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Demonstration of centralised energy market by IoT

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List of abbreviations

Abbreviation	Definition
BES	Battery energy storage
CHP	Combined heat and power
CL	Capacity limit
DER	Distribute energy resource
DSO	Distribution system operator
FED	Fossil-free energy districts - FED
FlexiGrid	Enabling flexibility for future distribution grids with high penetration of variable renewable penetration
FSP	Flexibility service provider
HP	Heat pump
IoT	Internet of thing
LEM	Local energy market
LESOOP	Local energy systems object-oriented programming platform

LFM	Local flexibility market
LP	Linear programming
PV	Photovoltaic
SoC	State of charge
TRL	Technology readiness level

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Executive Summary

Local flexibility markets (LFMs) are market-based solutions to address congestion issues at distribution networks. Local energy markets (LEMs), although being primarily designed for local energy trade, can also be designed in such a way that they can mitigate local congestions i.e., by integrating the local constraints and defining status-based tariffs. l. Two designs for these concepts have already been provided in Deliverable 2.3. The LEM design in Deliverable 2.3 needs to be further improved and tested to achieve a more applicable design for real applications. Moreover, it is important from a societal perspective to compare different congestion management solutions and find the most technical- and cost-effective solution or mix of solutions. The objectives of this deliverable are

- To improve further the design of the two markets
- To demonstrate the markets in real-life using local IoT platform of the testbed and increase the technology readiness level (TRL) of the solutions
- To demonstrate the interaction of grid operator, market operator, retailer, customers, and flexibility service providers (FSPs)
- To compare local energy and flexibility markets using a common platform that facilitates the comparison

The report presents an overview of the testbed, the chosen scope for demonstration, the measurement system and controllable devices, the local IoT platform, and the object-oriented programming platform for comparing the two market models. Five test cases are defined: the real-life demonstration case studies of LEM and LFM designs, a qualitative comparison of LEM and LFM, exchange of services in the LFM, and exchange of services in a commercial LFM between Akademiska Hus and Göteborg Energi. The preliminary results of the testcases are analyzed and discussed.

The object-oriented programming platform for local energy system is developed and integrated with the local IoT platform to demonstrate the two proposed market models. It enables following functions:

- Read measure points from DERs through web APIs
- Generate forecasts of local consumption and production based on historical data
- Define bids on LEM and LFM for different types of agents according to the required bid formats
- Clear the markets by matching the supply and demand bids for benefit maximization
- Convey market clearing results and convert the results to control commands for controllable devices
- Send the commands to devices through web APIs

The two test cases defined for LEM and LFM are implemented using the platform. The test cases have been carried out within a small section of the campus testbed that consists of five buses. The tests show that the platform is functioning, and preliminary results are obtained.

The LEM model is developed based on the model proposed in FED (Fossil-free Energy Districts) project [1]. A status-based grid tariff is introduced and integrated with market clearing function to further relieve the local congestion and stimulate the efficient utilization of distribution grid. In the test case, the market is cleared once per day after the wholesale electricity market is cleared. The preliminary results show that algorithms and communications for agent bidding and market clearing work as expected. The market is cleared by matching the supply and demand bids submitted by the agents. The market clearing prices

reflect finer spatial resolution by integrating both supply cost and distribution cost. The control commands for flexible resource, i.e., BES in the demo, are converted from the market clearing results. The execution of commands will be further tested during the next phase of the demonstration.

The LFM model is an improved version of the peer-to-pool market design presented in Deliverable 2.3. the design includes a triple-horizon organization of long-term reservation, short-term activation, and continuous adjustment market. The traded flexibility product is a temporary limitation of subscribed connection capacity of grid users. A full cycle demonstration of the short-term activation market is tested in an automated manner. The preliminary results show that agents' bidding and control algorithms are interconnected with the forecasts, IoT platform, and the market clearing algorithm. Moreover, the preliminary results of the LFM indicates the impact of forecast errors on failures in the delivery of the flexibility products and thus the importance of utilising continuous adjustment horizon and stochastic or robust optimization algorithms for dispatching the flexibility.

Both market models aim to address the challenges faced by the electric power system nowadays, especially the challenges on distribution level. The report qualitatively compares the two market modes regarding the market organization, roles of market players, integration with overlay markets and existing regulatory frameworks, etc.

The provision of services to Göteborg Energi's flexibility market using Akademiska hus flexibility resources gave good insights in the market operations and showed the importance of setting up solutions that automatically dispatch the resources.

This report presents the results obtained in the demonstrations of the planned test cases. The evaluations of the demonstration results against KPIs will be presented in the coming deliverable D6.4. The results in this report show that the demo site, the IoT platform, the forecasts, the agents' bidding and control, and market algorithms are interconnected and well-functioning as they should. The future activities include:

- Longer real-life demonstrations of the LFM and the LEM
- A more thorough qualitative and quantitative comparison of the LFM and LEM designs
- An automated demonstrations in the commercial LFM of NODES LFM using agent algorithms in LESOOP
- The assessment of adding other flexibility resources such as heat pumps or ventilation system in the demonstration activities

1. Introduction

Local flexibility markets (LFMs) are market-based solutions to address congestion issues at distribution networks. Local energy markets (LEMs), although being primarily designed for local energy trade, can also be designed in such a way that they can mitigate local congestions i.e., by integrating the local constraints and defining status-based tariffs. The background and the design of these markets have been thoroughly discussed in Deliverable 2.3. During the FlexiGrid project, Chalmers Campus testbed have been under development to host demonstrations of these markets. These developments and characteristics of the testbed have been elaborated in detail in D6.1 and D6.2.

The LEM and LFM market designs in Deliverable 2.3 needed to be further improved and tested to achieve a more prepared design for real applications. Moreover, it is important from a societal perspective to compare different congestion management solutions and find the most technical- and cost-effective solution or mix of solutions.

1.1. Objectives and scope

The objective of the work in this report has been:

- To improve further the design of the two markets
- To demonstrate the markets in real-life using local IoT platform of the testbed and increase the technology readiness level (TRL) of the solutions
- To demonstrate the interaction of grid operator, market operator, retailer, customers, and flexibility service providers (FSPs)
- To compare local energy and flexibility markets using a common platform that facilitates the comparison.

In addition, further tests have been conducted using a commercial LFM called NODES in a collaboration between the owner of the testbed and the local DSO.

