-day market opens after the day-ahead market is closed. This is also the case for the *Elbas* market, the intraday market in place in Nord Pool. (Ritter et al. 2017). The Elbas market has certain national specifications between the NordPool countries; in Finland gate closure is just before start of each hour for trades within Finland (piloting started end 2019 (Fingrid 2019d)), 30 minutes for trade between Finland and Estonia and 60 minutes for trades between Finland and other countries (Nord Pool 2020. The product length is one hour. Interestingly from the flexibility market point of view, also 15-minute and 30-minute products are in place at least for trading in the German market area (Nord Pool 2019). The intraday market is expected to gain in popularity with the increase in wind and solar power production.

There is a variety of products that can be traded in the Nord Pool markets, both in the spot and intraday markets. The spot market, for example, offers single hourly blocks, block orders, minimum acceptance ratio, linking, flexi orders and exclusive orders. Interestingly for the Smart Otaniemi, the so called *flexi orders* are block orders with a maximum duration of 23 consecutive hours. Their starting hour is determined by an algorithm instead of fixed by the user, maximizing the value of flexibility from the social welfare point of view. The interval limit of flexi orders can span any period from 0:00 to 24:00. (Nord Pool 2019)

2.1.1.2 Locality

In the day-ahead and intraday market scheme in the Nordics and Finland, the main local elements are presented by zonally split market areas. Thus, the supply and demand in the Nord Pool spot bids in the Nordic/Baltic market are labelled according to these areas, of which there are 15 at the moment in 7 countries (Nordic (FI, SE, NO and DK) and Baltic (EE, LV, LT)).

The Nord Pool continuous intraday market, in turn, offers continuous intraday trading within 13 countries through the European Cross-Border Intraday Market (XBID) solution, customers can trade on 12 intraday markets via Elbas and thus get access to a large intraday liquidity pool. These encompass the Nordic, Baltic, German-Luxembourg, French, Dutch, Belgian, and Austrian markets (Nord Pool website 2019). In global scale of even more fine-tuned locational market structures (so called nodal markets), integrating physical and economic dispatch even on a level of power plants, are operational (see e.g. Ruska & Similä 2011).

In addition to geographical dimensioning, another restricting factor for the day-ahead and intraday markets is the bid size: according to the Nordic power exchange, Nord Pool (2019), market participants can partake in the spot market and in the intraday market where one hour slots, with a granularity of 0.1 MWh/h, are sold and bought. Thus, bidding units smaller than this limit are ruled out from the markets. However, aggregators pooling together ether resources of several partners can be raised up within the local flexibility market considerations, as will be touched upon later in this report.

2.1.2 Capacity reserves

Capacity reserves for the energy market in Finland are power plants or demand response units that are activated when the availability of commercial sell offers is insufficient to meet the Finnish demand in the day ahead market. From a market perspective, the activation price is the same as the ceiling price of the market. They are wholesale market operation reserves, not system operation reserves per se. The capacities are decided upon every three years in auctions by the Energy Authority and the capacity in the winter 2019/2020 is 729 MW. The units get reimbursed for stand-by, as offered, and additionally if activated, according to their actual production costs as given in their auction offers. (Energy Authority 2020)

Capacity reserves have not activated in years, and only a few times ever since the initiation in 2007.

2.1.3 Frequency containment reserves markets (FCR-N, FCR-D)

The frequency containment reserves markets are based on automatic control based on local frequency measurement. For Finland the allocated reserve amount of FCR-N is 138 MW and of FCR-D 220-265 MW (Uusitalo 2019).

2.1.3.1 Flexibility

The products in FCR markets can be traded in both yearly and hourly markets organised by Fingrid, and the procurements and prices are based on capacity (MW, €/MW). The hourly bids to the FCR-N and FCR-D markets shall be submitted for the hours of the next day until 18:30. (Fingrid 2018a)

FCR-N operates in a range keeping the frequency between 49.9 and 50.1 Hz. The FCR-N resources must be symmetric, that is, they must be able to respond to demands for both up and down regulation. In case of larger frequency deviations, the FCR-D markets are activated. (Ritter et al. 2017)

The energy amounts due to FRC-N but not FCR-D activation will be compensated according to up and down regulation prices.

FCR-D is activated in case of larger frequency deviations in 5/30 seconds. Loads have an option to participate with one step activation in 1-5 second activation time in larger frequency disturbances. FCR-D applies only to up-regulation (power plants increase power, loads decrease power). FCR-D has capacity payment based on availability. Price level of FCR-D has been around 3 €/MW/h in yearly market for each hour available and dozens of €/MW/h in the hourly market. (Fingrid 2018b)

2.1.3.2 Locality

According to the market rules (Fingrid 2018a), for both yearly and hourly market, the minimum capacity of one bid for the FCR-N is 0.1 MW and for the FCR-D 1 MW. Correspondingly, the maximum capacity of one bid for FCR-N is 5 MW and for the FCR-D 10 MW. Furthermore, the bids shall be submitted at an accuracy of 0.1 MW.

Clearly, the limitations on bids have an impact on the potential Smart Otaniemi project demonstration to be taken into account in assessing different options, although aggregation is possible. In addition, both the FCR-N and FCR-D markets have technical requirements to be fulfilled (please see Fingrid 2018a). As one part of the FCR requirements, name or list of the Reserve Units that are used for contributing to the maintaining of the reserves, are to be specified in the bids submitted to Fingrid (Fingrid 2018a). FCR has no limitation on locality for resources in Finland (resources can be acquired from Estonia or via the Vyborg DC-link from Russia, Fingrid 2020b). From a system operator and FCR market perspective, there is no value in having a specific Otaniemi bid. The inclusion of identifiers of units reflecting location-specific elements make the FCR-N and FCR-D interesting for possible local flexibility market business cases, in Smart Otaniemi or otherwere.

2.1.4 Frequency restoration reserves markets; Balancing energy market (FRR-M)

Balancing energy markets operated in Finland by Fingrid are a part of Nordic balancing energy markets. Normal manually activated frequency restoration reserves (mFRR or FRR-M) form the basis of the balancing power market.

2.1.4.1 Flexibility

Balancing bids can be submitted by all resources capable of implementing a power change of 10 MW (5 MW for electric activation) in 15 minutes. Bids can be delivered and updated 45 minutes before each operating hour, and must be able to uphold the whole hour. Separate up- and down-regulation bids are in use. (Ritter et al. 2017, Fingrid 2018b)

Marginal pricing is in use in balancing energy market operated by Fingrid, i.e. payment is calculated by ordered energy and the most expensive bid used in each hour. Price level is always better than the day ahead market price, sometimes the price in balancing energy markets rises to hundreds or even to thousands of euros. (Fingrid 2018b)

Considering the potential of balancing power markets and Smart Otaniemi, the 5 or 10 MW restriction in bid size challenges the capability of some small-scale resources to participate in markets. On the other hand, time resolution relevant for flexibility and observed high prices might be tempting for some loads located in the area to find a way to participate in balancing markets, e.g. with the help of aggregators. At the moment, aggregation from multiple balance responsible parties' balances is not possible but is allowed between consumption and production balances.

2.1.4.2 Locality

Bids in the balancing market are activated in price order taking the technical conditions into account (Fingrid 2018b). That is, the activation of bid takes place only if it is possible taking the operating situation of the power system into account; otherwise the bid is neglected. The expression on activation order above clearly signals the locational information only to be accounted in exceptional cases in balancing markets, and the core idea of the market seems to be independent of balancing bidders' location. Hence, the added value of integrating Local Flexibility Market in current balancing market architecture does not seem to be in improving its locality-dependent criterion (e.g. congestion management) for the TSO, but for the DSO, assuming the DSO were allowed to trigger bids. Pooling small-scale flexibility capabilities locally and supplying them to balancing markets, however, represents an alternative option. Bid sizes would either way still be a problem.

2.1.5 Frequency restoration reserves markets; reserve power and capacity market (FRR-M for disturbances)

Fingrid meets its obligation for **fast disturbance reserves** with the reserve power plants it owns and with the leasing power plants. The fast disturbance reserves (also part of the FRR-M class) have to have the stamina for 36 hour disturbances. Fingrid's own power plants and leasing power plants are not used for commercial electricity production, instead, the balancing power market is the main source for normal FRR-M. In end-2018, there were 301 MW of leasing reserve power plant capacity in Finland, whereas Fingrid's own capacity totalled 953 MW. The market of reserve power plants is organised as a yearly market with same compensation for all market participants for maintaining the capacities. (Fingrid 2019a, Ritter et al. 2017)

In spring 2016, a short-term capacity market for FRR-M/upregulation started (Ritter et al. 2017). The weekly balancing capacity market's main target is to compensate for e.g. maintenance in Fingrid's own or leased fast disturbance reserves. Parties who have won balancing capacity market contracts have the obligation to bid on the balancing energy market.

Demand response and batteries would have a hard time answering to this call, as the minimum contract if for one week, or with a durability of at least 36 hours, so this type of disturbance reserves are in all probability outside the realms of Smart Otaniemi.

2.1.6 Automatic Frequency Restoration Reserve (aFRR)

"Automatic Frequency Restoration Reserve (aFRR) has been in operation in the Nordic countries since 2013 but was put on hold in 2016 due to lacking offers. It started again in 2017. aFRR is maintained only in morning and evening hours and the allocated Finnish share has been about 70 MW. aFRR bids can be submitted separately for upward and downward capacity. The activation of aFRR is based on a power change signal calculated on the base of the frequency deviation in the Nordic synchronized area and sent by the TSO. Full activation is to be achieved in 2 minutes." (Ritter et al. 2017)

The FRR-A markets have minimum bid size of 5 MW, and it is an hourly market with capacity payment on availability based and activation payment. Capacity payment price levels have resulted around dozens of euros/MW/h, and activation payments according to balancing energy market price. (Fingrid 2018b)

2.1.7 Potential new markets

2.1.7.1 Fast Frequency Reserve (FFR)

As less and less spinning power plants offering inertia[1] are up and running, the question arises, will the system survive large instantaneous changes, such as the loss of a single electricity production unit or a HVDC link, without very fast reserves?

The Fast Frequency Reserve (FFR) is procured to handle low-inertia situations. The market is schedule to be implemented in the Nordics in May 2020 and Fingrid will open a national market. The needed volume of Fast Frequency Reserve depends on the prevailing inertia in the power system and the size of the reference incident. The activation time of the FFR is 0.7…1.3 seconds, depending on frequency deviation from normal. The Finnish market will be an hourly market, with the highest bid determining the price level for all. (Fingrid 2020b)

However, this is system specific issue and local aspects concern only microgrids.

2.2 Future harmonisation and developments planned in Nordic and European (ENTSO-E) level concerning market structures

The system-wide markets are continuously changing, especially as the EU Commission is pushing all parties on integration and harmonisation. Nordic Balancing Model development plans and timetables are presented in Figure 2.

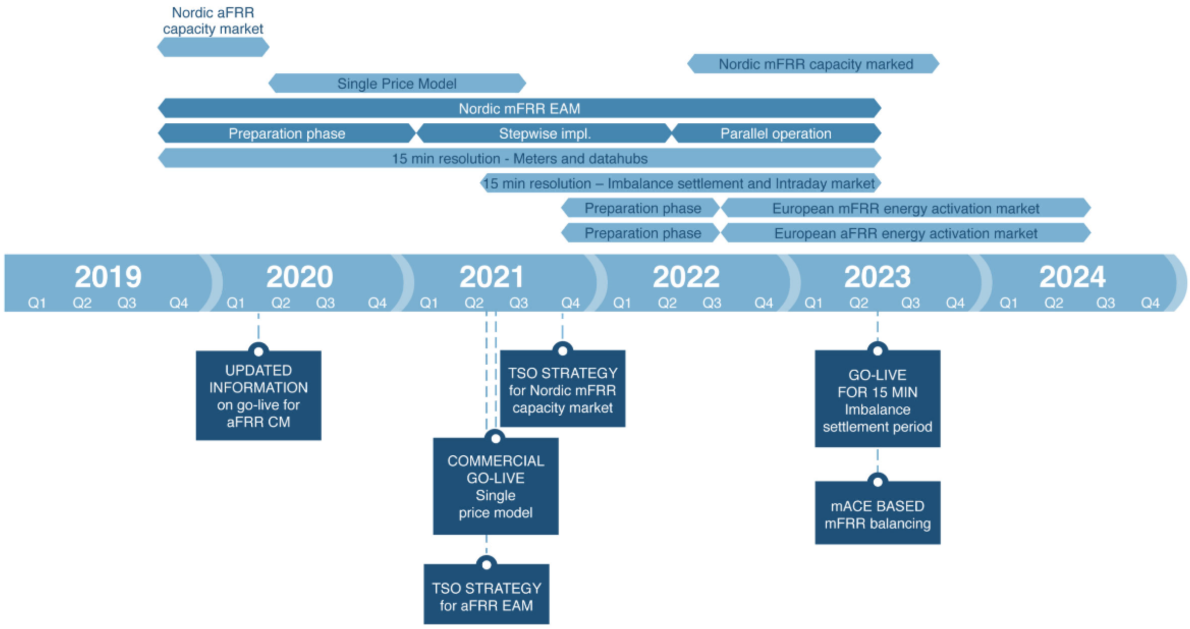

Figure 2. Nordic balancing model development timetable (NBM 2020)

At least the following changes are of interest when considering Local Flexibility Market option:

- New FFR (Fast Frequency Reserve) market to be launched in 2020 to tackle large frequency deviations in small inertia occasions. (Kuivaniemi & Uimonen 2019)

  In the Nordic synchronous area securing frequency stability will in the future be ensured by introducing a new fast reserve, Fast Frequency Reserve (FFR), as a complement to the primary reserve for disturbances (FCR-D). FFR takes over as the

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[1]Inertia is ability of the kinetic energy stored in the rotating masses in the electricity system to resist changes in frequency

first mitigation measure at situations with low inertia and large reference incident (ENTSO-E 2019)

- 15-minute imbalance settlement periods (ISP) in the Nordic market as a part of Nordic balance management project. The initiative includes common market places for reserves in the Nordic level (mFRR, aFRR (capacity markets)). The Nordic balance market project is an interim step towards the common European markets. (Heikkilä 2019)

  The aFRR and mFRR market places will be coordinated with the move to 15 minutes imbalance settlement time resolution scheduled for Q2 2023 at the moment (NMB 2020)

  Spot and intraday markets are expected to change to 15 min in relation to ISP changes.
- Initiatives aiming at standard products for aFRR and mFRR. For example, the size of the bid can vary between 1…9999 MW, the resolution would be based on 15-minute periods, the bids could be left 25 min before delivery (see more detailed in Lundberg 2019)

  EU-wide aFRR and mFRR markets, PICASSO and MARI respectively, are being implemented later and Nordic balancing markets are expected to be integrated thereafter. (Fingrid 2020c, NBM 2020)
- In the future there will be more than one market operator in the wholesale markets also in the Nordics. At least EPEX Spot in preparing to start its operations here. For managing many market operators in a bidding area, Market Coupling Operations is being set up.
- The single price model will, according to the roadmap, be introduced in Q2, 2021. The implementation model of single pricing is, however, depending on that TSOs and stakeholder find mitigating measures to avoid self-balancing overreactions by market players, which is an operational concern for the TSOs. (NBM 2019)
- DSO flexibility, independent aggregators and customer empowerment are important targets in the Commission’s Clean Energy Package. It is still to be seen how these targets affect the existing market structures. DSO Flexibility is discussed in Chapter 2.5 and independent aggregators in Chapter 5.
  As to customer empowerment, a small scale local market, with low minimum bids and low bureaucracy might seem enticing. However, end-users are quite empowered already in the Nordic market system, compared to more traditional market models in parts of EU, with e.g. indirect access to the wholesale market (spot based dynamic tariffs, hourly measurements) and aggregator-aided possibilities to participate in ancillary markets.
- Aggregation from multiple balance responsible parties’ balances is being piloted and the target is to allow it in the coming years, so this would broaden the potential for small scale flexibility to participate in the different markets.

It is good to note that new mechanisms for market facilitation might be needed in the near future to manage the trading of local flexibility. These are described in the Active System Management report (TSO – DSO Report 2019) where the expectation is brought forth that the Clean Energy Package (Electricity Directive, article 32.1) gives the possibility to the DSOs to procure non-frequency ancillary services to manage, among others, congestion on their grid, and that they shall procure these services in a transparent and market-based approach, when this represents the most cost-effective way to do it. The report focuses on congestion management and balancing, and the first of two recommendations in the report is especially worth noting: TSOs and DSOs should pursue an integrated system approach when developing new solutions and should avoid any isolated solution. It also concludes that information on flexibility resources in congestion management and balancing should be shared and available for both TSOs and DSOs, through a flexibility resources register.

2.3 Local neighbour

Local energy markets can sometimes be heard to be advocated as the future of the power system. Local producers selling their surplus to local consumers on local markets, all small scale and cosy. We can extend the thought to flexibility. Local surplus generation is sold to flexible local end-users.

The question arises, why is locality important for the energy market? It is not. Guarantees of Origin (GO) allows end-users to buy renewable electricity from anywhere in EU. From the energy market's point of view, small separate local markets are detrimental as they at best only suboptimise the system. In the Nordic market, the more separate price areas we have, the worse the market and price formation is working. What would the price of electricity be in the market? Assuming both local producer and seller have access to the spot market, as they do in Finland (with a small extra margin), if the local price is higher than the spot price, then local buyers are supporting local sellers, vice versa if the price is lower, and not different from the spot market if the price is equal. The local market is thus a support system for either, or the local market operator. There are possibilities for arbitrage, if the end-user has a fixed tariff based normal supply. If spot price is higher than the tariff price, sell surplus to the spot market and buy electricity from main supplier at lower tariff cost. If the spot is lower than the tariff price, sell surplus to end-user at a price between spot and tariff. Aside from diminishing main supplier's profit margins, an additional cost burden comes from increasing imbalances. But even here "local" is an added dimension, the same can be had with a nationwide market for small actors. There is no benefit of being "local" in the energy market.

We can further look at flexibility. Why would a neighbour buy your flexibility? Small end-users or producers are not balance responsible. If they were, they could have an interest to buy flexibility, but there would not be an incentive, or need, for it to be local. As balancing is a one-price system for consumers and small producers, imbalances generally even out over time. From a system point of view, there more flexibility is used for small scale imbalances, the more costly the system will become. If one party corrects his imbalance down and the other party up, the system effect is null and now valuable flexibility potentials have been used.

There is no need for a local flexibility market for energy trading purposes per se.

2.4 Local energy community

The traditionally assumed benefits of local energy communities are twofold: achieve local self-sufficiency and to decrease interaction with the grid. To decrease the interaction with the grid, we maximise the self-consumed production. Instead of adding storage, we can extend the "self" by extending the area behind the meter to include consumers not previously included. In addition, some not directly economic reasons for local trading could apply such as social community benefits, community empowerment, local sharing and learning. If the d rules and boundaries of local energy communities develop suitably, local energy communities could function as flexibility aggregators offering it to where it is most beneficial, be it minimisation of grid interaction or in ancillary markets.

Some of the aspects brought up regarding local neighbours are relevant to local energy communities, especially distributed local energy communities. Local energy communities are to be seen as more stringent partnerships, though.

The Smart Grid Working Group (Pahkala et al. 2018) defined energy communities as either within a property energy communities, including directly/privately connected generators in the immediate vicinity, or as geographically distributed energy communities. In the same property produced and used electricity is to be tax free and without network costs in an energy community, whereas generation that is distributed through the distribution network has to pay all the grid fees and taxes.