1.2. Deliverable structure

In this report, the utilized demonstration site is explained in Chapter 2 including an overview of the testbed and the chosen demonstration site, measurement system and controllable devices, the IoT local platform, the common platform used for comparison of the markets. In Chapter3, an overview of the demonstrated LEM and LFM are provided. Chapter 4 elaborates the demonstrated test cases. The preliminary results of the test cases are presented and discussed in Chapter 5 including a qualitative comparison between the LEM and LFM models. The report is concluded and next steps are presented in Chapter 6.

2. Demonstration site with IoT platform

In this chapter, different elements that have contributed to conducting the demonstrations are explained. In Section 0 an overview of the campus testbed is presented. Then, the specific demonstration site is elaborated in Section 2.2. Section 2.3 includes information about the measurement system and the controllable devices at the demonstration site. The IoT platform and its integration is explained in Section 2.4. The common platform for implementation and comparison of the markets are elaborated in Section 2.5.

2.1. Chalmers campus as a testbed

Chalmers campus is located in Gothenburg, Sweden, and consists of several office buildings and research lab facilities. A map of the campus area is presented in Figure 1. Most of the campus buildings are owned and operated by the real estate owner Akademiska Hus. The measurement system measures the electricity consumption for each building as well as voltage, frequency, and reactive power in several of the nodes which has been given in detail in Table 1 of D6.2. Table 2 of D6.2 presents details on each building/node present in the demonstration site on the Chalmers campus together with the tag name for reading the measurement data. The campus area includes different assets such as heat pumps (HPs), photovoltaic panels (PVs), battery energy storages (BES), a combined heat and power unit (CHP), etc. Various parts of the campus can be used for different demonstration purposes.

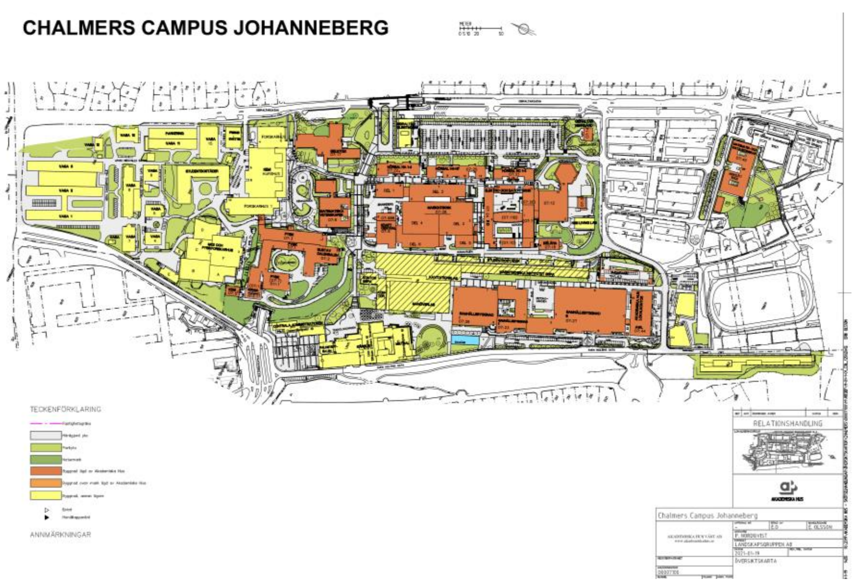

Figure 1 Map of Chalmers Campus

2.2. Demonstration site

The demonstrations in this report are the initial demonstrations of the solutions on this testbed. In this initial step, a smaller section of the campus testbed is chosen. This is because the demonstrated concepts include numerous modules such as forecasts, agents' decision-making algorithms, market modules, and control signals. These number of modules and their relatively complex interaction introduces large amount of variability which lead to challenges in troubleshooting and analysis of the results at the first place. Therefore, the smaller section highlighted with the stripe-filled rectangle in Figure 2 is selected as the demonstration site at the first step.

The chosen demonstration site has different suitable characteristics besides its size. First, it hosts different flexible resources such as PV, BES, and HP. Second, it can be isolated from the rest of the campus and can be seen as a grid-connected microgrid with a point of common coupling. This facilitates evaluating the impact of the solution on congestion events happening at the component that is situated at the point of common coupling, i.e., the line connecting bus 07:8.1.2 to bus 07:8.1.

Although the solutions are demonstrated in this smaller section, the different mentioned modules are developed in a way that can be scaled up if demonstrations are to be done on a larger section of the Campus testbed.

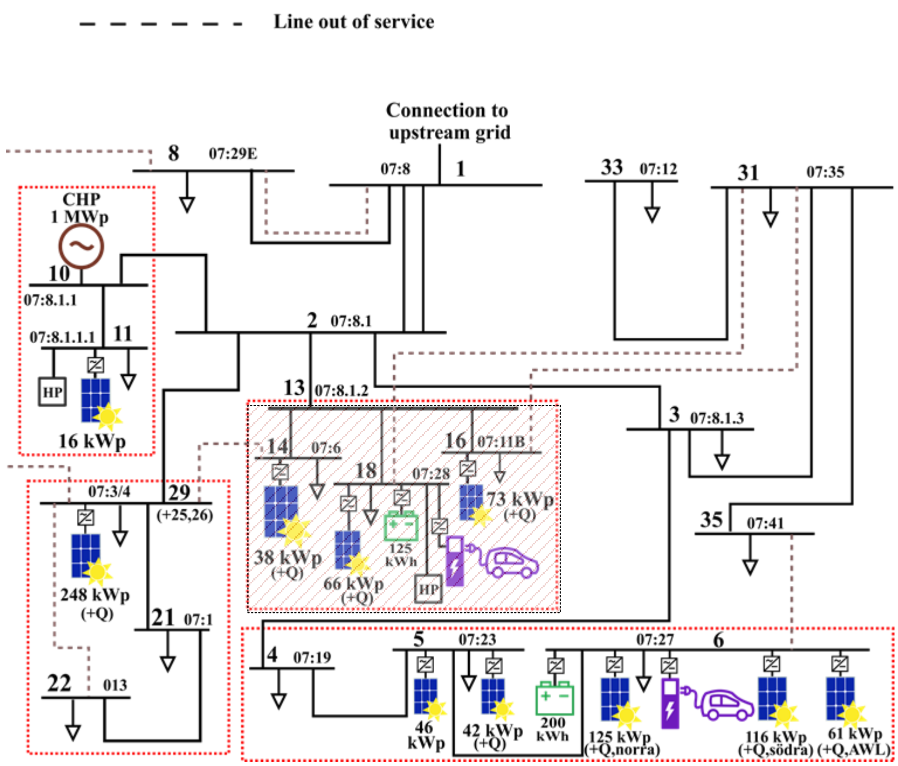

Figure 2 One-line diagram of Chalmers campus indicating highlighted demonstration site with flexibility resources

2.3. Measurement system and controllable devices

The demonstration site has several controllable assets including BES, PVs, and a HP as well as uncontrollable loads. The controllable assets are presented in Table 2-1. The marked assets in red had to be disconnected during the demos due to technical issues. The battery has been assumed to be replaced by the battery placed at bus 07:27. This assumption will not affect the evaluation of the solutions because the loading of the line between bus 07:8.1.2 and bus 07:8.1 is calculated by power flow calculations with DER measurements as input. The uncontrollable loads are presented in Table 2-2. There are different loads at each bus. The HP, although being in the demo site area, is not controlled as a flexible resource at this stage of WP6. This is because at this stage of the demonstrations, integration of the different tools and functions in the local IoT platform has been the focus. The control of the heat pump requires strict constraints in the control algorithms which would have add complexities in debugging and evaluation of the integration. Therefore, the inclusion of the HP is planned for the next demonstration period.

Table 2-1 Distributed energy resources at the demonstration. Assets marked in red had to be disconnected during demo due to technical issues and replaced with other assets as a workaround. Battery 1 is assumed to be at 07:28/Maskin as a substitute for Battery 2.

Controllable Devices	Ratings	Bus name/Building name Available Measurements	Control parameters	Resolution
Battery 2	• Peak Power: 56 kW	**07:28/Maskin** Active Power Consumption Voltage per phase Current per phase	Active power setpoints	1 minute
Solar PV 5	• Active Power: 66kWP		Controlled via Battery 2's inverter	
HP 2	• Possible Power Range: 80-190 kW		On/off control Active power setpoint	
Solar PV 2	• Active Power: 38 kWp • Reactive Power: 38 kVAr	**07:6/Bibliotek** Active power consumption Voltage per phase Current per phase Frequency	Active power limit Reactive power setpoint	1 minute
Solar PV 3	• Active Power-73kWp • Reactive Power: 73 kVAr	**07:11B/EDIT** Active Power Consumption Voltage per phase Current per phase	Active power limit Reactive power setpoint	1 minute
Battery 1	• Peak power: 95 kW discharging, 60 kW charging • Max energy: 260 kWh	**07:27/AWL assumed to be at 07:28/Maskin** Active Power Consumption Voltage per phase Current per phase	Active power setpoints	1 minute

Table 2-2 Uncontrollable loads at the demonstration site

Uncontrollable loads	Bus name/Building name Available Measurements	Resolution
InflexLoad_O7:28/Maskin	**O7:28/Maskin** Active Power Consumption	1 minute
InflexLoad_O7:28/HB	**O7:28/HB** Active Power Consumption	
InflexLoad_O7:28/HA	**O7:28/HA** Active Power Consumption	
InflexLoad_T11.2/Edit	**O7:11B/Edit** Active power consumption	
InflexLoad_T11.2/Idelara	**O7:11B/Idelara** Active power consumption	
InflexLoad_T06.1/Bibliotek	**O7:6/Idelara** Active power consumption	

Forecast algorithms are made for the uncontrollable loads and the PVs. Forecasts are implemented using artificial neural networks. Load forecast models can provide forecasts up to 48 hours ahead while PV forecast models can provide only up to 30 hours due to limitations in availability of weather forecasts. Forecast models are elaborated further in the congestion forecast section of Deliverable 5.3.

In the demonstrations of this report, the controllable assets and uncontrollable assets are aggregated under different agents depending on the test case. Further information about which agent owns what assets are explained respectively in each test case.

2.4. IoT platform integration overview

A schematic figure of the software gateway developed for Chalmers's testbed is presented in Figure 3. The software gateway is installed within Akademiska Hus network and initializes the communication with their SCADA system, Webport, as well as a WebSocket server that enables communication with a control module running on a Chalmers server and explained in detail in D6.2. For the Chalmers demonstration site, a specific API services were developed to collect the data related to the site for further usage. For demonstrations in this deliverable, a local IoT platform is utilized. This local IoT platform can be defined as a combination of the local energy system object-oriented programming platform (LESOOP) and the web-API. The local IoT platform can be replaced by any other IoT platform that can host the algorithms, communications between actors, and visualizations.

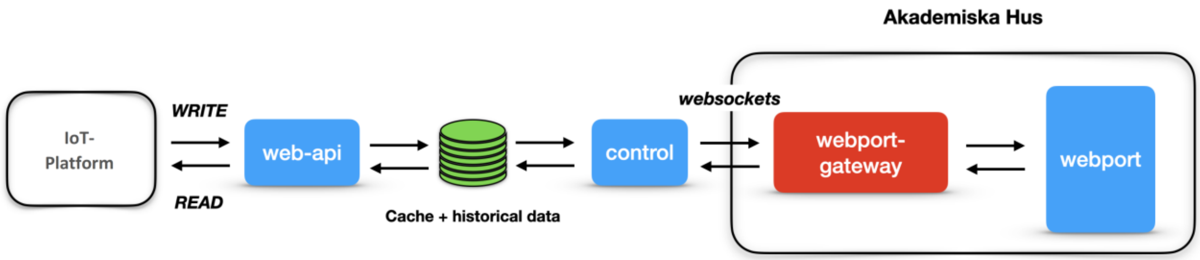

Figure 3 Overview of the "Webport gateway" that enables external parties to communicate with Akademiska Hus

2.5. Local energy systems object-oriented programming platform (LESOOP)

A python-based platform is developed to demonstrate LEM and LFM. An object-oriented framework is used to implement the two market models for ensuring the modularity, reusability, and expandability. The network components, distributed energy resources, agents and market clearing process are abstracted as classes to encapsulate the attributes and operations. This section summarizes the major class structures, and the procedures to initiate bidding, market clearing and device control.

2.5.1. Classes

This subsection summarizes the main classes to represent the network, distribute energy resources, agents, and market operator.

Network representation

Three types of components are considered for representing an electricity network: buses, lines, and transformers. Three corresponding classes are defined with the attributes to store the id and physical parameters of the components. An electricity network is abstracted as class ElNet, which is composed of instances of the three component classes.