2.4.1 Local self sufficiency

Although local self-sustainability sounds nice, there is no real rationale for local self-sufficiency if there is a grid connection. There is no point in directing available flexibility, from a system point of view, to unnecessary local balancing that in the worst case could demand an opposite balancing action on the system level. What more, if one tries to fully balance intermittent wind and/or power production, the most cost-effective way may, in addition to energy storages, rely on diesel burning generator sets. If 10 % of electricity needed is produced using diesel or light fuel oil, that will result a specific greenhouse gas impact very roughly as large as that of the Finnish power system in 2030.

If we go off-grid, there is of course an inherent need for self-sufficiency.

2.4.2 Minimisation of interactions with the grid

The main driver for local energy communities is the desire of end-users and prosumers to minimise their network tariff costs. It is felt that if production and consumption takes place locally, network is used less and should therefore cost less. As, in reality, energy use forms only a small share of the actual costs of a DSO, there is no real system cost savings, and a heavier reliance in the future on peak load based tariff structures will reduce this benefit for the energy communities as long as it doesn't change the peak load of the energy community.

In Finland, local production has been more the rule than not, with many utilities having a district heating branch with additional combined heat and power. Transmission grid costs of the local distribution network have thus been lower and all have been happy. The forming of a local area network below the level of the distribution network will bring similar profits to the energy communities, although maintenance and bureaucratic tasks might form a danger of eating up the benefits. The added bureaucracy would come from internal debiting of transferred energy, for example if the buying apartment has to pay for the energy purchases to the housing company. In that case there has to be a billing system, it has to be operated, supervised, late payments have to be demanded and even put to execution etc.

On the other hand, if surplus production is divided within an apartment building following clear rules, e.g. ownership shares, this could be done already now by many DSO's at , presumably, no or small extra cost, if the law would allow it, as it soon is expected to do. At the same time, end-user would avoid electricity and VAT taxes for self-consumed production, bringing an added benefit. (Auvinen et al. 2020)

However, if surplus is divided according to pre-set rules to procurers, it is not a case of flexibility but of how to best or most cost efficiently implement photovoltaics in an apartment building.

2.4.3 Energy trade perspective

From an energy trade perspective, local energy communities are superfluous and do not bring any benefits to the system, if end-users have more or less access to the spot market. For example, in Finland superfluous prosumer RES production receives nearly spot price (minus a small management margin), and end-users can buy their power at spot price (plus a small management margin), so that the benefit window for local trade is quite narrow. Of course, if energy trade inside the energy community is freed from VAT, this would form an incentive.

One, if not the most important, energy trade aspect of energy communities is the possibility for even smaller end-users to participate in even larger scale RES generation projects and procure their electricity from there, for example following the Mankala principle, or to be able to dislocate own energy production, for example, to the summer cottage. This is a more concrete experience of empowerment than the purchase of GO stamped RES electricity and might also give a stronger boost to RES production. It is, however, not in any way restricted to the local perspective.

In a distributed energy community or a local market place operating under one (balance responsible party) seller, internal energy trades do not affect the balance settlement, not even after the fact trades. For the seller, this could be a way of enticing customers and binding them closer to herself at the cost of lost margins for the internal trades. The seller could also function as clearing partner for the participants. Novel market tools such as block chains could well be put to use. For the participating end-users, there might be social community values to be had like local sharing, and the warm feeling in the gut from buying locally.

For islands and other micro grids, local markets have a function, but the smaller it gets, the more simple rules of operation and reimbursement may suffice.

2.5 Distribution system operator

2.5.1 Demand based bottlenecks in the area

Instead of adding the transmission capacity of the distribution network, local flexibility could be used to postpone investments and thus be able to keep tariffs lower than otherwise would be the case.

To avoid blackouts or brownouts, the best way is to have long term flexibility contracts or other security that the local flexibility market will be able to offer flexibility in all cases. The back-up plan of construction new transmission lines takes time to implement. One way of getting security is to have everybody participate, for example through dynamic demand tariffs.

The remuneration model for distribution networks benefits investments in copper as opposed to market system investments, which is a reason that DNO’s might be more eager to forget about soft solutions. The national regulations should be changed to be more neutral to selected solutions. If a solution is more cost efficient to end-users, that is what should be the preferred direction, not which solution allows for a higher profit for the network company. This is envisaged to be included in the next regulatory framework, which will come into force in 2024, both stemming from the need to stop the increase of distribution fees and the need to allow DSO's use of flexibility in grid management.

2.5.2 RES production based bottlenecks in the area

Local overproduction would benefit from increased local consumption in times of bottlenecks, otherwise the production has to be curtailed. From a DSO’s point of view, there are three main alternatives: new distribution line capacity, curtailment and active demand response enabling. The solution which allows for the highest net revenues for the DSO is generally selected, and the solution is influenced by the regulatory method in use.

A local energy market in itself does not necessarily improve the situation, as it might not form an incentive for the producer. If the production is sold to the spot market, the spot price is received, but if sold at the local energy market at a time of local overproduction, the local price would be very low. There is a high chance that the total energy market revenues for the producer would be higher without a local market. For example, a 20% curtailed production at twice the price gives 60% more revenues compared to selling all at half the price. In addition, local network company might have to reimburse the producer for the curtailed production. As a DSO, who has the most interest in a local market, is not allowed to be an active partner in energy trading (except for covering losses), it cannot be the buyer or seller in the trades.

One solution is to have a flexibility operation similar to the system operator’s countertrade mechanism. Low local buy offers would be approved, but the local DSO would compensate the local seller for the price difference and the local price would be kept at spot level. For the DSO, this would be cheaper than compensating the curtailment at, say, full spot price.

The energy market has, however, no locality component, unless the local area is a bona fide spot market price area, so imbalances would not be looked at a local level. To restrict “non-locals” from being buyers in a local energy market seems counterproductive as the whole point of the Nordic market is to not have local, i.e. nodal restrictions or pricing, but as large price and thus market areas as possible.

A local flexibility market would concentrate only on the surplus production, and try to find additional local consumption. The role of the DSO must be the enabler. This could be done, for example, by dynamic distribution tariffs where there would be no, or a very low, cost at times of surplus, or through ancillary DSO markets.

2.5.3 Quality issues in local area

Control of voltage or reactive power might be locally needed. Solutions in use today might benefit from more market type of solutions. The type and setup of these kind of markets would be similar to transmissions system operator’s ancillary markets.

3. Local Flexibility Market examples

A multitude of examples of local flexibility markets exists, but on closer inspection we do need to distinguish their status a bit better: demo, research project vs running solution, and is it really a local flexibility market or just a market for small scale flexibility, a seller realm concept, a RES support scheme, or something else.

Small scale flexibilities such as demand response and energy storage are generally agreed upon to be of the highest importance for the cost effective operation of future power systems, smart grids. Here we estimate different examples to determine the cases where the flexibility has a strong local demand and use.

3.1 Local flexibility markets in Germany

For introduction of local flexibility markets in Germany, different types of local markets with their special aspects and characteristics are discussed.

In local energy and flexibility markets, there are participants for demand and supply. In this Working Package are five different types reviewed: Private consumption, Energy communities, Microgrids, Tenant current, and VPP.

Prosumers are going to participate more actively in the electricity market. Today prosumers produce and consume their own generated energy, are part of energy communities and tenant electricity they participate also in Microgrids. Only in Virtual Power Plant (VPP) are the Prosumer's rarely, it depends on the generated amount of energy or flexibility. In following Table 1 the characteristics of each local market is illustrated.

Table 1. Overview of local energy usage markets (Data sources Nylund 2018, p. 17, bmjv 2017, BMWi 2019)

	Private consumption	Energy community	Microgrid	Tenant current	VPP
Supply relationship	Operator of the power plant and consumer	Operator of the power plant, consumer and delivery to third party	Delivery to third party	Delivery to third party	Delivery to third party (reserve markets)
Local aspect	Same building / spatial proximity	Depends on the provider	Defined area	Same building / spatial proximity	Distributed power generation plants and offer of flexibility, central operation
Grid use / Grid charge	No	Yes	Yes	No	Yes
EEG reallocation charge	40 % (some cases 0 %)	100 %	100 %	100 % (EEG 2017?)	100 %
EEG-compensation / Market premium	For private consumption no compensation will paid	Yes	Yes	For direct use the compensation is not paid	Yes
Esteemed?	More economic than sale	Sharing of Energy	Yes, to be autarkic and independent	There is since 2016 an act in Germany	Yes, allowance to trade power for smaller power plants
Gross margin	Little	Ok	Little	Little	Good
Motivation / Benefits	Autarky, more independent from supplier	Autarky, 100 % known-power plants, and prosumer	Independent area, own balance responsible area	Rise of earning power / rate of return, new / to hold consumers	Offer access to the market for smaller power plants

In Germany and Europe are several projects linked to explained local markets. In Table 2 is an overview of some projects, which could be interesting for this Working Package. This Table is a comparison of these projects. The last three characteristics are the advantage, drawback and benefits for the 'Smart Otaniemi' Project.

In the first projects, Ampard, Swytch, WindNODE, and Enera are many benefits for the definition and developing of a local flexibility market. E.g Aggregation of small-scaled prosumer’s in Ampard project, trade platforms – Swytch is Blockchain-based, WindNode is developed by TSO’s and the Enera project and platform is supplied by EpexSpot.

Sonnen and Buzzn are two provider of energy communities, on which the Smart Otaniemi Project is focused on.

The LAMP project is an example for a Microgrid which could be operated public grid-connected or off-grid in Island mode and the last is a general VPP described and how it’s designed.

Table 2 Comparison of local flexibility projects

Project	Focus on	Trade platform / market	Local aspect	Local flexibility market?	Advantage	Drawback	Benefit for WP4
Ampard	EMS[2] in battery swarm	No	Yes (FCR-N[3])	No, aggregation of prosumers	Small scaled Different battery devices used	Energy supplier ≠ Aggregator No market place	# Smart / Aggregation / Flexibility / scalable
Swytch	Blockchain-based plat-form	Yes,Block -chain (token)	No	No, it's an energy market platform	Trade Platform for renewable energy generation	Only large scaled plants	# market platform / Global / RE[4]
Wind-NODE	Flexible market (grid bottlenecks)	Yes Platform	Yes, Geoinfo in offer	Yes	Offer with Geo-informa-tion important for DSO /TSO Part of SINTEG[5]	Germany's northeast, need of flexibility because if wind power	# local flexibility market / integrated energy /
Enera	Flexibility market at EPEX SPOT	Yes, EPEX SPOT	Yes, Friesland	Yes	EPEX SPOT, offer with Geoinformati on for DSO /TSO	Research of Demand side Flexibility Germany's northwest because of wind power	# DSM[6] / smart market / local
Sonnen	Energy community: Batteries + PV	Yes	Global DE: FCR-N	Yes, offering flexibility (Prosum-ers)	All inclusive: PV, Battery, smart EMS, el. Flatrate	Self-financed Financial sharing of energy ≠ not physical	# sharing platform / FCR-N / storage devices
Buzzn	Distributed & local groups, settlement	No	Yes, Tenant Electricity and no, Communi-ty	Yes	Choice between both group SM[7], Apps, Software	Only in Germany (German laws / acts)	# tenant electricity & distributed group
LAMP	Microgrid Blockchain-based trade	Yes	Yes, Microgrid	No, it's an energy market	Learning from LO3 (Brooklin Microgrid)	Imported system from US, not a local company	#Local flexibility market / global projects
VPP	Trading PP[8], demand and storage facilities	No	No	No, it's an energy and reserve market	Using existing markets, trade / utility of flexibility	Local aspect only in FCR-N Most VPP are for large scaled participants	# Aggregation / Flexibility trade

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[2] Energy Management System
[3] Frequency controlled reserve in normal operation
[4] Renewable energies
[5] SINTEG = Smart energy showcases. A programm for funding showcase regions fir the energy supply of the future.
[6] Demand side management
[7] Smart meter
[8] Power plant

E2m is part of Ampard, Swytch and WindNode Project and it operates a VPP.

For a deeper understanding, the projects are explained in the following:

Ampard Project is a sub-aggregation project, which collects battery storage devices from PV owners for trade at FCR-N market. It's developed the first swarm storage solution for monetizing small-scaled batteries (around 10 kW). The sub-aggregator of the devices is Ampard. Its VPP is connected to aggregators (e2m) VPP, who provides access to the energy markets. Benefit for this Working Package are the small-scaled and aggregated battery devices for trading their flexibility at reserve markets.

Swytch Project is a blockchain based developed platform for trading renewable flexibility with proof of origin. It's established for renewable generation trade and the platform should be used globally. The benefit is the upscaled idea of a flexibility platform.

WindNode Project in Northeast Germany is established by the TSO 50Hertz and the DSO's Grid service Berlin, Wemag, ENSO Netz and e.dis. The TSO offers the platform, where trades could be done. The main idea behind, is the utilize of potential flexibility between Redispatch of power plants and feed-in management of the renewables.

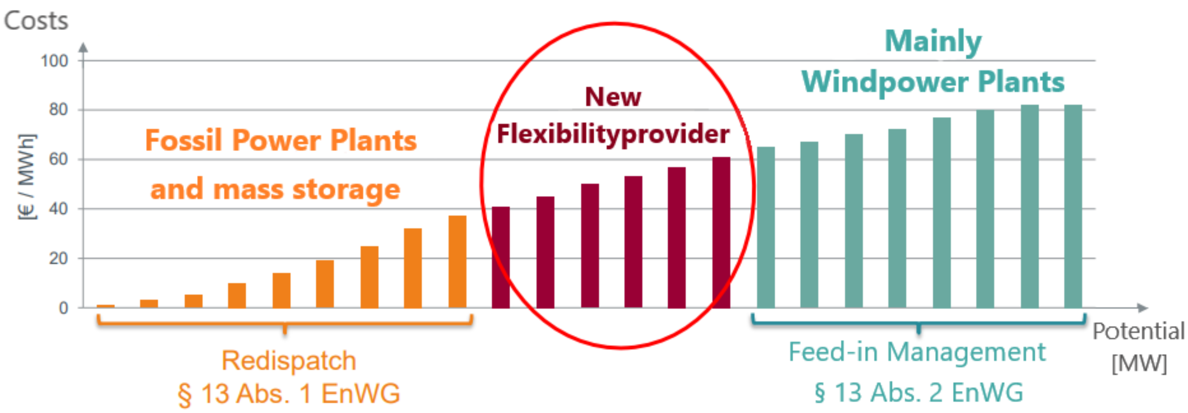

Figure 3: Flexibility Potential between Redispatch and feed-in management

Thus, the platform is used as a single-buyer-platform where flexible demand offers could be done including time slot, place, and price. This is shown in Figure 4.

Figure 4: Aim of the WindNODE Flexibility Platform

In Germany the TSO's and DSO's buy the electricity from power plants which are mentioned in the 'renewable energy source act' and in 'Act on combined heat and power generation' but it's a transit item, see Figure 5. The TSO sell the same amount at the power exchange, they didn't generate some profit.

The interesting thing is that the TSO itself operates the reserve market and decide when Redispatch and Feed-in Management has to be conducted. Feed-in management is expensive as shown in Figure 3 to have a single-buyer-market for flexibility as built in the platform may be a solution and reduce the costs for the consumer. TSO and DSO are able to account these costs directly in their balance sheet.

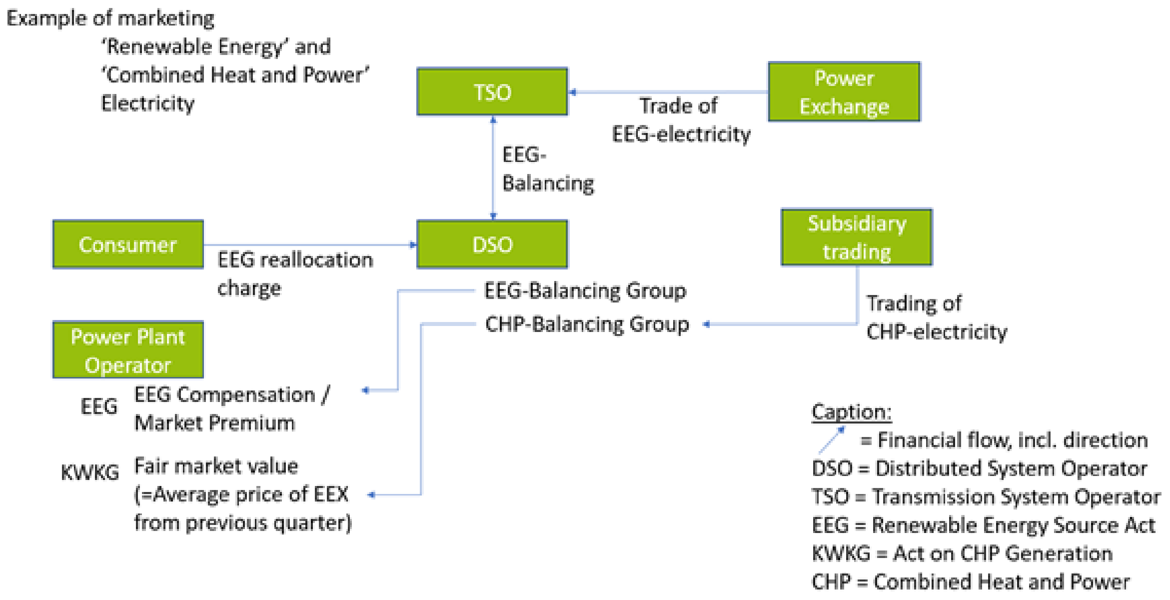

Figure 5 Financial principle of DSO's and TSO's in Germany (own Figure, data bmjv 2017, bmjv 2019, p. 8)

Focus on the **ENERA Project** (enera) is energy demand transparency for an individual and the whole energy system. To reach this aim, enera install for a small fee smart meters in households and municipalities in the EWE Grid area. (EWE Aktiengesellschaft 2019)

Next to the smart meter, the consumers get also a smart meter communication module SAM. In this application is their current electricity demand shown.

Part of the project is also to build a local energy market platform with EPEX SPOT, to remedy grid bottlenecks in this area. The flexibility is given by the consumers, because of price signals of the market. (Schubotz and Diebels 2018)

The TSO and DSO ask for flexibility demand and the providers offer positive and/or negative flexibility, but the negative flexibility outweighs. Flexibility offers are in this project e.g. industrial processes, power-to-X, power plants, etc. (Sommer et al. 2019)

This Platform framework is same as the Intra Day framework. The processes, communication, and interfaces are the same. The most different in this market is the single-buyer system and the usage of a local order book for the proof of origin. There are three options to use flexibility: grid-based, whole system stability or market based. In this case, grid-based flexibility is most used and sometimes system based from TSO. (Sommer et al. 2019)

The next Figure 6 shows the general structure of the flexibility marketplace, which was explained.