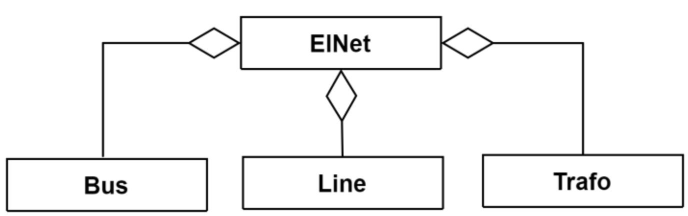

Figure 4 Class ElNet is the aggregation of instances of classes Bus, Line and Trafo

Distribute energy resources

A parent class DER is defined as a general classifier of distribute energy resources. It contains common attributes e.g. asset id, bus id, API tags for reading measurements and writing control points, etc. Four child classes inheriting from DER are defined for battery, PV, heat pump and inflexible load, respectively. Each child class contains specific attributes and operations for the resource type. For example, class BES contains attributes such as nominal energy capacity, max charging/discharging rate, initial SoC, etc.

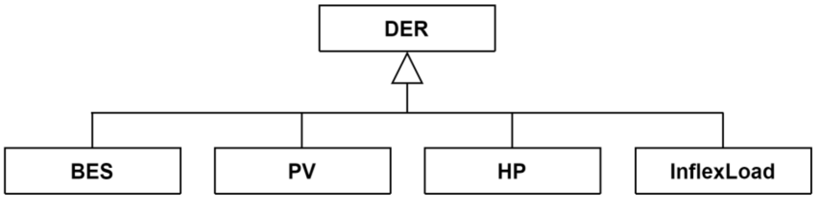

Figure 5 Inheritance hierarchy between parent class DER and child classes BES, PV, HP and InflexLoad

Agents

In the proposed market models, agents are crucial market players who submit bids to the market and dispatch energy assets according to the market clearing results. Two agent classes are defined in the demo:

- BuildingAgent: a building agent represents property owners. It submits energy or flexibility capacity bids according to the physical constraints of DERs and the forecast of local production/consumption. The class contains attributes such as agent id, bus id, list of DERs in the portfolio, etc. Different bidding strategies are formulated as class operations. According to the required bidding format of the LEM and LFM designs, following operations are defined:
  - Set bids for minimizing the energy cost of a building
  - Set flexibility capacity bids on LFM according to forecast and available flexibility
  - Set flexible bids on LEM according to forecast and available flexibility
  - Set inflexible bids on LEM according to forecast
- SystemOpAgent: a child class DSO is further defined to represent the buyer of flexibility service on LFM, which is the system operator of the local grid. An instance of network is the major attribute of the class. A class operation is formulated to determine whether the DSO needs to buy flexibility service from market and what bid shall be submitted.

Market operator

Two classes are defined for LEM operator and LFM operator, respectively. Both classes contain following operations:

- Configure the market setup regarding the planning horizon, length of trading period, network information, grid tariff, etc.
- Collect bids from buying and selling agents.
- Clear the market by matching the supply and demand bids.
- Save the market clearing results and convey the cleared volume and market clearing price to the agents.

2.5.2. Procedures of bidding, market clearing and device control

This subsection introduces how modules are interacted with each other in three major use cases of the demonstration: bidding, market clearing, and device control. The modules could be classes, data storage and functions.

Agents submit bids

Before the market gate closure, agents submit bids on behalf of the DER owners. For each DER in its portfolio, the agent gets the attributes and forecasts from the data storage. The forecasts include production forecast, consumption forecast and external spot market price forecast. The attributes and forecasts are used as inputs of the agent bid function to determine the bids which comply with the market requirement. The bids are then saved in the data storage.

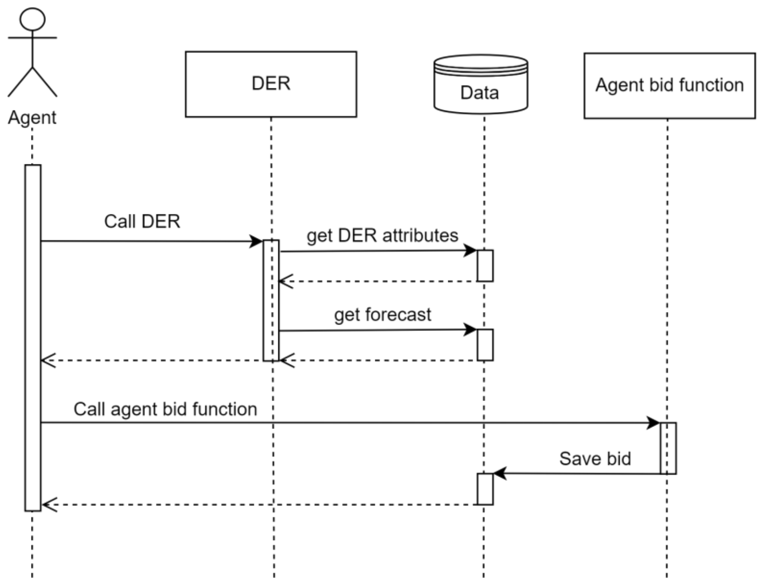

Figure 6 Sequence diagram: an agent submits bids

Market operator clears the market

After gate closure, the market operator configures the market setup by initializing DERs, agents and the network. Then it reads agents' bids from the data storage. Using the bids as input, the market clearing function is called to match supply and demand, and calculates the market clearing price and agreed volumes for each agent. The market clearing results are saved in the data storage.

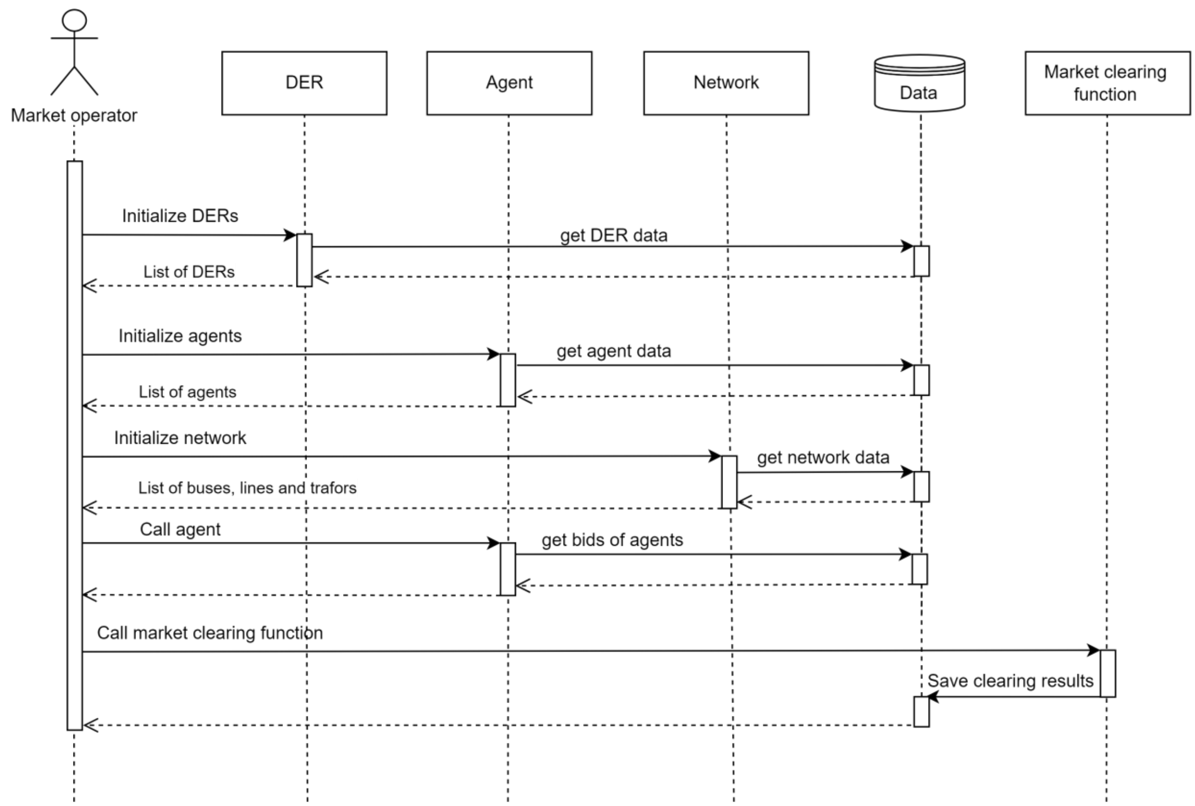

Figure 7 Sequence diagram: the market operator clears the market

Agents send control commands to devices

After the market is cleared, agents can read the market clearing results from the data storage, convert them to control commands and send the commands to devices through APIs.

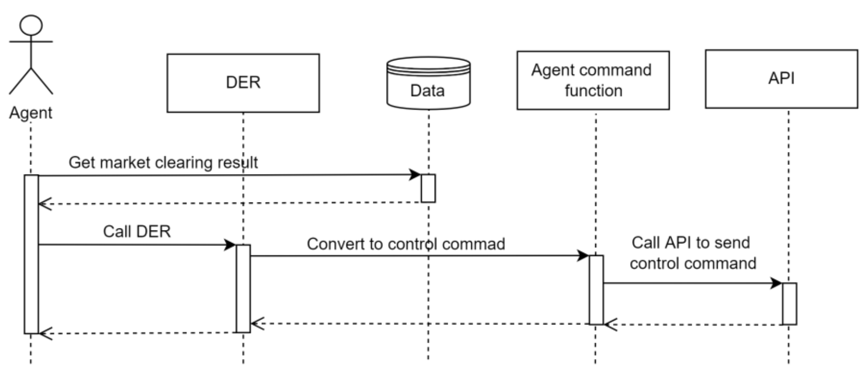

Figure 8 Sequence diagram: agents send control commands

3. Descriptions of local energy market and local flexibility market

3.1. Local energy market

The LEM model is proposed to manage the challenges in local energy systems, which are caused by growing share of variable renewable energy, increasing demand of electricity and grid bottlenecks. It is an improved version based on the market model developed in FED (Fossil-free Energy Districts) project [1]. The proposed market framework aims to create system-wide incentives for a more efficient investment and operation of distribute resources. It enables local trading, unlocks flexibility potentials, and facilitates a more efficient utilization of distribution infrastructures. This section summarizes the main features of the LEM model.

3.1.1. Market organization

The market is organized as double-sided auction with three steps:

1) Agents submit supply and demand bids to the marketplace according to the required format.
2) After gate closure, the market is cleared according to merit order. A balance between supply and demand is achieved in the market.
3) According to the clearing result, the accepted volumes and market prices are conveyed to agents.

A centralized market is organized as Figure 9 with the interactions among following actors:

- Resource owner: the local actor possessing energy assets for consumption or production.
- Retailer: the intermediary between the local market and the overlay market. It buys electricity from Nord Pool and sells to the local market, or vice versa if there is a net surplus in the local grid.
- Agent: the interface between resource owners/retailer to the market for sending bids and receiving clearing information.
- District heating supplier and DSO: local operators of the heating and power grids. They define the grid tariff and capacity limit of the networks.

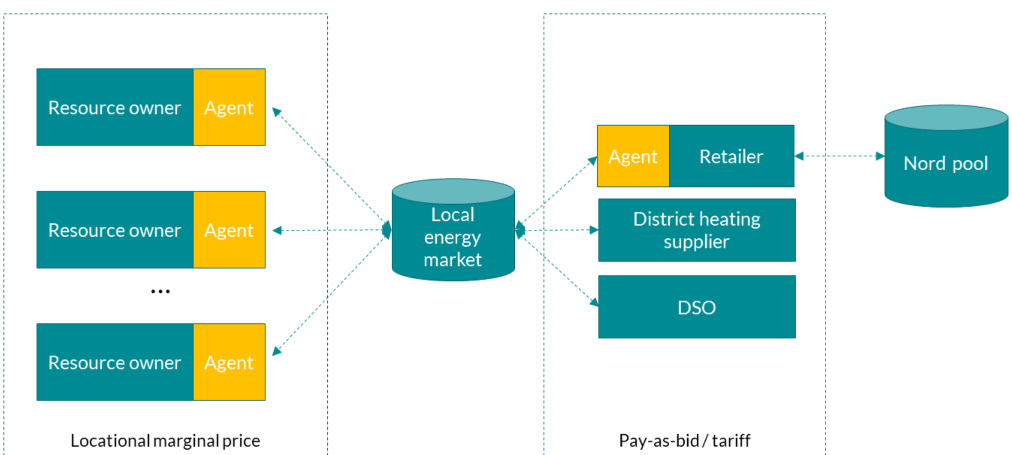

Figure 9 Organization of the local energy market

3.1.2. Bid structure

The agents of resource owners and retailers send bids to the market according to a standardized format:

- Agent ID
- Bus ID
- Energy carrier
- Supply or demand
- Trading period
- Valuation [SEK/kWh]
- Volume [kWh/trading period]

The accepted volume of a standard bid shall not exceed the bid volume. Besides the standard bid format, the market also provides a functionality called bid dependency. It enables agents to provide flexibility to the market by connecting bids in different ways. The bid dependencies are defined as Table 3-1.