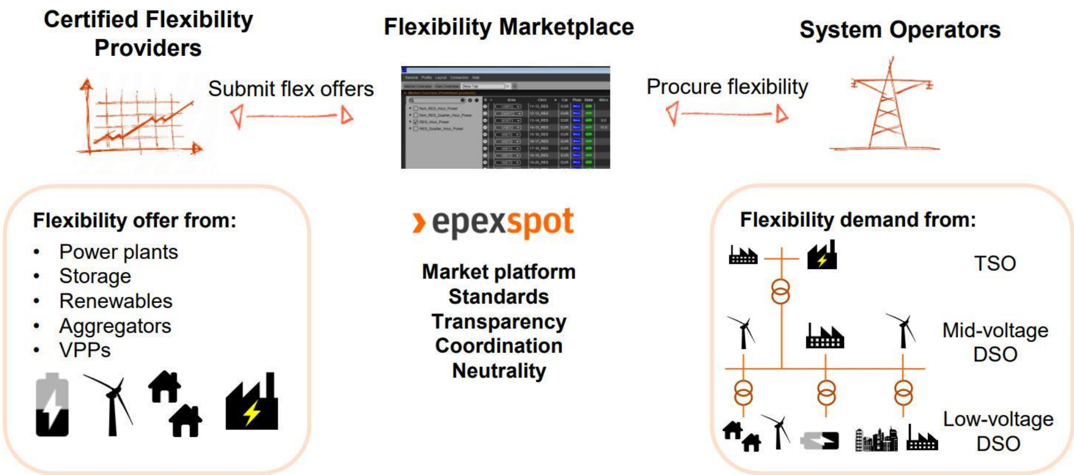

Figure 6: Enera / EpexSpot Flexibility Marketplace (Sommer et al. 2019)

First trade on enera happened on 04/02/2019 at 15h25 with a contract for delivery on the same day at 17h00-18h00 in the market area SOET1 (Sögel) (Bücker 2019, Sommer, et al., 2019), see Figure 7.

TradeID	RemoteTradeID	Exe Time	State	Product	Ctrct	TmZ	Qty	Prc	Cur	P/O	Phase	BOrdrID	BMbr Id	BMbr Name	BTrdr Id	BTrdr Name	Buy Area	BO/C	E
2		04.02.2019 15:25:34	ACTI	Non_RES_Hour_Pow	17-18_NRES	CET	2.0	-45.50	EUR	O	BALA	6	VWKEX	VW Kraftwerk G	TRD002	JENS MEYERH	SOE_T1		P
3		04.02.2019 15:25:41	ACTI	Non_RES_Hour_Pow	18-19_NRES	CET	2.0	-45.50	EUR	O	BALA	7	VWKEX	VW Kraftwerk G	TRD002	JENS MEYERH	SOE_T1		P

Figure 7 First trade on enera flexibility platform (Sommer et al. 2019)

Followed are the principles of energy communities by the '**sonnen GmbH**' example described. The structure of the distributed group from BUZZN is similar, as seen in the table above.

Requirements for being a member of the Sonnen Community (sonnen GmbH 2019, Bund der Energieverbraucher e.V. 2017) are a PV Plant and a storage devise bought from sonnen (Sonnen GmbH). If the member ordered also the sonnenFlat, there is the possibility trading the energy resp. flexibility at the reserve market and earn a profit and if the balance is not smooth, sonnen trade the surplus/lower deviation at Intraday or Day-ahead Market at EpexSpot Leipzig. In this case of reserve trading, the member doesn't get anymore the EEG (Renewable Energy Act) reallocation charge but change into the direct sale of his energy, included in the EEG too. With this possibility, the payback period of the storage device is reached in few years.

Sonnen trade negative frequency controlled reserve of normal operation (FCR-N) to the TSO TenneT (TenneT GmbH). This means, if there is overmuch feed-in from PV, Wind or biomass the Sonnen storage devices charge.

Sonnen Community members sharing their energy on balance sheet, there is no physical balance. This concept is shown in following Figure 8.

Figure 8 Concept of sharing energy in Sonnen Community (sonnen GmbH 2019)

Summarized acts sonnen like an energy supplier and has the benefit of selling the battery storage devices and trading the negative FCR-N at reserve markets.

This principle is shown in Figure 9 Financial principle of sonnen company (own Figure, data Sonnen GmbH 2019). Sonnen sells the prosumer the battery storage device and if requested the PV plant and the Prosumer gets an electricity supply contract with an option of the sonnen Flatrate, as mentioned the prosumer gets either the EEG compensation or the market premium, depends if sonnen trade the surplus or not. Sonnen participates in the reserve market and EEX power exchange in Leipzig for trading energy and flexibility. The reallocation charge and grid costs got from prosumer, sonnen pays to DSO/TSO.

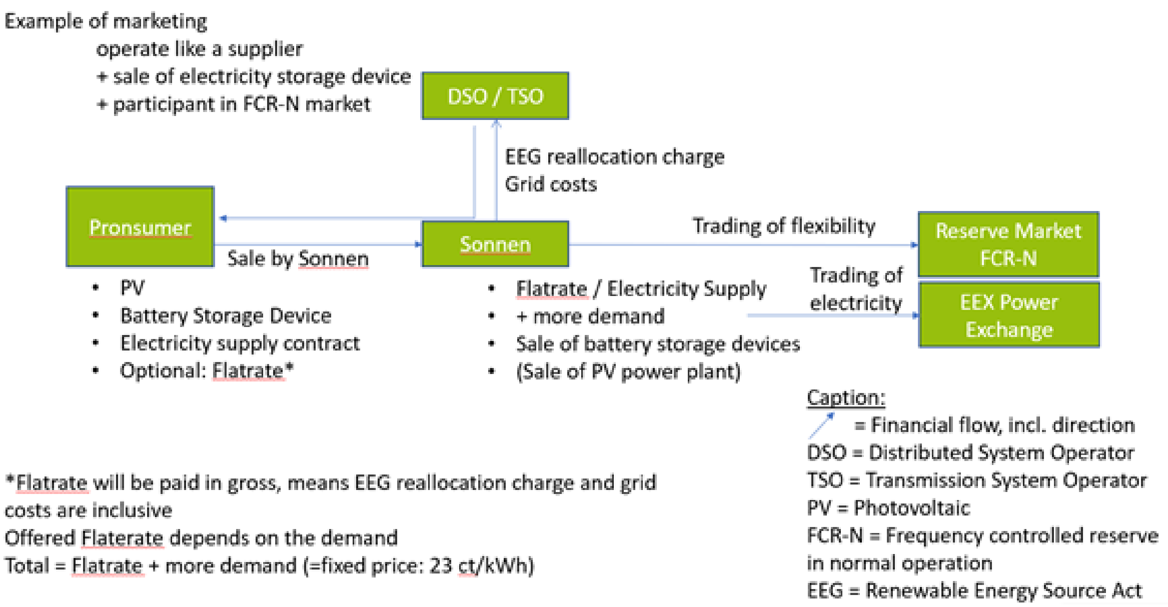

Figure 9 Financial principle of sonnen company (own Figure, data Sonnen GmbH 2019)

In conclusion, sonnen offers the possibility for participating with its battery storage device in the reserve market. Therefore, sonnen sales a storage device and the prosumer get a gross margin and the payback period of the storage device is shorter than without the aggregation of devices. Sonnen act like an electricity supplier means the prosumer has no responsibility for balance and is not able to share electricity itself.

The **LAMP Project** (Landau Microgrid Project) is a research project from Energie Südwest AG and the Karlsruhe Institute of Technology. The aim is a local trade platform for 20 participants in the Lazarettgarten district in Landau. Every consumer and prosumer get a client, a smart meter and the app, all paid by Energie Südwest. This Microgrid is alike and adopted of the Microgid in Brooklyn (Brooklyn Microgrid 2019) .Studies are the prices of the renewable electricity, the market mechanism, and the consumer and prosumer acceptance. (EnergieSüdwest AG 2019)

This Microgrid could be operated off-grid and connected to the public grid, because it’s a closed grid, there is only one point to the public grid. In this grid are ca. 100 meeting points and it's possible to use this area like one building as tenant electricity, because there is a "gap in the law". Thus, it's possible to cut down the grid fees in Landau. (Richter 2019)

Benefits of this Microgrid are the strengthening of coherence in the municipality and the resilience of disturbances, cyber and ecological calamities. Another plus is the promotion of the 'Energiewende', because of the using of renewable energies and involving of the consumers and prosumers.

Summarized a Microgrid is a local energy market for a defined area, it's not a local flexibility market. But, the customers' and suppliers' aim is to raise the autarky of own produced and consumed electricity to 100 %, which means both act more flexible.

A **VPP** aggregates distributed power plants, consumers and storage facilities, which are operated at the market as one plant. Thus, a VPP is more flexible in operation because of many diverse power plants and flexible consumers and storage facilities, it can be used to make contracts in the wholesale market and offers also services to the system operator.

But, is the VPP able to operate nowadays locally? It mostly depends on the market. In the wholesale market, the plants offer energy locally, but price is the variable and not the location. In FCR-N market it's operated somehow locally because of the frequency-based activation of power plants' flexibility. But the other products of the reserve markets are not operated locally, the variable is the system balance, means the price of the flexibility offer defines the accessing.

If we look at the local aspect, a VPP offers little (less than the minimum bid size of the markets) distributed energy resources be part of the energy and flexibility markets for earning a profit. This may be the benefit of a local flexibility market. Aggregators have the infrastructure bringing distributed energy resource plants to market and are able to take balance responsible if needed. (Cf. *Nylund 2018, p. 11, e2m, Koirala et al. 2016, p. 727,* Fingrid 2019b,c, next 2019)

3.2 DOMINOES

The DOMINOES project[9] is an ongoing Horizon 2020 research and innovation project[10] which aims to enable the discovery and development of new demand response, aggregation, grid management and peer-to-peer trading services by designing, developing and validating a transparent and scalable local energy market solution. The project will show how DSOs can dynamically and actively manage grid balance in the emerging future where microgrids, ultra-distributed generation and energy independent communities will be prevalent. The context for the operation of the local market is illustrated in Figure 10

[9] http://dominoesproject.eu/
[10] European Union's Horizon 2020 research and innovation programme agreement No 771066

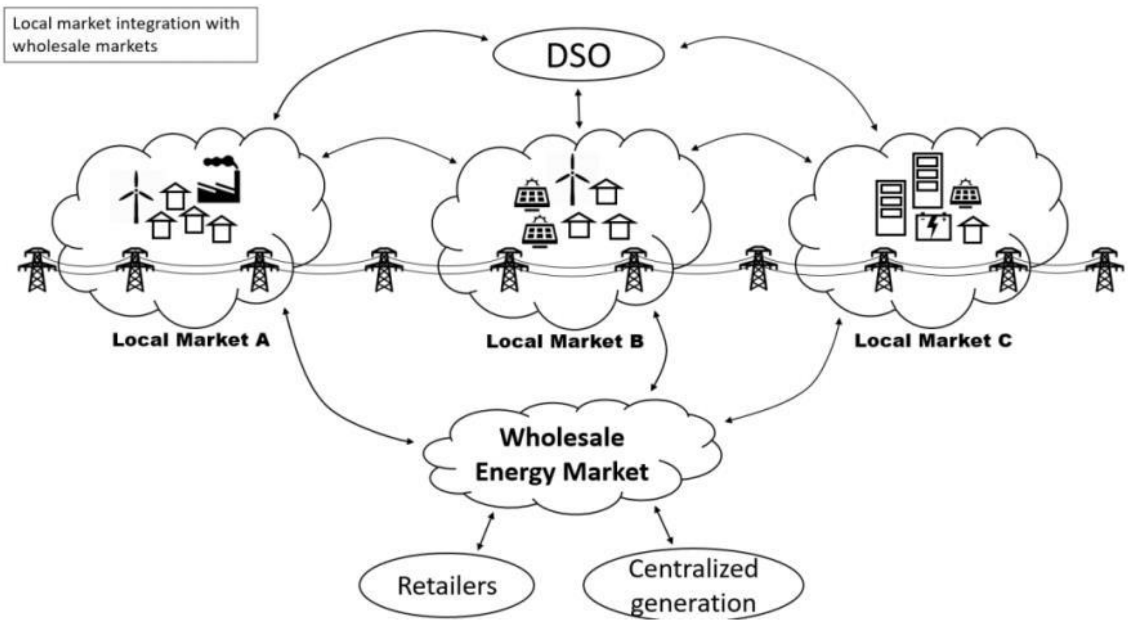

Figure 10 DOMINOES local market context[11]

The DOMINOES concept is making the combination of a local energy market structure and supporting aggregation & demand response services transparent and effective so that it will be possible to enable local sharing and optimization of renewable resources in MV and LV grids. Project will empower prosumers and demand response service provision. The DOMINOES project aim is to create relevant and liquid flexibility for innovative distribution management.

3.2.1 Market design in DOMINOES

DOMINOES is a different kind of market development project since it is focusing into interoperability of flexibility resources instead of local optimization. Without a proper market design, part of the flexibility value will be lost, and resources wasted. It can be seen that we are moving from centralized markets to internetworked communities and there are already local markets appearing. DOMINOES tries to solve how DSO can actively manage grid balance in emerging future.

The core of the market design in DOMINOES are the aims used to develop a local market structure/mechanism that:

- enables local sharing, and optimization of renewable resources in MV and LV grids
- creates relevant and liquid flexibility for innovative distribution management
- empowers prosumers and demand response service provision

These targets are going to be reached with the DOMINOES model which is compatible with wholesale markets while embracing the potential of distributed resources. Figure 11 shows the overall interactions between the local market(s), wholesale market and connected stakeholders. Here the ECSP (energy community service provider) can act as the facilitator of the market or the facilitator for a group of prosumers in case the local market is operated

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[11] DOMINOES D1.1 Local market reference architecture and business requirements: http://dominoesproject.eu/wp-content/uploads/2019/07/D1.1_DOMINOES_LocalMarketReferenceArchitecture_v1.2_final.pdf

by another independent stakeholder. In the implementation model, the choice of sequential markets while avoiding overlap with existing markets will enable the cascading use of the resources in a hierarchical manner, starting from local use. In addition, extending the concept of balance responsibility to a smaller scale will enable the network operator to precisely procure flexibility in case of need and provides incentives for the inclusion of locational information in trading, as well as to improve accountability and verifiability of flexibility in contrast to purely baseline methodologies. These choices enable a scalable solution which can utilize existing infrastructure and services for auxiliary services such as market analysis.

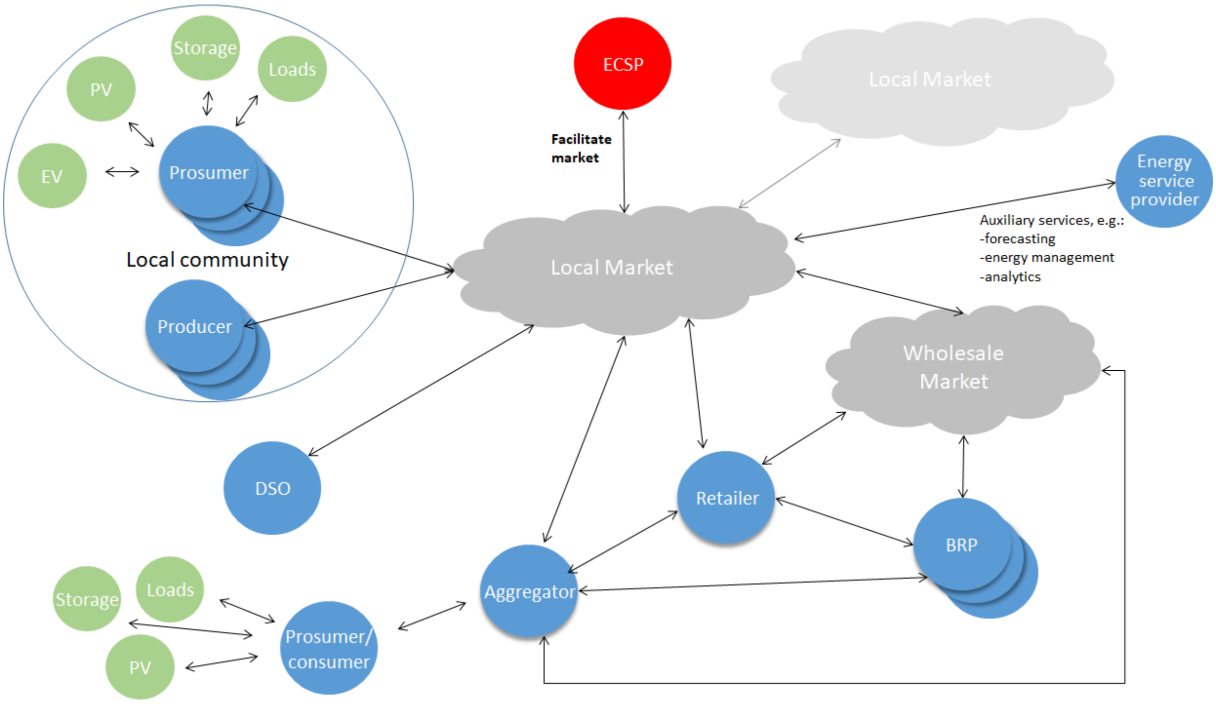

Figure 11 DOMINOES local market, wholesale market and stakeholder interactions[12]

In the DOMINOES model, the local market includes all the trading of electricity within the scope of a distribution grid, as well as the provision of flexibility for the purposes of congestion management within the local grid as well as for the system operator. The local and wholesale markets are set up in a cascading structure, where at first energy and flexibility are used locally and then aggregated for availability on the wholesale level by suppliers or aggregators. The delivered energy and flexibility are settled and validated by tracking the local balances on the metering point level. The local network operator is involved in the local trading by validating the market transactions as well as by procuring flexibility. In addition, in accordance with the widely proposed traffic light concept, the network operator can issue an emergency (red) state, where a network outage is avoided by activating available flexibility in spite of market allocations.

3.2.2 Demonstration of DOMINOES

The DOMINOES model is going to be demonstrated in three validation sites in Portugal and Finland. A DSO environment in Évora (Portugal), a VPP site distributed across commercial sites in Portugal and the green campus in Lappeenranta (Finland).

[12] DOMINOES D1.1 Local market reference architecture and business requirements: http://dominoesproject.eu/wp-content/uploads/2019/07/D1.1_DOMINOES_LocalMarketReferenceArchitecture_v1.2_final.pdf

Project defined five different use cases that define the scope of the project and will help to identify how the results of this project could be implemented as well as supporting the validation. Use cases were also used in designing the local market infrastructure and business models.

- Local market flexibility and energy distributed resources for optimal grid management: Focus on the optimization of distribution network operation using flexibility
- Local energy market data hub manager and technical validator of market transactions: behaviour of the Data Manager (DM) and Technical Validator (TV) at local market
- Local community market with flexibility and energy asset management for energy community value: The objective is to validate the retailer's activities as local market manager
- Local community flexibility and energy asset management for retailer value: Investigate and validate how retailers can take advantage of the flexibility
- Local community flexibility and energy asset for management for wholesale and energy system market value: Aggregation of resources from communities for the benefit of the energy system for some services.

3.2.3 From DOMINOES to Smart Otaniemi

The experiences from the DOMINOES project were used during the development of the framework for flexibility within the Smart Otaniemi context. The market framework and supporting use cases and business models considered in DOMINOES were discussed with the Finnish consortium from a Finnish perspective. Especially the role of the network operator and tariffs were a main point of study. In addition, the research on the role of the balance responsibility and settlement processes were shared between the projects.

Local markets could be used for enabling the utilization of energy and flexibility for local use such as congestion management or local trading, or for aggregation into use for the benefit of the larger energy system. Congestion management as a use case is not currently at least as valuable in Otaniemi (or Finland in general in distribution grids), while it is already an issue elsewhere in Europe in some locations. Local trading of energy within e.g. communities could also prove to be by itself of limited monetary value. However, in general, as in DOMINOES, it was established that flexibility should be available for multiple uses in order to get the best value for the resources, enabling value stacking. In addition, all the components of the electrical bill should be considered (distribution tariffs and taxes) in order to cover investment into the required updates to the ICT and physical infrastructure. The alternative is over investment into network assets.