Table 3-1 Bid dependencies in the local energy market model [2]

Bid dependency	Description
EQ	The sum of accepted volumes of the bids shall equal a certain volume.
LE	The sum of accepted volumes of the bids shall be less than or equal a certain volume.
GE	The sum of accepted volumes of the bids shall be greater than or equal a certain volume.
AND	The bids shall be treated by the market as complements that need to be accepted or rejected in tandem.
OR	The bids shall be treated by the market as substitutes, such that at most one of the bids can be fully accepted.

Distribution bottleneck and grid tariff

A target of the market model is to manage the potential bottlenecks in the distribution grid. This is achieved by modelling the grid topology and optimizing the power flow in the market clearing function. In addition, a status-based grid tariff is developed as an instrument to stimulate a more efficient grid utilization. The tariff is dynamic and varies with the grid load. It assumes that the distribution cost increases when the grid load grows due to 1) larger network losses, 2) increased risk of exceeding subscriptions from transmission grids and thereby incurring penalties, and 3) potential costs for network reinforcements.

Figure 10 illustrates a status-based grid tariff with the black curve. The tariff increases gradually as the grid load increases. For example, if the network is 90% loaded during a trading period, the grid cost in the period is calculated as the red area under the tariff curve.

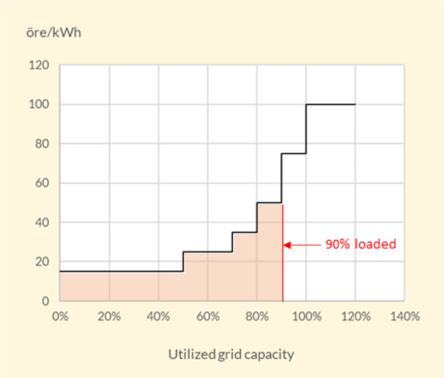

Figure 10 Principle of a status-based grid tariff

3.1.3. Market clearing

The market is cleared by maximizing social utility while matching the supply and demand. It is defined as a LP optimization problem:

Maximize *Benefit of consumption – supply cost – grid cost*

Subject to:

- *Load balance at each bus*
- *Power flow and capacity limit*
- *Bid dependencies*

The detailed mathematic formulations are described in [3].

Marginal pricing is applied as the market price. It is the dual variable of the load balance equations and is obtained after the optimization problem is solved. The price may vary among buses for each trading period depending on the load level. It internalizes the marginal cost for both electricity supply and distribution at each bus, reflecting the lowest cost for serving an additional 1 kWh electricity demand at the bus.

3.1.4. Pricing and surplus

Two pricing schemes are applied in the market as illustrated in Figure 9:

- **Nodal price** or locational marginal price is applied for resource owners. Since the price may vary among buses, it provides incentives for resource investment and operation considering the geographical dimension of the system.
- **Pay-as-bid** or tariff payment is applied for retailer(s), DSO and district heating supplier to cover their operation costs.

The different pricing schemes result in a surplus of the market i.e. the income of the market is larger than the actual cost. Utilization of the surplus is not deeply investigated in the study. In general, it could be used for two purposes [3]:

1) Operation of the local market

2) Redistribution among the resource owners through various mechanisms e.g. to further compensate the delivered flexibility, to subsidise the investment of local production, storage or smart control systems, etc.

3.2. Local flexibility market

The peer-to-pool LFM design extensively explained in D2.3. This design with slight improvements is utilised for demonstrations. The main improvement concerns the payment allocation method in pricing and settlement. The method has been changed from social welfare based methods such as Vickrey-Clarke-Groves (VCG) and Shapley to pay-as-bid to match better product design. In this section, an overview of the LFM design is briefly explained. Interested readers are recommended to read Chapter 3 on Peer-to-pool local markets of the Deliverable 2.3.

3.2.1. Market organization

The overview of the market organization is presented in Figure 11. It includes a triple-horizon structure. All the horizons are centralized double-sided auctions. The product in all the horizons is a (connection) capacity-limitation product. The first horizon is for reserving the product years ahead when the decision on reinforcement of the grid is to be made. The second is for activating the product closer to delivery time (t). In this study, day-ahead is considered. The third is an adjustment period from after the short-term activation market until close to real-time. The first two horizons are call-auctions while the last horizon is a continuous one. The payment allocation rule for all the horizons is pay-as-bid.

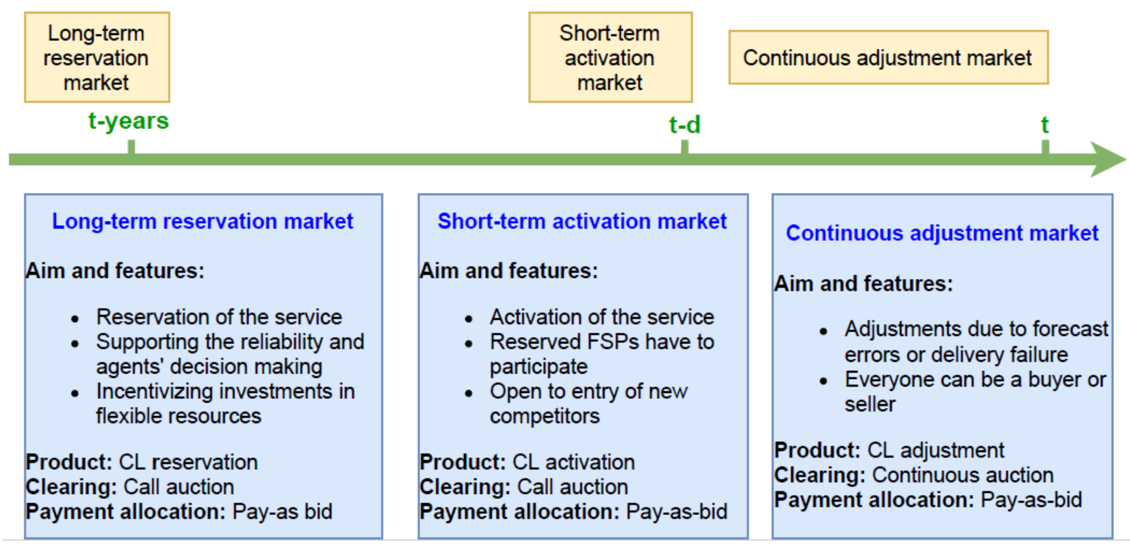

Figure 11 The overview of the market organization

The roles in the market are as follows:

- Flexibility seller: Flexibility service providers, or sellers, can be aggregators, or individual consumers/prosumers.
- Flexibility buyer: DSO is the buyer that monitors the distribution network and requests flexibility according to its congestion forecasts. Moreover, if an end-user does not participate in the market directly nor indirectly by an aggregator, the DSOs have to take it into account in their bidding.