The different aspects of the distribution network related issues were established based on DOMINOES and alternatives developed for different types of tariffs relevant for the Finnish / Smart Otaniemi case. New information requirements were identified during the definition workshops such as the need for location information in the market operation as well as the linking of that information to the grid topology. For the implementation, more granular forecasting is required. Cost reflectivity for predictable congestions could come from more dynamic and power-based DSO tariffs. However, it was identified that the regulatory and social aspects such as fairness and distribution of income in the more cost reflective tariffs are considered.

The role of balance responsibility in local markets was also developed during the workshops starting partly from the models presented by Empower. What was established was that the balance responsibility could be extended closer to the end-consumer in order to enable P2P trading, validation of activated flexibility and transparency of costs.

3.3 Local flexibility markets elsewhere

3.3.1 Review of exemplary platforms and research projects

Discussion in Chapter 2 identifies the potential benefits for local flexibility market. Given the experienced and forecast rapid rise of var-RES capacities worldwide over this century, it is not surprising that there is a lot of on-going research, demonstration and piloting activity around the world under the topic. Furthermore, it is natural that the specifications of local flexibility activities vary between markets, energy system specifications and other factors related to different operational environments. Also, the maturity of solutions varies from research projects, or small-scale pilots to far-implemented, established parts of the functioning markets; in addition to direct operational markets, there are initiatives aiming at finding harmonized standards for market models offering flexibility etc. Thus, we review chosen international examples of local flexibility markets elsewhere to get their lessons and identify the scope for the Smart Otaniemi Local Flexibility Market case. Hence, we improve the chances to achieve a solution well suitable for Finland and Nordic system with novel characteristics.

For the purpose of advancing definition phase of LFM in the case of Smart Otaniemi, some 10 international examples of different kinds of market platforms and/or research projects were reviewed as reference cases. The cases were selected highly based on consortium's experience in the sector. In accordance with characteristics identified in Chapter 2 addressing flexibility (gate closure and time resolutions), the following main criteria main used in classifying the references:

- Description
- Scale of the demo/project
- Country / City / Key operators
- Time reference
- Characterization / Technology demonstrated

The review suggested that not all the projects could be classified as advancing locality **and** flexibility. For example, some of the initiatives seem to be have their primary effect as "accounting mechanisms" - i.e. finding a way to match a user and consumer of electricity *after the actual use of energy unit*. This kind of mechanism is interesting as tools for increasing RES-E in the system per se, but has not direct impact in operational actions of electricity market participants on their supply or demand of flexibility based on a response to market signals - i.e. to market-based ability to flex. Table 3 presents selected international reference cases especially relevant for Smart Otaniemi LFM, having locational and flexible elements. Hence, they include the following additional criteria.

- Flexibility product description
- Way to consider network topology

Table 3. Selected international reference cases for local flexibility markets.

	ETPA (The Energy Trading Platform Amsterdam)	**NODES**	**ENERA**

Flexibility product description	Independent trade platform for aggregators, collectives and smart grid solutions to e.g.offer flexibility also in small scale. Trades enabled in 15-minute blocks with a high level of automation. Intraday, day ahead, week and weekend contracts.	Flexibility to solve local congestions and other grid management issues. A flexibility product has two main properties: availability payment and activation payment	Transparent market mechanism for flexibility providers who wish to participate in market-based congestion management will be created.
Way to consider network topology	”All trades accounted”	Key idea: all flexibility assets need to be tagged with their location.	“Locational orderbooks” to efficiently centralize flexibility offers
Scale of the demo/project	System in operation, ”open”	Company created in early 2018, ”Open, transparent and independent”	The market platform will be available to system operators and flexibility providers of the project consortium, larger scale targeted
Country / City / Key operators	The Netherlands / Amsterdam, TSO TenneT has a share of 40 %	Norway / NordPool, Agder Energi (3th largest hydro company in Norway, co-owned by StatKraft)	Germany: EWE, EPEX SPOT, DSOs Avacon Netz, EWE NETZ and the German TSO TenneT
Time reference	Started in April 2016	Company created in early 2018	Implementation 2018, demonstration in 2019/2020 as proof of concept
Characterization / Technology demonstrated, ”uniqueness”	Lowers the market entry thresholds – minimum 0.5 MW to benefit from the flexibility in their energy capacity. “Innovative solution to collateral.”	Fully automated marketplace Connects local and central power markets to an integrated market	With local flexibility market platform the project partners aim to efficiently tackle the widespread issue of grid congestion (can be used by DSOs and TSOs).
Website / Sources	1 2	1	1

Table 4 and Table 5 present reference cases somewhat related to local or flexibility issues: small-scale market issues, integration of var-RES, verification mechanisms to allocate the RES production, standard initiatives or projects still on-going. Hence, also they have relevance in the Smart Otaniemi LFM related issues. Especially, collaboration between the H2020 project DOMINOES (section 3.2) to establish viable local flexibility market hypotheses that can be scaled beyond the Otaniemi region and local Nordic conditions, can be raised up, as Empower IM as the coordinator of the DOMINOES project participates in Smart Otaniemi LFM work package as well.

Table 4. Selected international reference cases related to local flexibility issues.

	DOMINOES	**PowerMatching City**	**USEF** (Universal Smart Energy Framework)
Description	DOMINOES proposes an environment where local markets populate a distribution grid	The energy trading on the local market is fully automated through a system – the Powermatcher – that optimises, independently	Delivers the market model for the trading and commoditisation of energy flexibility, and the architecture, tools and rules to make it work

		and objectively, the interests of all participants.	effectively *(an international common standard for smart energy).*
Scale of the demo/project	EU H2020 Research project	Demonstration: ”Laboratory for sustainable living”, 40 households	Foundation, non-profit partnership of seven organizations, active in the smart energy industry
Country / City / Key operators	Three validation sites in Finland and Portugal. Empower (coordinator – Finland), EDP (CNET and EDP Distribution), ISEP (GECAD), Lappeenranta University of Technology – LUT (Finland), Queens University of Belfast (UK) and University of Seville (Spain).	Near Groningen, Netherlands.	Netherlands; ABB, Alliander, DNV GL, IBM, ICT , Stedin, Essent
Time reference	October 2017-September 2021	2007-2015	2014-
Characterization / Technology demonstrated	A market mechanism and supportive IT tools to provide an energy market architecture enabling local energy communities will be designed.	Households equipped with micro co-generation units, hybrid heat pumps, PV-solar panels, smart appliances, home energy storage and electric vehicles.	Several demonstration projects where USEF is applied. 18 flexibility services
Website / Sources	1 2	1 2	1

Table 5. Varying international reference projects / co-operatives interesting from Smart Otaniemi point of view.

	Pacific Northwest GridWise Olympic Peninsula project	**Parker**	**Swytch**
Description	Consumers residing in a transmission constrained region could send bids to a local energy market about their energy use. Control of these resources was conducted as if all resided on a common virtual feeder. Market clearing took place every 5 min. Load bids were automatically calculated for thermostatically controlled loads based on comfort settings.	Electric vehicle’s potential in balancing the Danish power system: esp. electric vehicles' role in contributing to balancing the future power system. By using the properties of the electric vehicle as a power resource, they can actively support the grid both locally and system-wide.	A blockchain based platform that seeks to verify and reward the production of sustainable and renewable energy through the issuance of an ERC20-compliant utility token.
Scale of the demo/ project	112 homes, two diesel generators.	Budget: DKK 14,731,471	A global and easily tradable incentive mechanism targeted
Country / City / Key operators	USA/ Washingtonin State/ Port Angeles/ BPA, PacifiCorp, and Portland General Electric	Denmark / Nissan, Mitsubishi Corporation, Mitsubishi Motors Corporation, PSA ID, NUVVE, Frederiksberg Forsyning A/S,	The Swytch platform was created by the Token Commons Foundation, a non-

		Insero A/S, Enel and DTU Electrical Engineering (PowerLabDK	profit foundation based in Zug, Switzerland. Over 20 technology, organizations, city/regions/governmental partners, e.g. E2M, Korean cities
Time reference	2005–2007	August 2016 - July 2018	The foundation was built in 2017 and is ramping up in 2019
Characterization / Technology demonstrated	Distribution constraint could be managed by local real-time market.	Validation that series-produced electric vehicles as part of an operational vehicle fleet can support the power grid by becoming a vertically integrated resource, "World's first cross-brand V2G demonstration"	The Swytch platform includes token-based incentives, open-source data aggregation, and unique blockchain protocols to secure and verify energy production data.
Website / Sources	https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-17167.pdf	http://parker-project.com/	https://swytch.io/

3.3.2 Review of local flexibility markets based on recent initiatives from Great Britain

To complement the international review conducted in Smart Otaniemi WP 4 (section 3.3.1) and more focused analysis in sections 3.1 and 3.2, Local Flexibility markets of Great Britain were scrutinized in December 2019 based on a review of more than 50 recently published professional articles (mostly *Current News,* a news platform for industrial activities, sources dated 2018-19). As selection of cases in section 3.3.1 is largely based on consortium's experience in the field and is dated back in early phase of the project, this approach was seen to add with timely news on a quickly evolving sector. Furthermore, as GB is widely recognized as one of the pioneers in the evolution of liberalized electricity, reflected, for example, in its introduction of capacity-based elements in the market system during recent years, a look at activities in GB in the context of LFM was recognized as a justified case.

Generally, the target of GB oriented LFM review was refined as to find and explore Smart Otaniemi WP4-relevant trials, reflecting the characteristics identified important earlier in the project:

- A trading platform enabling flexible, technology-neutral bidding
- Use for local congestion management enabled
- Integration in wider market systems enabled (ancillary services)

Key interests of the LFM initiatives meeting the aforementioned criteria fall under *product definition, timescales, roles and responsibilities*, following the guidelines of other parts of this report.

As a general observation of the status of sector in GB, transition of Distribution Network Operators (DNOs) to Distribution System Operators (DSOs) in GB over to 2030 is often referred in the reviewed documents[13]. Under the DSO model, the operator will take a more

[13] The electricity distribution system of GB is divided under six DNOs operating in GB

active role in managing local electricity generation and use over traditional one-way delivery of energy, explaining the interest of DNOs in R&D of more market-based options for procurement of flexibility.

Wheras the review showed activity in many aspects of local flexibility in GB, *Piclo Flex* platform (Piclo), *the independent marketplace for trading energy flexibility online*[14], was identified as a primary reference from the Smart Otaniemi point of view, highly meeting the criteria introduced earlier. In April 2020, the platform is up and running with all the Britain's six network operators involved. Table 6 summarizes the cases identified based on a reviewed documents from 2018-19 and hence summarizes some of the steps in its development. Clearly, Table 6 demonstrates that the evolution of a platform requires step-wise testing processes and other activities with different DNOs and flexibility providers.

Table 6. The presence of Piclo Flex platform in review of Local Flexibility Market activities in GB.

Name of the deal /initiative/project	Characterization	Operated by/participants	Local market aspect	Flex market aspect	Source
Piclo-SSEN flex agreement	Flex marketplace, local congestion management	**Piclo**, SSEN (network company)	Local grids in congested areas	Flexibility marketplace, 175 providers, 4 GW	Current News, June 27th, 2019
Scottish Power Energy Networks (SPEN) joining the **Piclo** platform	Local flexibility tested: income from flexibility, savings of grid upgrades…	Scottish Power Energy Networks (SPEN), **Piclo**	Yes	Yes	Current News, September 19th, 2018
UK Power Networks flexibility tender, 'biggest ever'	18.2 MW of power contracted from six companies using Piclo's platform	UK Power Networks (UKPN, DNO), **Piclo**'s platform	Yes, eight locations in GB: Brandon, Leighton Buzzard, Lewes Newhaven,	Yes, Flexibility contracted (total value £ 450 000).	Current News, May 15th, 2019
SSEN's seek for capacity alleviating network constraints	Flexibility resources seeked through **Piclo**'s platforms	Scottish and Southern Electricity Networks, **Piclo**	Yes, Western Isles and Skye.	Yes, providers capable of delivering flexibility	Current News, August 7th, 2019
UKPN competition for flexibility on Piclo Flex	170MW of flexibility requirements competed on **Piclo's** flexibility marketplace	UK Power Networks (UKPN), **Piclo**	Yes; locality specified; across 115 areas on UKPN network.	Yes; flexibility products specified in the tender	Current News, November 14th, 2019
Scottish flexibility marketplace	Test how to trade participants' flexibility using a digital	Fife Council, the University of St Andrews and Imperial College London	Yes, East Fife	Yes, flexibility included (details unclear in	Current News, October 5th, 2018

[14] picloflex.com

	marketplace **(Piclo)**			the early press release)	
List of flexibility providers in Piclo's platform discussed in an article (50)	Includes energy suppliers, aggregators, brokers, end users, battery manufact., EV charging firms…	**Piclo**	Yes, locality included in platform	Yes, variety of products, e.g. congestion issues	Current News, November 12th, 2018
WPD expanding its flexibility offering, opening a tender window for the procurement of demand response services	DR seeked 93.4MW across 12 locations. WPD joined **Piclo** at the end of 2018.	Western Power Distribution (WPD)	Yes, 12 locations specified	Yes, details of the requirements of each zone (MWhs, months etc)	Current News, March 29th, 2019
Scottish Power Energy Networks (SPEN) joining the Piclo platform	Local flexibility tested: income from flexibility, savings of grid upgrades…	Scottish Power Energy Networks (SPEN), **Piclo**	Yes	Yes	Current News, September 19th, 2018

The main premises of the Piclo platform are summarized in the following (based on Current News, July 4th, 2019)

- Piclo works with all six of Britain's distribution network operators.
    - Years of development, first commercial auction announced 5/2019 and successfully completed.
- Piclo platform creates a heat-map of areas of congestion, correlating them with providers of flexibility with resources (DSR, batteries, …).
- Flexibility procured by DNOs can be used to minimize the bottlenecks and offset more costly grid reinforcements in constrained areas of the network.
- Flexibility types desired by DNOs are specified in the open competitions – qualification period, lead time up to several years.

Details of an auction and needed flexibility are specified under each competition by the DSO that acts as a buyer in that auction set up in the Piclo platform. One can review the specifications of the at least dozens of open flexibility competitions all over GB from the interactive maps available of the website of Piclo Flex [14]. Based on a review conducted on December 2019, an example of the auction details presented in Table 7 and Table 8 to illustrate the nature of open competitions. Table 7 fixes the location and type of the flexibility, and providers with qualifying assets are instructed to be contacted by the system operator, whereas Table 8 presents an example of many of the type contracts auctioned in this exemplary auction.

Table 7. Example of characteristics of an auction reviewed in December 2019. Note: there are very many similar type of auctions constantly open all over the UK with their own specifications.

Characteristics	**Parameters fixed in the example reviewed**
Location	Hyde Park A
Qualification timelines	Qualification close: 20 Jan 2020 14:30
Flexibility type	Power type: ('active') Need type: 'pre fault' Need direction: 'Generation turn up' / 'Consumption turn down'
Buyer	UK Power Networks
Connection	11 kV or below

Table 8. Specification of one contract auctioned. Note: there are multiple similar types of auctions than one in the below example open.

Characteristics	**Parameters fixed in the example reviewed**
Contract type identification	S2021 - Workday afternoon 1 MW, 193.1 hours available
Contract start	1 June 2021
Contract end	30 August 2021
Time required	13:00 - 16:01
Days required	Mo, Tu, We, Th, Fr
Est. utilisation events	-
Est. utilisation duration / event	-
Est. hours utilisation	-
Total need	1 MW
Min. aggregate asset size	0.05 MW
Min. run time	30 mins

Table 7 and Table 8 demonstrate that Piclo Flex platform enables auction on contracts with long lead times based on flexibility availability during the specified periods. As it strength, participants can openly review and, if eligible, participate the auctions open all over the GB instead of one-way centralized procurement of the assets. As a long-term tool, Piclo platform can prove to be an additional tool in the toolbox to advance its target of minimizing bottlenecks and offsetting costly reinforcements.

4. Tariff structures

Tariff structures can be enablers of flexibility if they represent the DSO desires while allowing for adequate remuneration. Dynamism can be more strongly induced by using more variating energy price classes than presently used in Time-of-Use (ToU) tariffs or by using demand based tariff components, which focus on peak loads.

4.1 Existing tariffs in use in Caruna Espoo and Helen Electricity Network

Table 9 presents some examples of current distribution tariff structures. The higher energy based components in time-of-use distribution tariffs are based on fixed times (e.g. 7:00–22:00) or seasons (winter) or a combination of both. The examples presented here do not include a tariff component based on dynamic load situation.

Table 9: Examples of existing distribution tariffs (excluding VAT)

<table>
<tr><th></th><th>General distribution</th><th>Time-of-Use distribution</th><th colspan="2">Low-voltage power distribution</th><th>Generation</th></tr>
<tr><td>HELEN Electricity network</td><td>€4.44/month
c3.28/kWh</td><td>€14.11/month
€1.28/kW/month
day[a]: c2.09/kWh
night: c1.09/kWh</td><td colspan="2">€26.00/month
€4.50/kW/month[b]
€2.29/kvar/month
winter day[c]: c1.66/kWh
otherwise: c0.88/kWh</td><td>€0.00</td></tr>
<tr><td rowspan="2">Caruna Espoo</td><td rowspan="2">€4.79/month
c2.53/kWh</td><td rowspan="2">€10.44/month
day: c2.48/kWh
night: c1.48/kWh</td><td colspan="2">€42.50/month
€4.05/kvar/month</td><td rowspan="2">≤ 100 kW:
€0.00

≤ 1 MW:
€0.5/MWh</td></tr>
<tr><td>€1.25/kW/month
c2.32/kWh</td><td>€2.09/kW/month
winter day:
2.42/kWh
otherwise:
c1.15/kWh</td></tr>
</table>

[a] Daily during 7:00–22:00
b Highest hourly mean power during Mon–Fri 7:00–21:00
[c] Mon–Sat during 7:00–22:00 from 1st Nov to 31st March

4.2 Tariff components and their design

Well-designed distribution tariffs should correlate with the costs and be neutral towards other market participants. Optimally, tariffs should also steer towards effective use of electrical energy. They should also be implementable with reasonable costs, compatible with the tariffs of the energy retailer as well as understandable by the customers. (Honkapuro et al. 2017.)

Tariffs can be divided into a number of components. Monthly fixed fee (€/month) is currently based on the connection capacity (main fuse size), but this only limits the maximum power that the user can draw from the grid.

Capacity fee (€/kW) component is currently included in some time-of-use and power distribution tariffs. The capacity defining hours are fixed (e.g. daily during 7:00–22:00). The time band could be even more narrow, e.g. wintertime 16:00–19:00. An example of dynamic estimation of capacity defining could be that the DSO would have the opportunity to dynamically select, e.g. max 10 capacity defining hours a year, always at least two days in advance.

Energy fee (€/kWh) component can be fixed or time-of-use based. In the existing examples shown in Table 9, energy fees are based on time-of-use patterns. In the future, they could be fully dynamic. With more narrow time bands and larger price spreads, energy fees could in practice emulate dynamic capacity fees.

Generation fee (€/kW, €/kWh) could be used for steering the generation so that it would help in local grid congestion situation, for example having negative tariff in congestion situation and a higher positive tariff in overproduction situation.

Table 10 shows alternatives for new Smart Otaniemi tariff structures. Option 2, a capacity fee based tariff structure, is similar to as suggested by Honkapuro et al (2017) and Pahkala, Uimonen & Väre (2018) for increasing cost correlation and steering effects. Additional components to the tariff could also include quality of service, for example allowing customers to downsize their contract by extending the maximum allowed time of no-service due to failures or premium power with higher voltage of frequency stability.