- Market operator: Market operator is a neutral, independent party that manages the market, receives the requests and the bids, clears the market, and handles the settlement.

In this demonstration only the short-term LFM is demonstrated. Evaluating the long-term reservation market would require very long demonstration periods with real commercial actors or investment models that would mean simulations and not demonstrations. The adjustment market is not included since it is more straightforward compared to short-term activation. This is because the clearing algorithm and the utility and cost functions for the short-term activation are rather novel compared to a continuous adjustment market.

3.2.2. Bid structure

The traded product is a connection capacity limit (CL) product. In other words, the DSO is buying the temporary limitation of the sellers' connection capacity (also known as, subscribed capacity). The quantity of the product is calculated with respect to the subscribed capacity or the fuse level of the flexibility provider (See Figure 12). If a CL-cap is traded at a quantity of 23 kW, the flexibility provider has to keep its net-load below the respective cap in dashed red. If a reversed power flow is expected in the network due to high distributed local production, a CL-floor can be traded. If 46 kW of CL-floor is traded, the provider must keep its net-load above the respective floor. Trading the product can be its reservation, activation, or adjustment depending on the horizon.

The main advantage of our proposed capacity limitation product is that it does not require a baseline and thus validating its delivery is both cheap and without complications. Capacity-limitation product and its advantages are explained extensively in Deliverable 2.3.

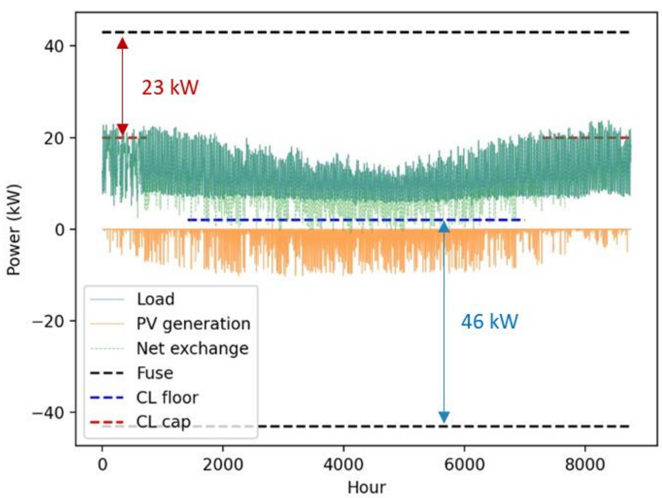

Figure 12 Quantity of the proposed capacity-limitation product is with respect to the fuse level or subscription capacity.

Market participants are allowed to submit curves for their bids or offers. The curves are submitted with multi-bids that are mutually exclusive but have a sequence number indicating their place on the agents biding curve. The sequence number is used in the clearing algorithm. The bid curve of an agent includes the following attributes:

- Agent ID
- Agent location

- Trading period
- Sequence number
- Quantity [kW]
- Valuation [SEK/kW]

The sellers' bid curve is calculated using their local cost optimization algorithm. The buyer's offer curve is calculated based on cost of congestions at various levels and the cumulative probability of congestion levels. Algorithms calculating the bids and offer curves are further explained in Chapter 3 of Deliverable 2.3.

3.2.3. Market clearing

The market clearing is a mixed-integer-linear-programming problem:

Maximize *Benefit of consumption - cost of supply*

Subject to:

- *Matching the quantity of the total cleared demand and supply*
- *Not exceeding the maximum quantity of each bid/offer*
- *Keeping the sequence of sub-bids in each bid/offer curve*

The market is cleared with maximizing social welfare as the objective function. It is subjected to matching the quantity of the cleared supply and demand, and maximum quantity of each bid/offer, and keeping the sequence of each bid/offer curve. The sequence of the sub-bids has to be kept because the offer curve is not a conventional descending utility curve. More details are presented in Chapter 3 of Deliverable 2.3.

3.2.4. Pricing and settlement

The pricing is pay-as-bid (PAB) for all the market horizons. The adjustment market is a continuous auction and thus is PAB. The long-term market for reservation and short-term market for activation are PAB due to specific design of the product. Uniform pricing is not suitable for CL product since the utility curve of the DSOs are not descending and thus a uniform pricing scheme is not matching with the willingness of DSOs for payment. Game theory-based payment allocation methods such as VCG and Shapley are not suitable either because they are dependent on contribution to the social welfare. For calculating the contribution, an assumption is needed for the state of the agent in case not flexibility was provided. This means a baseline need to be assumed for the agent which is accompanied by various challenges as discussed in D2.3 and Ziras et al. [4].

4. Description of test cases and their implementation

Five test-cases have been designed to be demonstrated. The first two test cases are about testing the local markets. Test-case 6.3 is about comparison of the two markets that has started in this report and will be evaluated further in the demonstration evaluation period for Deliverable 6.4. Test-case 6.4 is about exchange of services between the FSP and the assets. Test-case 6.5 is about demonstration that conducted using a commercial LFM for trading flexibility between the local DSO and Chalmers Campus testbed. These test-cases are explained in this chapter.

4.1. TC 6.1: Real-life demonstration case-study of LEM

Gate closure

The gate closure time is set as 13:45 CET every day, after the announcement of spot price on Nord Pool (12:45 CET). The announced spot price is used for agents to determine the bid valuation. Before the gate closure, agents submit bids to the market for next 24 hours. The trading period is 1 hour.

Agents and bids

The demonstration considers different types of energy assets. Each energy asset is represented by an agent.