For a DSO, the tariff structure itself can bear risks of reducing the remuneration too much. Flexibility is mainly used to keep new investments away, so existing costs have still to be covered. If an end-user provides full flexibility, how large a share of his total tariff costs can be allowed to be reduced? For example, if 90% of DSO remuneration is assumed to be gathered by highly dynamic energy fees, for the DSO to still be able to keep the network up and running, how much should be gathered from a customer representing full desired flexibility?

Table 10: Options for new DSO tariff structures. Percentages show average share of component in total remuneration for the DSO.

Tariff component	**Option 1: Monthly fee based**	**Option 2: Capacity fee based**	**Option 3: Dynamic energy based**
Monthly fee (€/month)	75 %	15 %	10 %
Capacity fee (€/kW)	0 %	60 % Dynamic capacity defining hours	0 %
Energy fee (€/kWh)	25 % Dynamic	25 % Time dependent	90 % Strongly dynamic
Generation fee	~0 %	~0 %	~0 %

4.3 The case for dynamic capacity based tariffs in Smart Otaniemi

Otaniemi is a scientific centre in Espoo, incorporates among others VTT and Aalto University research facilities, offices and student housing. The area is mainly district heated. The electricity network belongs to Caruna, as does the rest of the distribution network in the city of Espoo. The aggregated load of potential Smart Otaniemi buildings comprises 42 customers with power distribution tariffs at low or medium voltage level with a total annual load of ~44 GWh.

The hourly times series of the aggregated load of potential Smart Otaniemi buildings is very different from the average load of whole Espoo, see Figure 12. Smart Otaniemi forms a small percentage of the total Espoo load, approximately 3% to 5%.

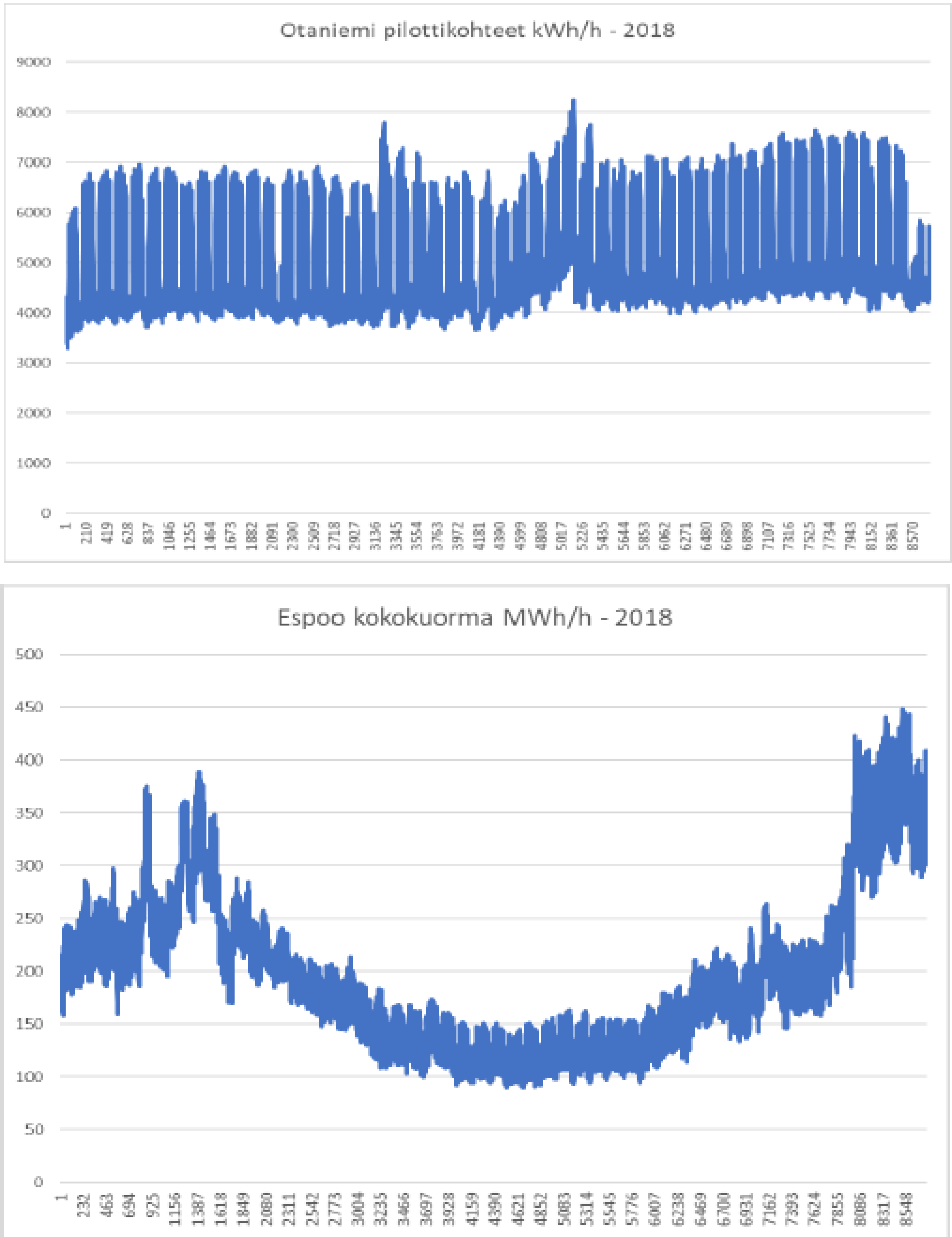

Figure 12. Hour time series in 2018 for Smart Otaniemi potential pilots, upper curve, versus Espoo total consumption, lower curve. (Source: Caruna/Smart Otaniemi project)

What is more striking is the difference in load behaviour. Potential Smart Otaniemi pilot area is dominated by offices, university and research facilities and shows a quite stable seasonal profile, with the peak a bit surprisingly in the summer (cooling load). Weekly profile follows office hours with elevated levels between 8am and 4pm with the peak at around noon. Espoo, on the other hand, is dominated by winter loads, approximately three times as high as summer loads, of which a significant part coming from electric heating. The daily peak is in the evening.

For Espoo purposes, any dynamic tariff testing should be aimed at winter evening peaks. Smart Otaniemi cannot be of use in that respect. Smart Otaniemi could be a suitable pilot for tests decreasing the summer cooling peaks. For any tests, we would need either shadow tariffs. Shadow tariffs would be what the loads follow, but the distribution tariff would be reimbursed according to real tariffs. The target would be to have the shadow tariffs emulate real annual tariff costs as closely as possible. However, the sub-optimal load control would have to be compensated to the customers, if they pay according to the real tariffs, or to the DSO, if they pay according to the shadow tariff.

4.4 Tariff changes and demand response

Tariffs designed to decrease the need for line capacity updates are cumbersome from a customer relations perspective.

If the DSO needs to take actions and they change their tariff structure, they want to see demand responding to the call. Customers who react to the incentive expect their expenditure to decrease, and rightly so. However, the network costs do not decrease, as the action deters future costs, not current. This means that the DSO has to be remunerated for the gap by those who didn’t react. The tariff components have to be increased a tad. Those who reacted see the tariff rise and might get the wrong feeling that the more they save, the higher the tariffs get. This is true, but on an annual scale, those who react might save a penny and those who don’t will compensate for the gap.

Tariff structure changes could perhaps be timed together with tariff price rises instead of having price rises following structural changes?

5. Balance settlement

Balance responsibilities and compensation schemes are a large hindrance to more complex markets and, for example, independent aggregators. End-user markets are at present a question of who sells what and who will be reimbursed and how. If an end-user lowers his consumption and sell this difference as flexibility, from which forecasted level do we calculate the flexibility and are all relevant market participants in agreement of this level? For example, new trading mechanisms involving small end-users will open the doors for arbitrage to be paid by the seller, and that might not be seen as fair by all market parties.

So what is the balance settlement in use today and what will it be tomorrow and what difficulties can be foreseen with each? If we take a novel approach and keep each end-user as balance responsible, how would it affect the systems and the difficulties? Overall, how will the balances and imbalances be affected when the complexity of involved parties (local markets and energy communities, independent aggregators and national ancillary markets) increase?

5.1 Balance settlement in use and its difficulties

Balance responsibility and the settlement of balances are an essential part of the operation of the energy system. For introducing flexibility from distributed resources, there are several approaches how the flexibility can be taken into account in the balance settlement. In general, the balancing chain reaches the end-consumers from the single balance power unit through BRPs and retailers, where the end-consumers have an open-supply contract with their retailers.

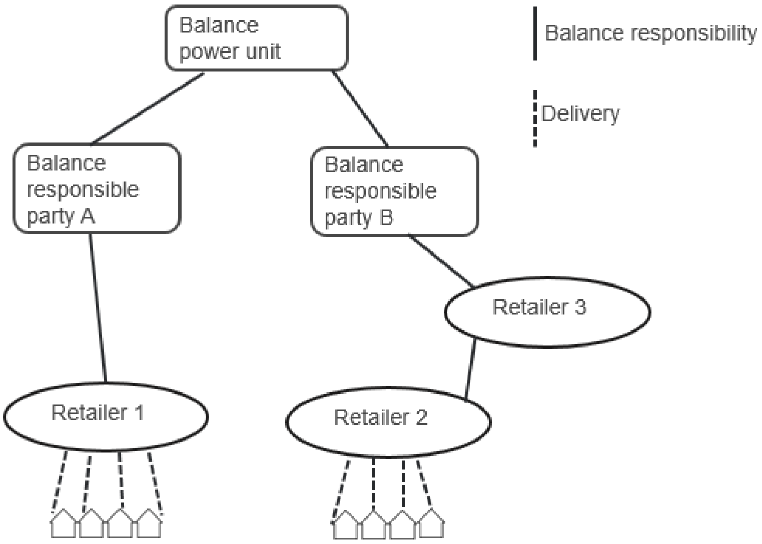

Figure 13 Balance settlement main principle[15]

Transactions in a local market and changes to their consumption (or production) profiles would affect the balances of the retailers (and BRPs). In order to counter the problems introduced by local trading (such as imbalance risks), three options were considered as starting points:

- **Smaller balance responsible units**, where communities or end-consumers could form smaller BRPs who have local balances and are responsible for the risks they take while trading.
- **Independent aggregators**, where an independent aggregator operates the resources under multiple balances. However, this requires separate mechanisms for compensating the effects, resulting multiple balance settlements.
- **Multiple retailers**, where separate retailers could be responsible for e.g. different resources within an end-consumers premises. This however requires sub metering and / or more complex allocation (baseline calculations, proportional allocation and fixed deliveries) of the resources.

[15] DOMINOES D2.2 Scalable Local Energy Market Architecture: http://dominoesproject.eu/wp-content/uploads/2019/07/D2.2_DOMINOES_Scalable-Local-Energy-Market-Architecture_v1.1_PU.pdf

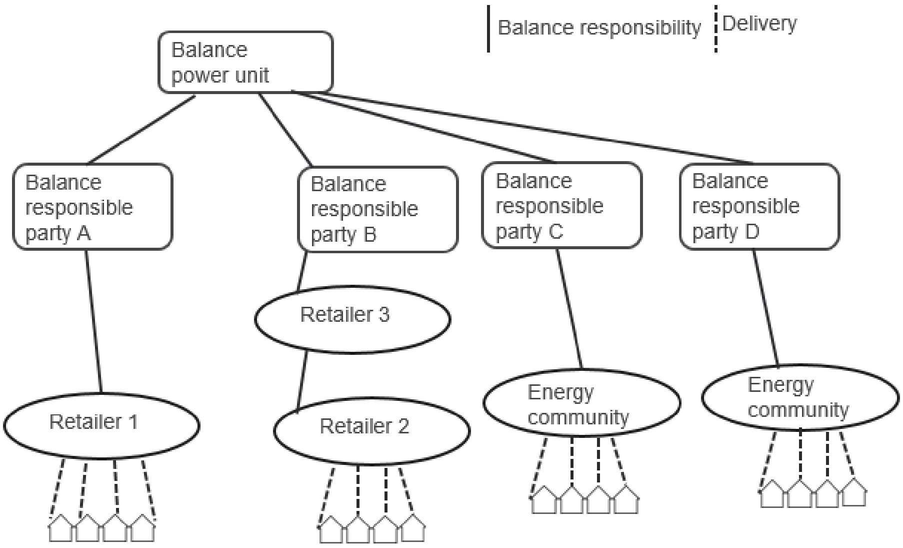

Figure 14 Option 1: Smaller balance responsible units

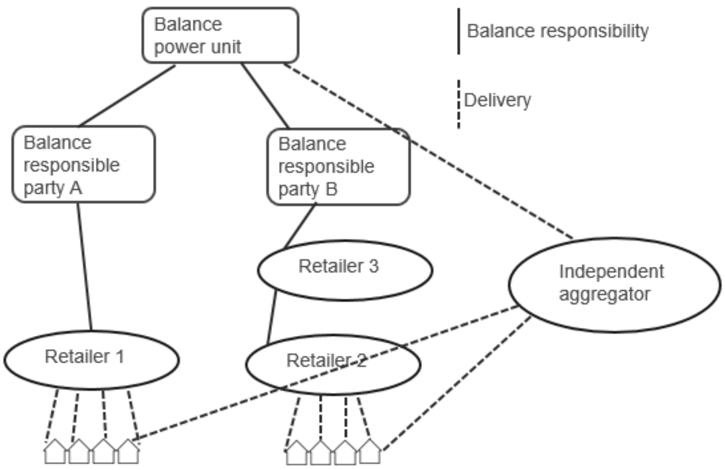

Figure 15 Option 2: Independent aggregator

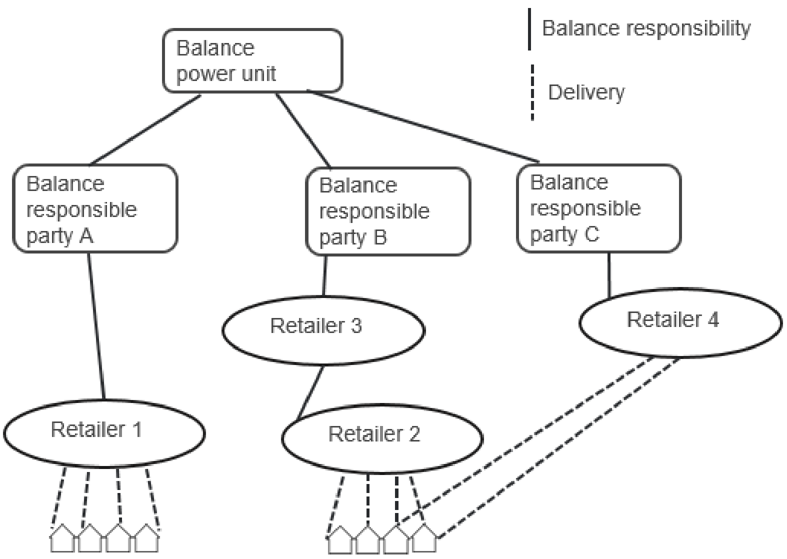

Figure 16 Option 3: Multiple suppliers

In Smart Otaniemi, it was decided to further investigate the first option by extending the balance responsibility to end-consumers. In this way, the market participants on the local market have a responsibility to provide plans for how much energy will be delivered at each location of the grid. These plans can be used for the validation of activated flexibility. In addition, the balances provide accountability of any system costs incurred from the uncertainties / deviations from plans, such as balancing or congestion management.

5.2 What if each end-user is balance responsible?

The idea might seem staggering. How could that even be managed? Well, to begin with, exactly as it is done at the moment. End-users can be understood as empowering the seller to manage their balance responsibility, so the responsibility can be understood as having been delegated upwards. And most end-users would be fine with it. It would even help end-users to understand what the seller actually provides for them even today: only balance management. Sellers do not provide single end-users with fixed spot purchases based on personalised forecasts and top it with imbalance settlement. No, sellers hedge the balance management they have sold to all their end-users with a spot purchase, trying to keep the sum of imbalances as minimum.

All the ponderings and project work related to imbalance management and aggregators in the last 20 years in multitudes of EU programmes and individual projects have not brought the field that much forward. Imbalance management has been the big obstacle. It is unfair for aggregators to add imbalances to sellers, so sellers should be compensated, but how? If an aggregator does something to an end-user load via the spot market, e.g. sells power, what actually happens? What would the load have been before that, and what if the seller assumed that end-user’s load was zero at that hour (electric heating with storage) and now it is negative?

With the end-user being balance responsible, the seller’s position could be simplified to being the BRP in case of no independent aggregators meddling but if there are independent aggregators involved, the end-user takes over the balance responsibility. Now it can be peddled to the independent aggregator or kept by the end-user, according to their mutual contract. The seller will be informed of the forecasted demand and he will deliver that exact amount and have no balance responsibilities. The seller might even keep the balance responsibility, but at a higher tariff and perhaps mandating forward notices of planned actions.

As it is nowadays, the seller benefits from the smoothing of the forecasted load deviations of a mass of end-users, so he can decrease his margin of business. However, with one price balance settlements, an end-user will have larger individual deviation from hour to hour, but as some deviations will bring money and other deviations lose it, the energy costs could be assumed to even out, but be riskier at least in the short term. The end-user will only have to pay for the basic low fee of being imbalanced, and this can be related to the extra income he gets from the aggregator.

EU directives are talking about independent aggregators, but with this solution, we could start talking about independent sellers, who just buy ordered amounts from the power exchange for the end-users at set spot market price. Incumbent sellers for example would lose their obligation if aggregators are involved.

6. Balance settlement simulation model

In this Chapter, we study how the potential flexibility measures are put into action in alternative organizational setups. Who is responsible and what are the means available for the responsible actor? The answers to these questions define the outcomes.

6.1 Defining the system

We define the structure and the energy flows in the local market as a two-level system, Figure 17.

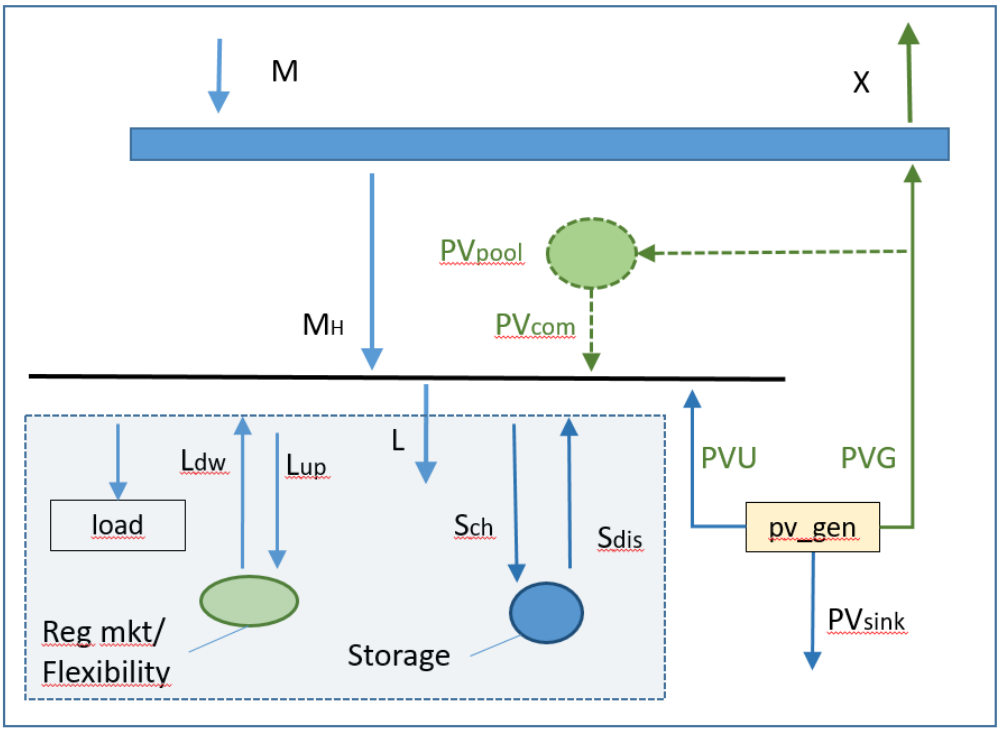

Figure 17. Variables and their relations in the system under study. The thick blue line describes the local grid balance and the thin black line describes end-user load. The blue ellipse allocates supply alternatives to meet the load. Orange arches refer to PV energy flows. Boxes indicate input data

The system consists, according to the Figure 17, of a two-level system in which the upper level is formed of market-wide energy flows and the lower describes the energy flows of an individual consumer. PVpool (the green ellipse) allocates the energy community's PV flows within that community. M_H refers to household's power purchase and PV_{com} refers to community power flow. Export (X) is allowed only in cases when PV generation exceeds prosumer's load, i.e., in real oversupply situations.

6.2 Load

Load is an input data. User flexibility, F_{up} and F_{dw}, decreases power purchase costs, works as a product in the regulation market and helps adapting to possible network bottleneck situation. This demand flexibility can be augmented by battery storage to time power use. The resultant demand, net load, to be met by grid supply is marked as variable *L(t,i)*.

$$L(t,i) - L_{up}(t,i) + L_{dw}(t,i) + S_{dw}(t,i) - S_{up}(t,i) - \mathrm{load}(t,i) = 0$$

$$load(t,i) - L_{dw}(t,i) \geq \lambda_{\mathrm{N}}(i)$$
$$load(t,i) + L_{up}(t,i) \leq \lambda_{\mathrm{X}}(i)$$

The upper and lower bounds are defined based on the original load variations. The upper bound for an end-user load is the maximum value in the data set:

$$\lambda_X(i) = \max_t \{load(t,i)\}$$

Minimum value is defined as a half of minimum in the data set. We assume that customers are willing to suffer a hard restriction on power use for a short period if in that way they can avoid a total blackout.

$$\lambda_N(i) = \tfrac{1}{2} \cdot \min_t \{load(t,i)\}$$

Power inflow from the grid to meet the end-user's demand is always non-negative:

$$G(t,i) \geq L(t,i) - PV_U(t,i)$$

This forms the basis for electricity taxes and grid fees.

6.3 Load flexibility

End-user flexibility comes from two sources: timing of loads, and charging and discharging storages. Flexible loads are typically connected to heat or cool storages, but not inevitably. After the control period, power use either increases or decreases compensating most of the control action. This applies to storage processes. For the non-storing processes, the compensation may not be needed, if the need is time-dependent. For example, outdoor lighting is needed during nights, not during daytime.

The model is not dynamic, but it scans through all the possible states for a balancing period. The overall up and down regulation for each customer has to be in balance the way the next equation describes:

$$\sum_t L_{UP}(t,i) - r_L \cdot \sum_t L_{DW}(t,i) \geq 0$$

The natural value for the parameter r_L is one, meaning full compensation for downward control. Less than one means that not all the energy that would have been used without load control will be used later, when the control is not active anymore. We use 2/3 as a base value for the parameter.

The total value of up and down flexibility is a sum over the clientele:

$$L_{up}^T(t) - \sum_i L_{up}(t,i) = 0$$
$$L_{dw}^T(t) - \sum_i L_{dw}(t,i) = 0$$

The possibilities to apply flexibility varies from consumer to consumer and this is expressed as upper bounds for up and down load range

$$L_{UP}(t,i) \leq f_F(i)$$
$$L_{DW}(t,i) \leq f_F(i)$$

Load situations differ from customer to customer. There may be simultaneous need to cut down the consumption and e.g. charge the battery storage. The setup of the problem dictates should every customer operate in coordinated way or should one act individually. If the simultaneous up and down control is an unwanted situation, it can be avoided by using binary variables b_L in a well know way:

$$L_{UP}^T(t) \leq b_L(t) \cdot \sum_i f_X(i)$$
$$L_{DW}^T(t) \leq (1 - b_L(t)) \cdot \sum_i f_X(i)$$

For the individual balance responsible case, these equations have to be defined for each customer separately

$$L_{UP}(t,i) \leq b_L^i(t,i) \cdot f_X(i)$$
$$L_{DW}(t,i) \leq (1 - b_L^i(t,i)) \cdot f_X(i)$$

This formulation corresponds to the overall setup of the case.

Flexibility demand is generated in the regulation market and it is given as input data. Both of the demand types, $reg_{up}(t)$ and $reg_{dw}(t)$, are defined as positive values.

$$reg_{up}(t) - L_{up}^T(t) \geq 0$$
$$reg_{dw}(t) - L_{dw}^T(t) \geq 0$$

Aggregator’s objective is to fulfil the market demand using all the flexibility resources available at the time of demand.

Flexibility range is assumed symmetric around the actual power use. A fixed coefficient and the difference between maximum and minimum load define the type of available flexibility

$$\Delta load(i) = \max_t \{load(t,i)\} - \min_t \{load(t,i)\}$$

$$f_F(i) = f \cdot \Delta load(i)$$

For *f* we use a value of 0.2, i.e., 20 % of the range. Participation in flexibility market generates a revenue stream that forms an item in the cost function in the aggregator case.

6.4 Battery generated flexibility

Those end-users who have PV panels can use storages (batteries) to time the use of electricity. We broke the storage capacity *S(i,z)* for each end-user into three cost classes z={1,2,3} to shed light to the valuation and sizing of the storages. This is not a dynamic model so we cannot define storage dynamics. Instead, we define an overall demand and supply balance of the system: Charging and discharging have to equal when summing up over all possible states.

At each moment, the sum of the capacities of the storage cost classes must be at least the energy charged or discharged:

$$\sum_z S(i,z) - \left(S_{CH}(t,i) + S_{DIS}(t,i)\right) \geq 0$$

Charging and discharging must fulfil the energy balance equation:

$$\sum_t \left[\eta \cdot S_{CH}(t,i) - \tfrac{1}{\eta} \cdot S_{DIS}(t,i)\right] \geq 0$$

The total energy for charging and discharging are obtained by summing up the individual values:

$$S_{UP}^{T}(t) - \sum_i S_{UP}(t,i) = 0$$
$$S_{DW}^{T}(t) - \sum_i S_{DW}(t,i) = 0$$

6.5 PV generation

PV generation, $pv_{gen}(t,i)$, is an input data. Generated electricity can be used directly, PV_U, it can be shared, PV_G, with other members of the community or if generation exceeds demand and export possibilities are non-existent or uneconomic, then it is spilled, PV_{sink}.

$$pv_{gen}(t,i) - PV_U(t,i) - PV_G(t,i) - PV\sin k(t,i) = 0$$

In case of excess, individual households can only spill the overproduction it there are no batteries where to put the extra energy but an energy community can share the generated amount (up to a point, at least) in a way they choose also without any batteries.

PV generation can be exported if it is not possible to share it with other community members:

$$PV_{pool}(t) = \sum_i PV_{com}(t,i)$$
$$\sum_i PV_G(t,i) = PV_{pool}(t) + X(t)$$

.

PV generator cannot sell electricity to herself via the grid. This constraint is implemented by using a binary variable $b^{PV}(t,i)$:

$$PV_{\mathrm{com}}(t,i) \leq lx(i) \cdot b^{PV}(t,i)$$
$$PV_G(t,i) \leq pv_{gen}(t,i) \cdot (1 - b^{PV}(t,i))$$

$lx(i)$ and $pv_{gen}(t,i)$ are the upper bounds for $PV_{com}(t,i)$ and $PV_G(t,i)$, respectively.

6.6 Imports and exports

The total amount of imports (grid purchase) is a sum over all end-users:

$$M(t) - \sum_i M_H(t,i) = 0\,.$$

Imports and exports have a simple upper bound due to line capacity.

$$M(t) \leq m_{in}$$
$$X(t) \leq m_{out}$$

6.7 Costs and revenues

Net costs cover all the cost and revenue categories (*k* refers to cost categories and *w* to revenue categories):

$$NC(t) = \sum_k p_k C_k(t) - \sum_w p_w R_w(t)$$

Table 11 shows the cost and revenues classes.

Table 11. Cost and revenue items. Formulas are presented as time-dependent values (battery capacity covers the whole time span).

Cost item	Unit cost	Formula
Electricity (imports)	p_M	$p_M \cdot M(t)$
Battery capacity	$p_B(i,z)$	$\sum_{i,z} p_B(i,z) \cdot S(i,z)$
Battery use	p_b	$p_M \cdot \sum_i \left(B_{up}(t,i) + B_{dw}(t,i) \right)$
Grid cost	p_G	$p_M \cdot \sum_i L(t,i)$
Electricity tax	tx	$tx \cdot \sum_i L(t,i)$
PV use	p_S	$p_S \cdot PV_{com}(t,i)$
PV generation	p_{SS}	$p_S \cdot pv\_gen(t,i)$
Revenue item	**Unit revenue**	**Formula**
Flexibility supply	p_F	$p_F \cdot \sum_i \left(L_{up}(t,i) + L_{dw}(t,i) \right)$
Exports	p_X	$p_X \cdot X(t)$
PV sales	p_{SS}	$p_{SS} \cdot PVG(t,i)$

6.8 Balancing

From the balance responsible party's perspective, the expected amount of residual load (original load minus the PV generation) forms the contract load. The deviations from this form the basis for balancing costs. Beforehand it is not possible to say whether the price of these deviations are negative or positive. That is why zero deviations is the natural target.

The expected (average) amount of residual load, y_0, is defined in the normal way:

$$y_0 - \frac{1}{n_t} \sum_{t=1}^{n_t} y_j = 0$$

where y_j is a possible realisation of the load. The deviations in either direction are equally costly so we can define the total amount of deviations as follows[16]:

$$D = \sum_j \left| y_j - y_0 \right| ,$$

in which D is the total deviation, y_j is the amount of the actual purchase in case j, and y_0 is the contracted amount. This function is non-linear, and cannot be included directly in the linear programming model. The transformation that will enable its inclusion is

$$D = \sum_j \left[W_j + R_j \right]$$

subject to additional constraints

$$\begin{aligned} & y_j - y_0 = W_j - R_j \\ \Leftrightarrow \quad & y_j - y_0 - W_j + R_j = 0 \\ & y_j, y_0, W_j, R_j \geq 0 \end{aligned}$$

in which W_j and R_j are the positive and negative deviation of y_j from y_0, respectively. This deviation describes imbalance and an imbalance cost is applied to price it. In all cases, it forms a reference cost, i.e. a basis for comparisons.

6.9 Objective functions

We define the balancing costs as deviations from some contracted value. They form only a small part of the total energy procurement costs. Electricity purchase and other system costs form the major part of the objective function. The trade payments between end-users within the local area do not show up because they simply vanish when all the cost and revenue flows are aggregated.

We define several alternative cases, which differ in that who is on the driver's seat: retailer (supplier), independent aggregator, energy community or individual customer. The first three cases consider all the customers as one group while the individual household case just sums up the results of each customer into the objective function.

6.9.1 General approach

The objective function describes both all the power procurement and system costs and the balance settlement costs. In the latter part, the deviation to be minimized is defined as the difference between expected and realized value over all possible system states. This deviation describes imbalance and an imbalance cost is applied to price it.

6.9.2 Retailer (supplier)

We define two versions of a supplier's objective functions: passive and active retailers. A passive retailer just aggregates costs and revenues to form net costs. The balancing costs

[16] Cohon, Jared, Multiobjective Programming and Planning. Academic Press, 1978.

are summed up afterwards to form an overall result. Not anyone makes any active load controlling activities – this case is close to the present situation.

The objective function is then

$$\text{Minimize} \quad f = \sum_t NC(t)$$

An active retailer wants to minimize the deviations from the contracted amount of imports, $\overline{M}$. First, we define the contracted amount and the deviations from it:

$$\overline{M} - \frac{1}{n}\sum_{t=1}^{n} M(t) = 0$$

$$M(t) - \overline{M} - W(t) + R(t) = 0$$

and then we use the up and down deviations, *W* and *R*, as a source of costs in the objective function as follows:

$$\text{Minimize} \quad f = p_d \cdot \sum_t \left[W(t) + R(t)\right] + \sum_t NC(t)$$

The second sum aggregates all the actual system and power procurement costs.

6.9.3 Independent aggregator

Independent aggregator maximizes revenues from selling flexibility to the regulation market. We define the maximization behaviour as minimizing the deviation of the flexibility supply from the regulation market demand (to follow the approach of the other cases).

$$\left[\sum_i F_{up}(t,i) - reg_{up}(t)\right] + \left[\sum_i F_{dw}(t,i) - reg_{dw}(t)\right] - W(t) + R(t) = 0$$

Upward regulation is zero side (it is impossible to deliver more than the amount demanded) but the down side deviation can be positive.

$$\text{Minimize} \quad f = p_d \cdot \sum_t \left[W(t) + R(t)\right] + \sum_t NC(t).$$

This has the same structure as the retailer's objective function although it describes the maximization problem.

6.9.4 Balance responsible customer

In this case each household makes a contract covering the expected grid purchase, $\overline{M_H(i)}$:

$$\overline{M_H(i)} - \frac{1}{n}\sum_t M_h(t,i) = 0$$

$$M_h(t,i) - \overline{M_H(i)} - W(t,i) + R(t,i) = 0$$

Deviations from the contracted amounts are penalized and the objective function follows the usual lines:

$$\text{Minimize} \quad f = p_d \cdot \sum_{t,i} \left[W(t,i) + R(t,i) \right] + \sum_t NC(t)$$

The difference to the retailer case is in the order operations: here the individual differences from the contracted amounts are calculated first and the overall difference is the sum of these differences whereas in the retailer case, the individual grid purchases are aggregated first and the difference is calculated on the overall level. The sum of individual differences is never smaller than the difference based on the aggregated quantities.

6.9.5 Energy community: allocating PV generation

We assume that the target of the energy community operation is to cover each household's power need with the *same PV share*. This share is determined using the original load data:

$$u(i) = \frac{\sum_t load(t,i)}{\sum_{t,i} load(t,i)}$$

This share enters into the equation that defines the target volume of PV use, $PV_{TGT}(t,i)$, for the household *i*:

$$PV_{TGT}(t,i) = u(i) \cdot \sum_i \left[pv\_gen(t,i) - PV\text{sink}(t,i) \right]$$

$$PV_U(t,i) + PVcom(t,i) - PV_{TGT}(t,i) - W(t,i) + R(t,i) = 0 \;, \quad \forall t,i$$

The first equation defines the target for the whole community whereas the second equation does it for each member and for every time step. We use the latter in the examples as the A alternative is in practise no constraint at all. It does not affect the energy flows at all but consists only of after-the-fact calculation in which the electricity bills will be balanced. This may well be the realistic option.

The objective function acknowledges the possibility that the community performs as a balance responsible party by augmenting the objective function with an overall import contract difference:

$$\text{Minimize} \quad f = p_d \cdot \sum_t \left[W(t) + R(t) \right] + \sum_t NC(t) + \delta \cdot p_d \cdot BAL_M(t)$$

The last term deserves an explanation. $BAL_M(t)$ refers to the imports balancing costs (part of the *retailer's* cost function above). If a community is balance responsible, then δ=1 and the balancing costs play a part in the optimization. If the community procures balancing as a service from a service provider (retailer), then δ=0 and the balancing costs are added afterwards as a service cost on above the direct energy procurement costs. We will compare the results of these approaches.

6.10 Cases

We define altogether six cases for four decision makers to find out how the solution varies along decision maker and her objective function. The four decision makers and their objective functions are the following:

1. Retailer minimizes the sum of net energy costs

2. Retailer minimizes the sum of net energy costs and deviation from contracted amount

3. Independent aggregator minimizes the sum of net energy costs and regulating market demand and supply differences

4. Balance responsible end-user minimizes the sum of net energy costs and deviations from individual contract volume

5. Energy community operator minimizes the sum of net energy costs while allocating the PV energy equally within the community

6. Energy community operator minimizes the sum of net energy costs while allocating solar energy equally within the community, and minimizes the deviations from contract volume

The first retailer just passes the balancing costs to the customers while the second one controls customer loads to minimize balancing costs. Independent aggregator sells flexibility to the regulation market but is not responsible for the balancing issues. These costs are simply added to the other costs afterwards. The two community cases differ in terms of balancing costs: In the first one, the community takes only care of energy procurement and leaves the balancing issues to the retailer but in the second one, the community operator takes care of the balancing as well.

6.11 Input data for the scenarios

First thing to notice is that the model defined above is not a dynamic model: the “time periods” are not connected in the system definition but only in the objective function: The search for the optimal volume of the contract connects all the separate time steps. Optimal level of a contract is the one that minimizes the sum of deviations from it.

We have a set of 10 end-users each of which have individual demand volume and variations. We assume that the variations can be described with an uniform distribution *U(0,1)* as follows:

$$D = D_{\min} + \Delta D \cdot U\left(0,1\right)$$

An example of demand variation of one end-user is shown on the left panel and a cumulative total demand of the area on the right in Figure 18.

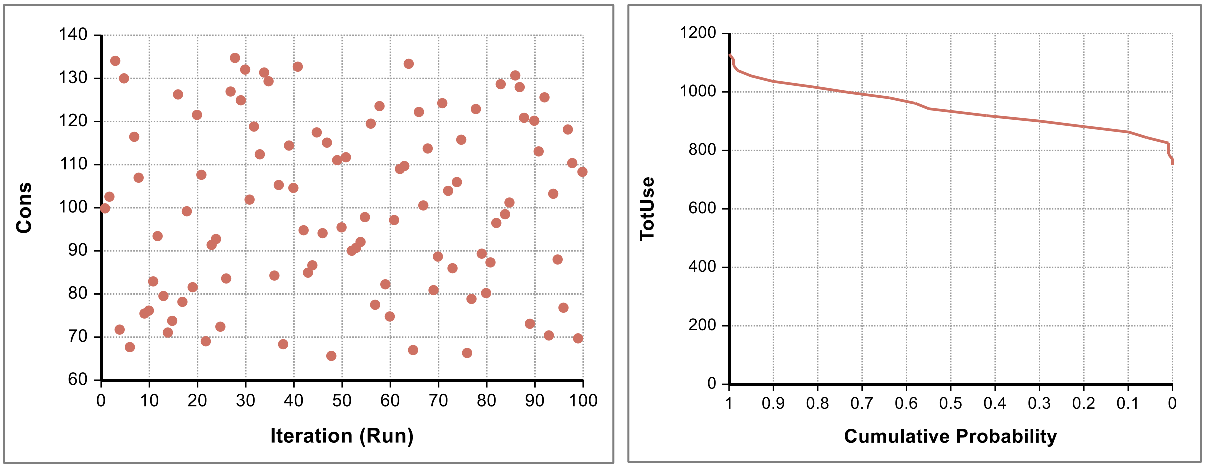

Figure 18. Left: An example of one end-user’s demand (Cons = demand). Right: Total demand distribution in the area (10 customers).

Figure 19 shows the properties of PV generation. Six out of these 10 customers have PV panels. Uniform distribution is used to describe variations in PV generation. All the installations use the same distribution because we assume that in a small area the generation environment is equal for all PV panels. An example of PV output in one installation is shown in the middle panel in Figure 19. Using same distribution for all the PV sets means that the cumulative distribution forms a straight line, Figure 19, right panel.

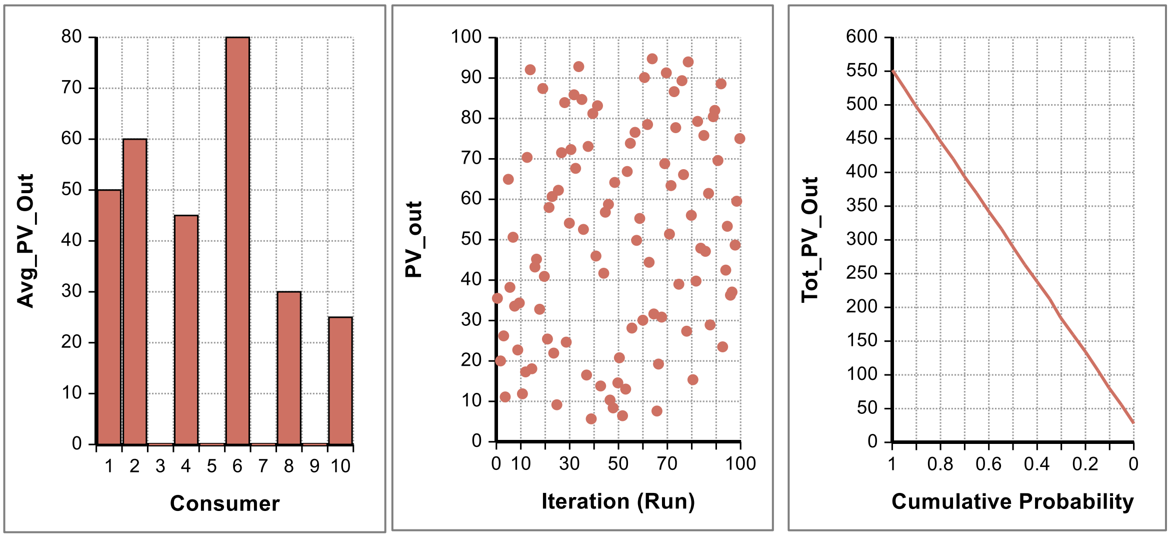

Figure 19. Average PV output (left), an example of output of one installation (middle) and the cumulative distribution of the total PV output (right).

Regulating market demand forms the third stochastic data input set. Following the same general lines as above, this demand is generated by a uniform distribution but now the value range is symmetric around zero, Figure 20.

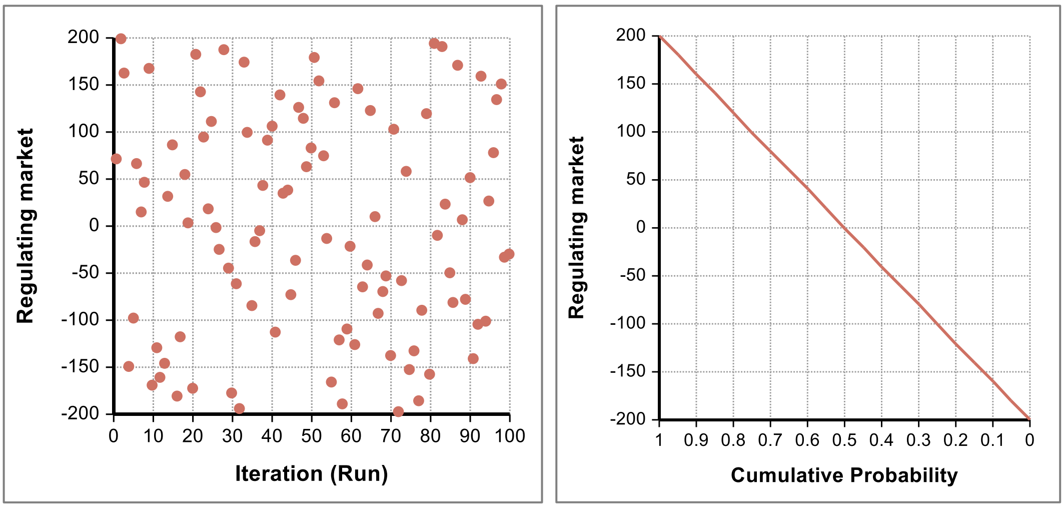

Figure 20. Regulating market demand.

The positive values form the set $reg_{up}(t)$ and the negative values $reg_{dw}(t)$.

The cost parameters are shown in Table 12. The cost of “imports”, the price of electricity taken from the grid consists of three components: energy, distribution and taxes. Typical shares for an end-user are the following: energy 40 %, distribution 30 % and taxes 30 %. Here we are interested only in variable costs and we assume that in distribution costs the fixed cost share is 50 %. The updated shares are thus 47 %, 18 % and 35 %, respectively.

Table 12. Price data. An aggregator obtains the pool price when she sells to the regulation market. Storage cost refer to the yearly costs of the investment. In addition to that, a small degradation cost is added for the use of the storage.

	Price
Energy	0.36
Export	0.2
Pvpool	0.01
Flexibility	0.02
Tax	0.32
Grid	0.32
Storage	[10;30;50]
Deviation	0.38

The storage consists of three blocks and each of them have a unique price. It is up to the optimization to choose the size of the storage.

6.12 Night – no PV generation

The only difference between day and night is the non-existence of PV generation during the nights. This is a nice check for the defined decision making mechanisms.

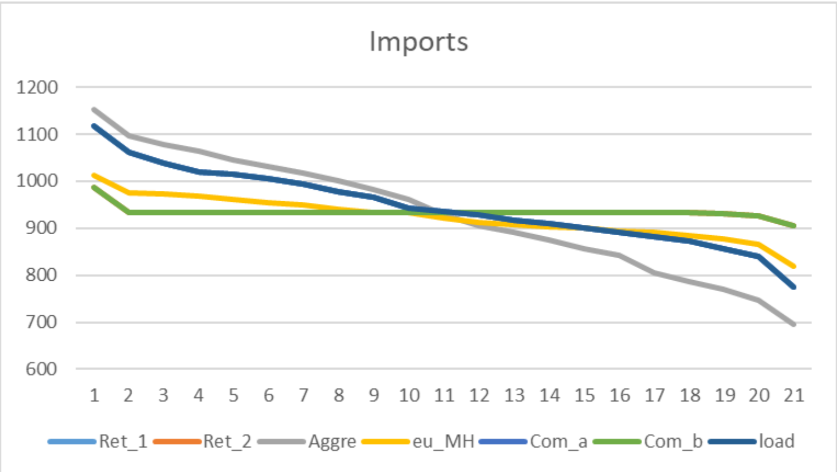

Figure 21. Imports or purchase from the grid and the original load.

There are seven cases but only four curves visible. The reason is that first, The load of Ret_1 and Com_a does not differ from the original load because there are no incentives to carry out any control actions. Second, Ret_2 and Com_b are identical if there are no PV generation. Community shares PV generation, and when there are no solar energy, there is nothing to be shared.

The overall energy procurement and the costs related to it are shown in Figure 22.

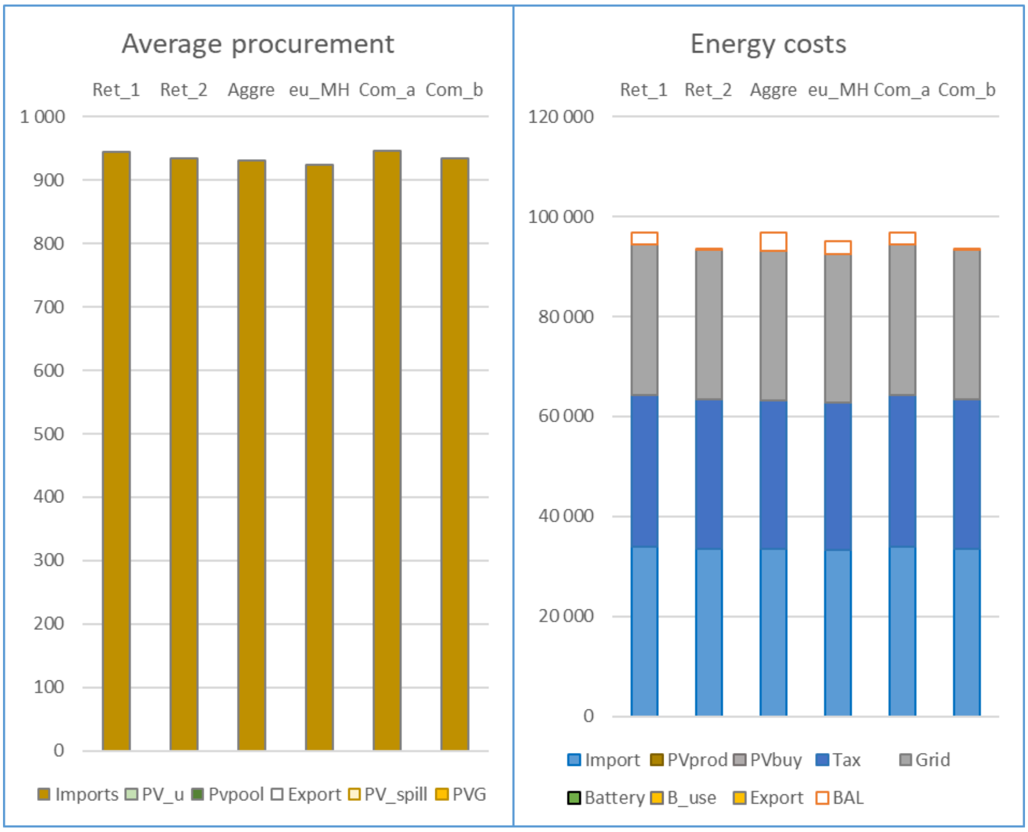

Figure 22. The supply mix is simple (left) and the related costs differ most in balancing costs (right).

Due to the problem setup the energy procurement is optimized in a slightly different manner that shows up both in the procurement volume and in the proportions and volume of the costs. Ret_2 and Com_b are equal without PV generation. Aggre uses controls that maximize the income from the balancing market and this operating policy has a side effect of the highest balancing costs.

The case of balance-responsible individuals, case eu_MH, optimizes grid purchases on an individual basis. In that case the deviations from contracted volumes are calculated on an individual bases while in all the other cases the individual consumptions are summed up first and the deviation is defined based on this aggregated amount. The individual balancing doubles the the balancing costs.

The Aggre case shows the largest variation in the grid purchase. The control operations are dictated by the up or down demands of the regulating market.

The balancing costs are based on the amount of deviations from the contracted volumes:

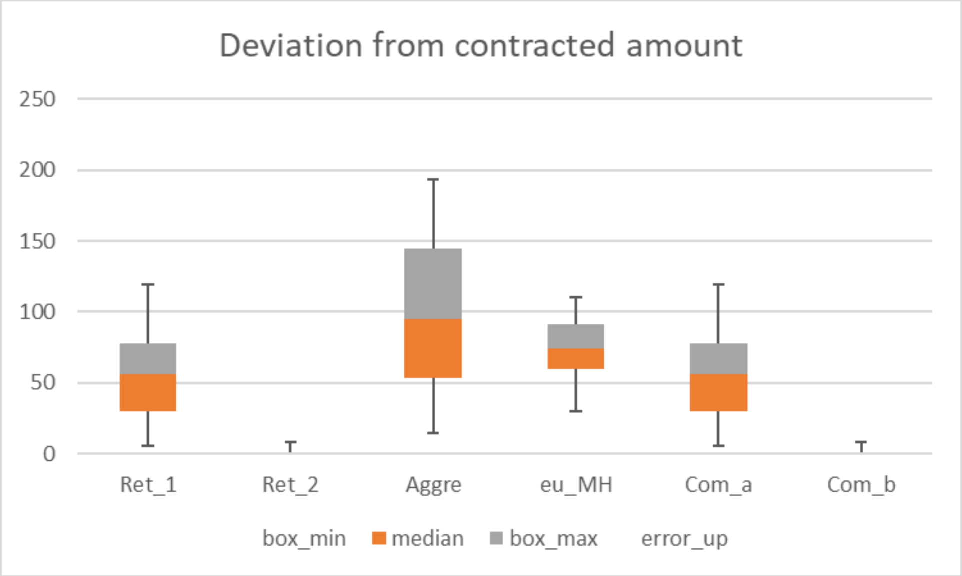

Figure 23. Deviations from contracted volumes by case during night (no PV generation).

Aggre case has the largest range and median of deviations – and the highest balancing costs. Ret_2 and Comb_b do not have practically any deviations whereas Ret_1 and Com_a equal when there are no PV generation present. The individual BRP case has a small variation in deviations although the median is on the higher side of the range.

The next figure shows the flexibility applied. Only those cases are shown where the flexibility actions are applied.

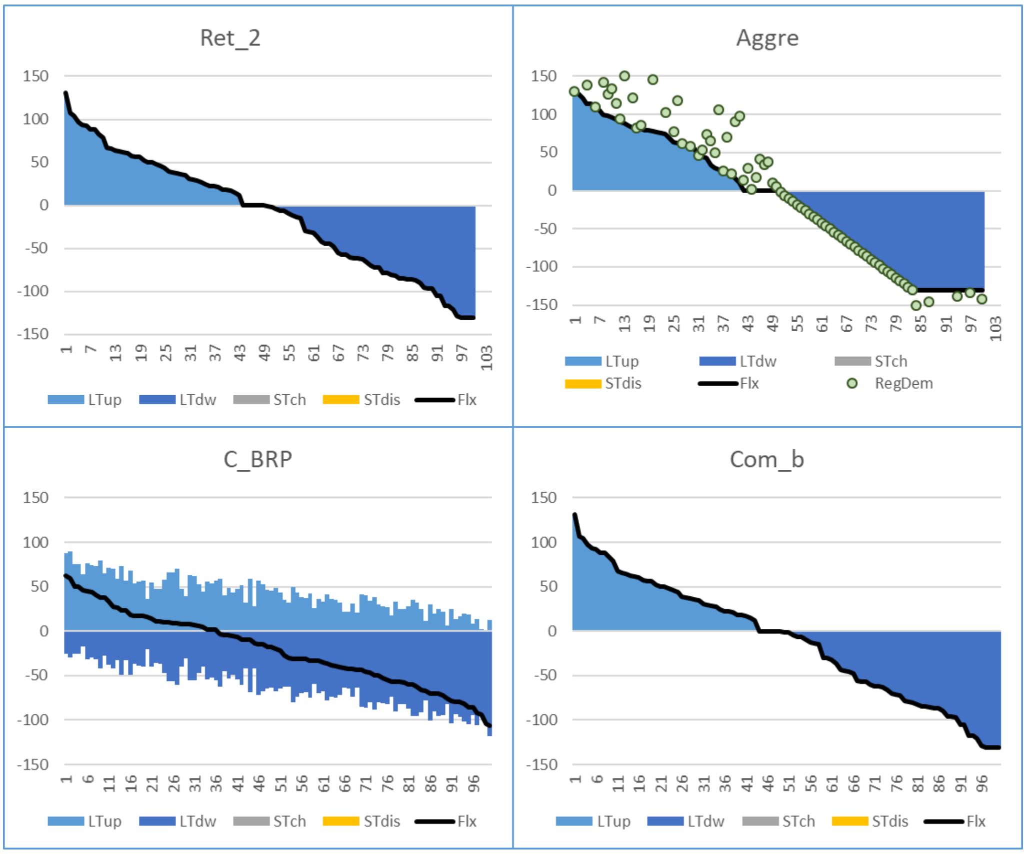

Figure 24. Flexibility measures by night. The black line shows the aggregated effect. LTup means load increase and LTdw load decrease compared to the original load.

The first thing one pays attention to in Figure 24 is the case C_BRP, the individual BRP case. There are simultaneous up and down controls. How can that be optimal? The answer is that every household acts individually, based on its own situation. Ret_2 and Com_b perform equally and Aggre case has its own incentives and outcomes: Regualting market demand for flexibility shown as dots. All in all, the aggregated outcome does not differ so much from case to case.

6.13 Daytime

During daytime, the PV generation changes the game. The peak power of the PV generation equals 1.3 times the average load of the corresponding customer in the sample set. On average, this corresponds to 42 % of the load of the total clientele. With this sizing, the PV generation does not exceed the aggregated local demand but it exceeds the load of the individual households. Without battery storages – or mechanisms to sell it to neighbours - this oversupply is exported. Battery installations are endogenous based on the economic factors. In the community cases, this excess is shared through a pool. This sharing does not exclude the battery installations.

Original load and the load in alternative cases are described in the next figure.

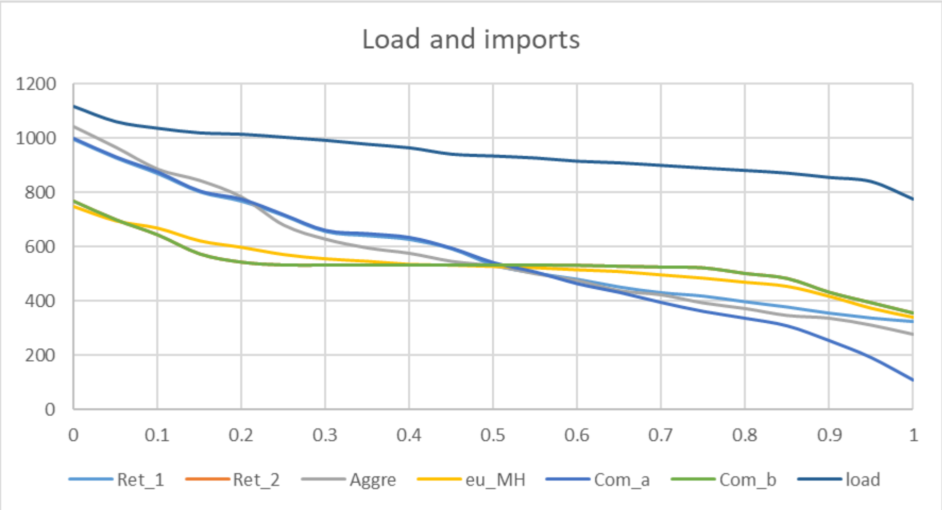

Figure 23. Original load and its value in alternative cases.

There are now two groups of cases as to grid purchases: Ret_2, Com_b and eu_MH form the first groups and the rest three form the other. The use of load flexibility and battery storages explains the differencies.

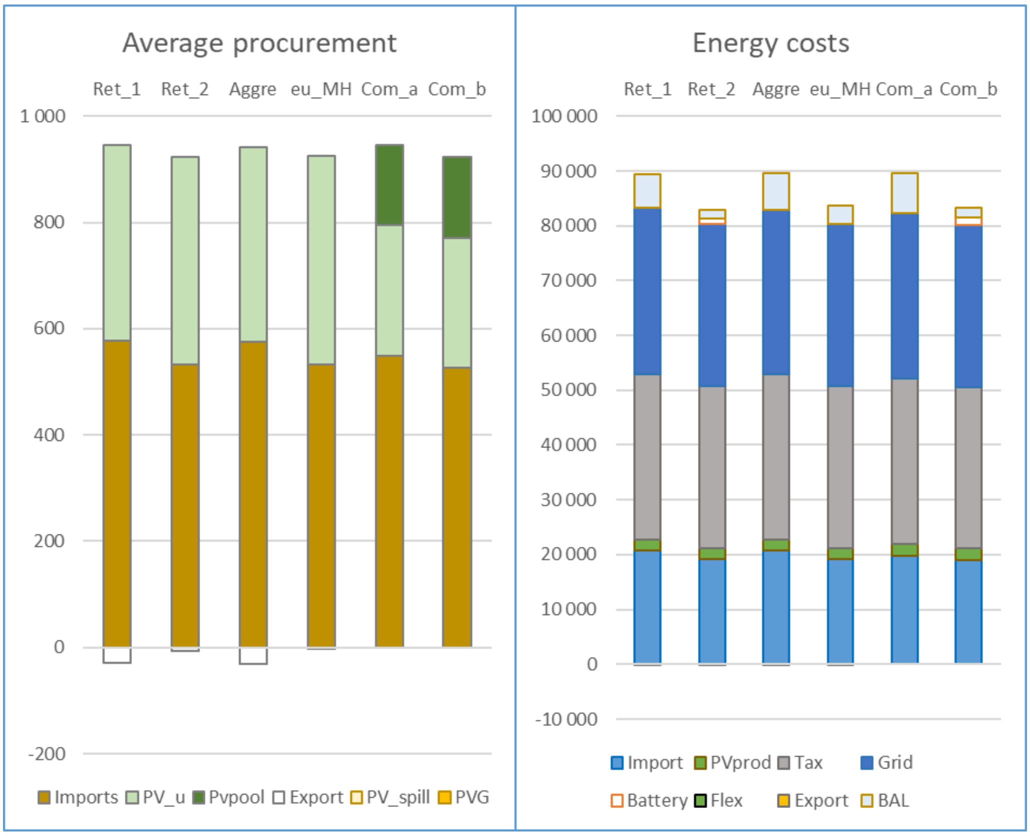

Figure 24. Left: Imports dominate with some variation from case to case. Right: The balancing costs are highlighted with white fill.

Ret_2 case shows only minimal balancing costs and so does Com_b. The battery costs are somewhat higher in Com_b. Using batteries makes it possible to avoid exporting solar energy but this comes at the cost of slightly higher balancing cost. The individual BRP case, eu_MH, performs almost as well as the two centrally coordinated cases.

The Aggre case, as a side effect to following the regulating market demand, exports the most and has relatively high balancing costs. In the Ret_1 and Com_a cases there are no incentives to control loads, and the loads are not controlled. This leads to higher balancing costs compared to other cases.

The deviations from contracted volumes are shown in the next figure.

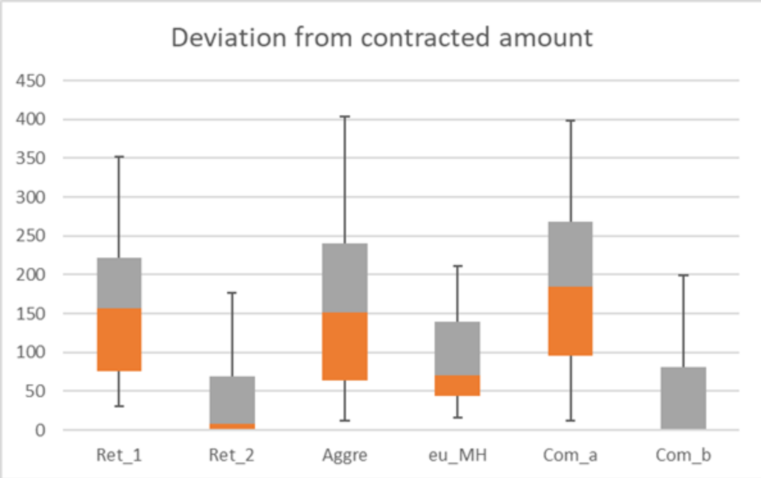

Figure 25. Ret_2 and Com_b are able to follow closely the contracts. Also the eu_MH case performs well. The three other for a class of their own.

Deviations from the contracted volume create differences among the cases. Ret_2 and Com_b are still practically equal. The individual BRP case has more difficulties to keep close to the contracts. But it performs well compared the rest three. The medians of the Ret_1 and the Aggre cases are the same but the Aggre case has larger variability in the deviations. The variability of the Com_a case is the same as that of the Aggre but the median is slightly higher.

How does the PV generation affect the flexibility? Figure flex_day reveals:

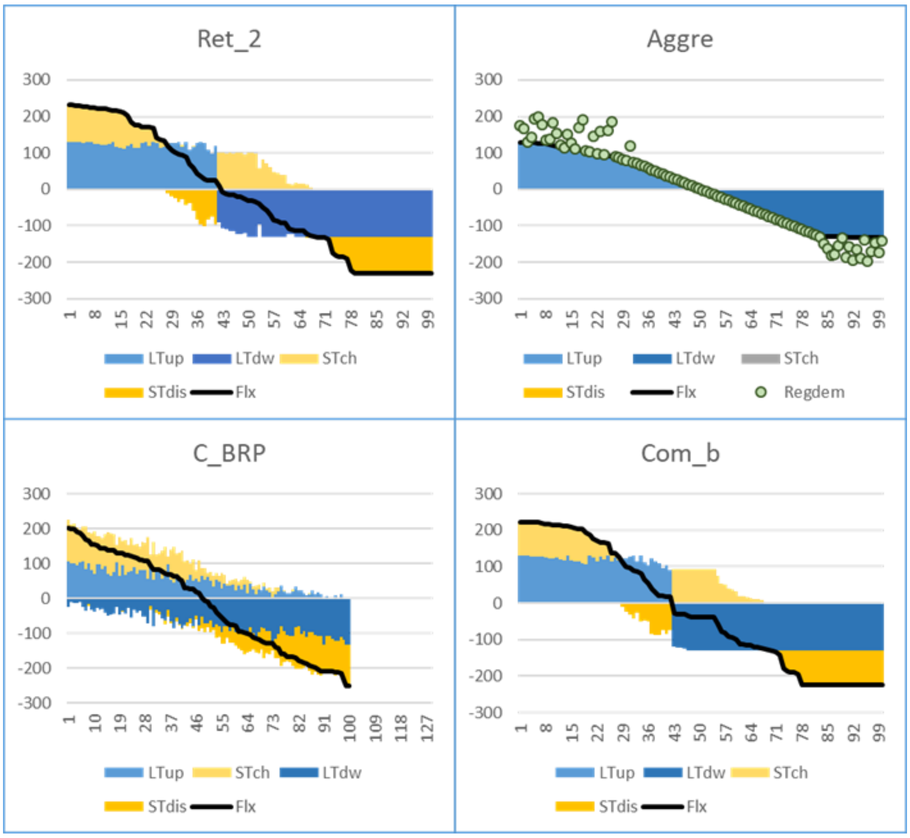

Figure 26. The blue areas refer to load control and the yellow ones to the battery storage operations. The black line describes the aggregated effect and the greed dots define the regulating demand. All the figures are sorted by the aggregated flexibility (the black line).

Figure shows three types flexibility patterns. In Aggre case load control is applied according to the demand of the regulating market. Compared to the night scenario, the supply follows more closely to the demand. Battery storages do not appear to be economic in this case.

In the individual balance responsible case, the outcome repeats the characteristics from the night scenario: simultaneous up and down controls now fulfilled with storage operations.

The Ret_2 and Com_b cases are quite similar in the setup and results – but not equal. The simultaneous, but opposite, operations of load control and battery charging or discharging seems odd. Both the battery and the load control has constraints that forces the overall energy flows to fulfil certain conditions. It is interesting that is optimal to have this kind of operation. The result is partly based on the perfect information the actors have in every case and scenario. It would be easy to exclude these simultaneous opposite controls if they are considered as unrealistic. It is beneficial to start the analysis by defining as few constraints as possible to give the possibility to the model to reveal something unexpected.

7. Synthesis of local flexibility market with Smart Otaniemi logic

This section details the overall Smart Otaniemi flexibility market framework, describes potential stakeholders (in general and in the Otaniemi region) as well as presents several potential flexibility market models for implementation.

7.1 Smart Otaniemi logic

The Smart Otaniemi flexibility market framework is focused on providing mechanisms for connecting to overarching value mechanisms. The main ways in which this is done is through the definition of the main properties in support of connection to existing modes of operation. The following aspects are detailed in general as well as for specific potential markets

- Balance responsibility
- Products
- Buyer of flexibility

7.1.1 Balance responsibility

In this report (as detailed in Section 5), it is proposed to extend the responsibility to maintain the balance in one’s own portfolio from currently used portfolio-level balances all the way to the end-users. This choice is made in order to improve recently highly pursued novel mechanisms such as demand response aggregation and (local) trading of energy and flexibility of small end-users. In the following flexibility market models, the end-user balance responsibility better enables tracking of energy baselines for flexibility trading and local energy trading.

In practice, the balance responsibility could be extended fully to the end-users and existing portfolio balances of BRPs and retailers could be discarded. Alternatively, an intermediate balance responsibility structure could be established with an additional imbalance settlement and settling of B2B transfers of energy between the system-level BRPs.

7.1.2 Products

In order for the local market to be compatible with existing market mechanisms, the products should be as compatible as possible in order to enable the use of resources where they are most valuable.

The different product options are further studied for the specific local flexibility market models in Section 7.3. In general, the market should firstly enable trading of energy for the local end-users. Furthermore, flexible resources should be tradeable through products which could be categorised as

- Compatible flexibility products
- Local flexibility products

The compatible products consist of existing system-level balancing products such as FCR-N. Local flexibility products could then provide services which aid in maintaining the local distribution network. The local products could offer congestion management or ancillary services such as voltage control.

Furthermore, more cost-reflective network tariffs could add to the incentives of the end-users to utilize the network more cost-efficiently. These tariffs could consist of more dynamic time of use or capacity / power based tariffs as detailed in Section 4. However, over-reliance on capacity-based tariffs could over-incentivize residential storages (Schittekatte and Meeus, 2019) at the expense of total system efficiency, while more market-based utilization should be the aim. In addition, dynamic tariffs might not be able to take into account local needs.

7.1.3 Trading, settlement and information exchange requirements

For trading on a smaller local scale, there would be changes of several orders of magnitude in the amount and granularity of data required. At least the amount of data used in trading would increase as well as the complexity in the case of multiple levels of markets. Automated trading agents would be required in practice in order to achieve the scale required.

In addition, more granular and real-time information on forecasted load is required in order to achieve balance on an end-user metering point level.

In case the scalability of the current solutions is not up to par, an increase in total operation costs could be expected. At least the distribution of the costs would be affected. However, potentially the distribution of the costs could be more cost-reflective, driving towards more efficient operation.

7.2 Stakeholders of local flexibility markets

This section introduces the main stakeholders in local flexibility markets which are studied in more detail in the following sections. The main stakeholders in local flexibility markets are the end-users and resource owners, who offer the flexibility, and the buyers of flexibility. In the proposed flexibility market framework, the balances are maintained per end-user metering point and thus the end-users act directly as energy buyers and flexibility providers. The end-users can also allocate this responsibility to some other parties.

7.2.1 Buyers of flexibility

The buyers of flexibility on the local markets depends on the use cases in question. In general, the buyers of flexibility could be

- other BRPs, through the local market in order maintain their own balances
- the DSO, for congestion management or service quality
- or the TSO, for balancing and reserves.

There should be a sufficient amount of participating end-users on the local market in order to have liquidity and to prevent market power. The DSO should be an interested party who is willing to participate in the market and the definition of its required products. The TSO is most likely not a directly participating entity on the local market, but can act as a final buyer of the flexibility through aggregation.

7.2.2 Other market participants

The balance responsible parties are either the operators or owners of the buildings depending on who has the energy procurement contract. There can be different objectives for the connected stakeholders for operating on the market depending on the short-term and longer term aims. These issues are not addressed here.

In addition, other stakeholders such as service providers are required for offering services such as operating the market, trading, forecasting, settlement and billing.

7.2.3 Key stakeholders in Otaniemi

At the moment, flexibility resources are scarce in Otaniemi, mainly adjustable air conditioning in some of the buildings. Off periods can’t be too long, as the need for fresh air is more dominant. How well do pumps etc. react to a flickering use is yet to be determined.

PV production is very limited at the moment, although new constructions are expected to increase the amount. However, PV is not a flexibility source although it is a local energy source.

With the start of EV charging stations, flexibility options will increase especially for longer term/work day charging posts. With fast charging, the time for charging can’t be extended to any noticeable degree, and for reserve operations to function, cars have to be connected and charging. Will there be enough charging posts to have a reasonable confidence in charge forecasts?

Heat storage and heat pumps in Väre, which are now being connected to Smart Otaniemi, form a traditional power-heat flexibility link. This WP has started, but is still far from having answers.

7.3 Local flexibility market models

This section details several use cases for local flexibility markets established for specific aims. For each of the models, the aim is to identify

- Buyer of flexibility
- Products
- Feasibility in Otaniemi and elsewhere

7.3.1 Energy community internal market

- Buyer of flexibility: (local) BRPs
- Products: energy
- At the moment, the main benefit of an energy community is to avoid distribution tariffs. This will be possible in energy communities within a property or where there is a separate local area network. The benefits of operating a local area network might well be drowned by the costs to operate a separate local area network: measurements, contracts, balance settlement rules and compensation schemes, billing and network maintenance and operation.
  - In addition, some not directly economic reasons for local trading could apply such as social community benefits, community empowerment, local sharing and learning
- With demand based tariffs, the occasional benefits would even further dwindle.
- Good opportunity for blockchain based solutions.
- There are no energy communities in Smart Otaniemi as of yet
  - However, many countries have active communities and are developing or have already implemented legislation for energy communities, as required by the EU
  - Finland is also in the process of implementing the legislation for energy communities, see for example Pahkala et al (2018).

7.3.2 DSO bottleneck / countertrade market

- Buyer of flexibility: DSO
  - Benefits for the DSO come from reduced need for costly investments into network, reinforcement deferral
- Products: Energy, flexibility (active power)
- Similar to network constraint solutions taken into pilot action in Great Britain, where in bottlenecked areas there is a market for long term flexibility contracts.
- This approach works especially for remote areas, where an independent generator would set up shop and offer the local flexibility. From a balance settlement point of view, flexible generation production would create an imbalance that has to be settled. Thus further customers or other networks (DSOs or the TSO) would have to be involved.

7.3.3 Local ancillary markets

- Buyer of flexibility: DSO
  - Benefits for the DSO come from improved service quality
- Products: Flexibility (reactive power, active power)

- In Smart Otaniemi project, the local flexibility markets would be simulated with the help of simulated demands and constellations that exist in other markets, e.g. Germany, desolate countryside, Africa or India etc.
- Use of market rules -Nordic or foreign- still an open question.
- Currently no need for these, and not expected to become interesting in the nearest decade in Otaniemi.
    - Possible need also in remote or not well-connected areas where service quality is not sufficiently good

7.3.4 Aggregation to balancing / system level markets

- Buyer of flexibility: TSO (through aggregation)
- Products: energy, TSO flexibility products
- (Independent) aggregator would gather local flexibility (VPP) and sell it to the TSO level balancing and ancillary markets.
- Would not affect distribution network costs of end-users.
- Requires suitable flexible resources from participating buildings
- e2m in Smart Otaniemi.

7.3.5 Seller based marketplace

- Buyer of flexibility: indirectly, surplus RES producers
- Products: energy , storage
- Similar to sonnen.
- Seller would allow his Smart Otaniemi clients, and perhaps other clients also, to trade internally. Mastering of surplus PV, wind power or other production, use of power storages dynamically or even “renting” them to neighbours. Seller would, for example, recoup his costs by a tad higher margins, and by increased clientel.
- Would not affect distribution network costs of end-users.
- Requires suitable flexible resources from participating buildings
- Need of a willing retailer to participate in Smart Otaniemi.
- Opportunity to demonstrate blockchains.

7.3.6 Moving balancing risk from variable RES producer to end-users

- Buyer of flexibility: variable RES producers
- Products: energy

- RES producer sells all his production to end-users at given shares, at production cost. For example wind power costs are already very low cost, less than 40 €/MWh. The end-user is financially responsible for his own balancing. RES producers is BRP for the end-users but balancing costs flow through to the end-users. This removes the balancing risk of the wind power producer, thus easing investment risks. Flexible end-user has strong incentive to follow the production and thereby reduce balancing price risks.
- Would not affect distribution network costs of end-users.
- Requires suitable flexible resources from participants (electric heating with storage, batteries)
- Need of a willing retailer to participate in Smart Otaniemi.
- Opportunity to demonstrate end-user as balance responsible party in practice.

7.3.7 Flexibility market model conclusions for Smart Otaniemi

Smart Otaniemi flexibility is mainly targeted at short term System Operator FCR ancillary markets. As it is, without Väre heat pumps and heat storage, the flexibility offered might not be durable enough for DSO bottleneck management, should such a situation be simulated. To keep Väre heat pumps and other controllable loads from increasing Otaniemi peak load, dynamic demand tariffs are the best bet.

7.3.7.1 Dynamic demand tariffs

Depending on Caruna eagerness and willingness to test new solutions, dynamic demand tariffs show the best promise of a product for the local flexibility market. The tariff type and structure is still open, depending on, for example, Caruna’s target for remuneration and remuneration risk, possible end-user’s willingness and sandbox approval.

7.3.7.2 Balance responsibility at end-user level

For an operational pilot, at least all sellers to the end-users involved should participate. For the sellers, this would amount to at least data programming. For Fingrid this would mean that the end-users should be added as balance responsible parties but with less rights than normal BRP’s.

On the other hand, this could be simulated in the Smart Otaniemi database. The main trick would be to have balance sheets for each participant, allowing for fixed deals, and to be able to forecast each end-user’s load (can be done with VTT software). Aggregator actions and real measurements would be recorded as they take place and then we could calculate how this affects the balance settlements for the different parties.

7.4 Local versus system-level flexibility markets

Without local need, what would be the benefits of local flexibility markets be compared to aggregator operations: do we really need local flex markets?

The products should be congruent (timeline, reaction time, duration etc.) with system level ancillary market products, although the minimum size can be small. And if this is the case, would it not be more beneficiary and cost efficient to decrease the minimum sizes in the actually system level ancillary markets, especially for automated reserves? And even add geographical information and open the markets to buyers from the DSO level?

Overall, would the benefits of a local flexibility market then not be best served by having the local market accepting second rate flexibility (such as slower, with less durability and not as secure) than the system level ancillary markets?

However, in the near-term, local energy and flexibility markets could offer further opportunities for flexible resources especially in grid-constrained locations. Furthermore, in the future the need for local flexibility will assuredly be more apparent.

In order to capture the local value of the flexibility, it is required that the resource location is taken into account in the flexibility market structure. The existing market mechanisms assume the network to be practically a copperplate besides the cross-border transmission connections. In Finnish mFRR-bid location in north/south Finland is required. The detailed location in the distribution grid can be scaled up, but the high level market area information is not useful in the DSO operation.

8. Conclusions

The notion of local flexibility markets hits the first snag with the question of who will buy the local flexibility: not other end-users, not the seller per se, not the local generator unless it is a clearly better solution than selling to the energy market. The main answer is the DSO. The DSO's demand for flexibility might have different reasons such as local ancillary service needs or fighting bottlenecks. However, in general, flexibility should be available for multiple uses in order to get the best value of the resources, enabling value stacking.

Local energy markets could be practical for reasons other than the utilization of flexibility for the management of the local network. Local markets could enable more specialised or granular trading and sharing of resources, especially as a near-term solution if trading is not possible on existing markets for the interested stakeholders. In addition, the local markets could act as an aggregation platform for existing markets. Furthermore, social aspects such as consumer empowerment could provide additional non-financial value.

This report included a state-of-the-art analysis of local markets, and proposed a general framework for flexibility markets (Smart Otaniemi logic) consisting of considerations for balance responsibility and product design. The framework could be implemented in Otaniemi and beyond.

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