- Inflexible load agent: the agent bids for the inflexible electricity demand of a facility. The demand bids are submitted with the standard bid format. The valuation reflects the consumer's willingness to pay for electricity. It is assumed that the inflexible demand is not affected by price in most cases. Therefore, a price cap is set as the valuation. The volume is based on load forecast according to the historical consumption pattern.
- PV agent: the agent submits supply bids for the PV production according to the standard bid format. The production is considered non-dispatchable and inflexible. The valuation reflects the seller's willingness to get paid. It is set as 0 SEK/kWh in the demo to ensure that all local production would be used first. The volume is based on the production forecast.
- Heat pump agent: The electricity demand of a heat pump is bid as a flexible load, considering the thermal inertia of buildings. It provides flexibility to the market using EQ and LE dependencies. EQ dependency specifies that the total electricity demand of the heat pump in the upcoming 24 hours, according to the heat demand forecast. LE dependency specifies the maximal electricity demand in each hour, based on the capacity limit of the heat pump. The heat pump has not been included in the preliminary tests. It might be considered in the later demonstration phase.
- Battery agent: The agent for a battery can set both demand bids and supply bids for charging and discharging the battery, respectively. EQ and LE dependencies are used to provide flexibility to the market. EQ dependency specifies that the total supply/demand of the battery within a certain period. LE dependency specifies the maximal supply/demand in each hour, based on the maximal discharging/charging power of the battery. A simplified rule is applied in the demo: the battery charges during off-peak hours and discharges during peak hours. According to the reference load

profile in the grid, the peak period is defined as 6:00-22:00 and off-peak period is between 22:00-6:00.

In addition, the demo considers an agent who bids for the retailer.

- Retailer agent: the agent submits supply bid align with the standard bid format. In the demo it is assumed that the valuation follows the spot price from Nord Pool i.e. the valuation may vary among hours. A fixed volume 10000 kWh is used to ensure that the electricity demand in the demo area is always satisfied.

Grid capacity and tariff

The market considers the power flow on 10 kV grids. The actual grid capacity in the demo site is sufficient and no congestion problem exists with today's conditions. It is to be noted that the grid of Chalmers campus has been to a large extent over-dimensioned. To simulate a grid with capacity problem, the line capacity in the test case is set as 15% of the actual capacity.

A grid tariff from Göteborg Energi [5] is selected as the reference tariff to define the status-based tariff in the demo. The reference tariff consists of four parts: monthly subscription, electricity distribution fee, power fee and energy tax. The power fee is charged monthly according to the meter value of the highest consumption hour during the month. Only electricity distribution fee and power fee (Table) are considered when estimating the status-based tariff.

The status-based tariff is assumed having six steps. The tariff of each step is estimated according to the historical power flow in the demo area during 2016. The load range and tariff for each step are shown in Table . Given the historical load during 2016, the yearly grid cost with the status-based tariff equals the grid cost with the reference tariff. This means to ensure that the status-based tariff is comparable with the reference tariff.

Table 4-1 Reference grid tariff and status-based grid tariff

Reference grid tariff	**Status-based grid tariff**	
Electricity distribution fee: 7.5 öre/kWh Power fee: 49.3 SEK/kW, month	**Load range**	**Tariff [SEK/kWh]**
	0-60%	0.185
	60-70%	0.4
	70-80%	0.8
	80-90%	1
	90-100%	2
	>100%	4

Market clearing and device control

After gate closure, the market clears according to the bids from all agents, considering the capacity limit of the grid and the status-based grid tariff. The marginal prices for each bus and the agreed volumes for each agent are determined from the clearing results. For the controllable device i.e. battery at O7:28/Maskin, the accepted volume at each hour is converted to a control signal, which is sent at the beginning of each hour through API.

4.2. TC 6.2: Real-life demonstration case-study of LFM

In this test case, the peer-to-pool LFM is demonstrated. The focus of the demonstration has been on the short-term activation horizon due to reasons mentioned in Section 3.1.1. the demonstration includes a full cycle, automatic implementation of required algorithms such as load and PV forecasts, probabilistic congestion forecast, bidding algorithm of the DSO for calculating quantity and value of the required flexibility, bidding algorithm of the FSPs for calculating quantity and cost of providing flexibility, market clearing, and dispatching algorithm of the FSPs for delivering the cleared quantities.

The flowchart of the demonstration for a day is presented in Figure 13. The flowchart includes two main work streams in parallel. The left stream handles the bidding of the agents and the market clearing for the day after while the right stream handles the delivery of the cleared quantities at the day before for the current day. The demonstration has been conducted for single days in September 2022.

Agents and bids:

Besides the DSO and the market operator, there are three agents participating in the market. Each agent is situated at one of the buses in the demonstration site highlighted in Figure 2. The agents are defined in Table 4-2. As explained in Section 2.2, the scope of the demo is kept small to facilitate evaluation and troubleshooting of the tools. Therefore, only one flexible agent is assumed in this phase. Agent bld_07:28 is the flexible agent that can provide flexibility with battery energy storage. The connection capacity of the agents is assumed to be 1000 kW that is a value higher than their maximum load. Agents' energy management system (EMS) is a cost minimization algorithm. The cost function includes energy spot price cost, energy tax, grid tariffs for energy and monthly grid tariffs for power.

Table 4-2 Agents definition for the LFM demonstration

Agent ID	Bus name	DERs ID	Connection capacity [kW]	Flexible [Y/N]
bld_07:28	07:28	Battery 1 InflexLoad_O7:28/Maskin InflexLoad_O7:28/HA InflexLoad_O7:28/HB	1000	Yes
bld_07:6	07:6	InflexLoad_T06.1/Bibliotek Solar PV 2	1000	No
bld_07:11B	07:11B	InflexLoad_T11.2/Edit InflexLoad_T11.2/Idelara Solar PV 3	1000	No

DSO and FSPs bids are calculated using different methods as mentioned in Chapter 3 of Deliverable 2.3. In brief, DSO's bid curve is a multiplication of the impact of the congestion in monetary values at different congestion levels, and the cumulative probability of the congestion level. In the impact curve, the value of lost load and the penalties to the upstream grid operator is considered. The cumulative probability function is generated from the scenarios in the probabilistic congestion forecast tool (see congestion forecast test-case in Deliverable 5.3). The FSPs calculate their offer curve by using their EMS algorithm. In their EMS algorithm, the operation cost at different quantities of CL can be calculated by constraining the net-load. When calculating the offer curve, FSPs add this constraint for all the requested hours by the DSO and calculated. This is a conservative approach since it assumes the hardest scenario for providing flexibility which is providing for all the requested hours. These algorithms can be further improved in our future work.

Grid and the congestion:

As mentioned in Section 2.2, the line connecting bus 07:8.1.2 to bus 07:8.1 is the component that connectsour demo site and the upstream grid. The maximum current capacity of this line is decreased by 86% in the model to see congestions in September 2022.

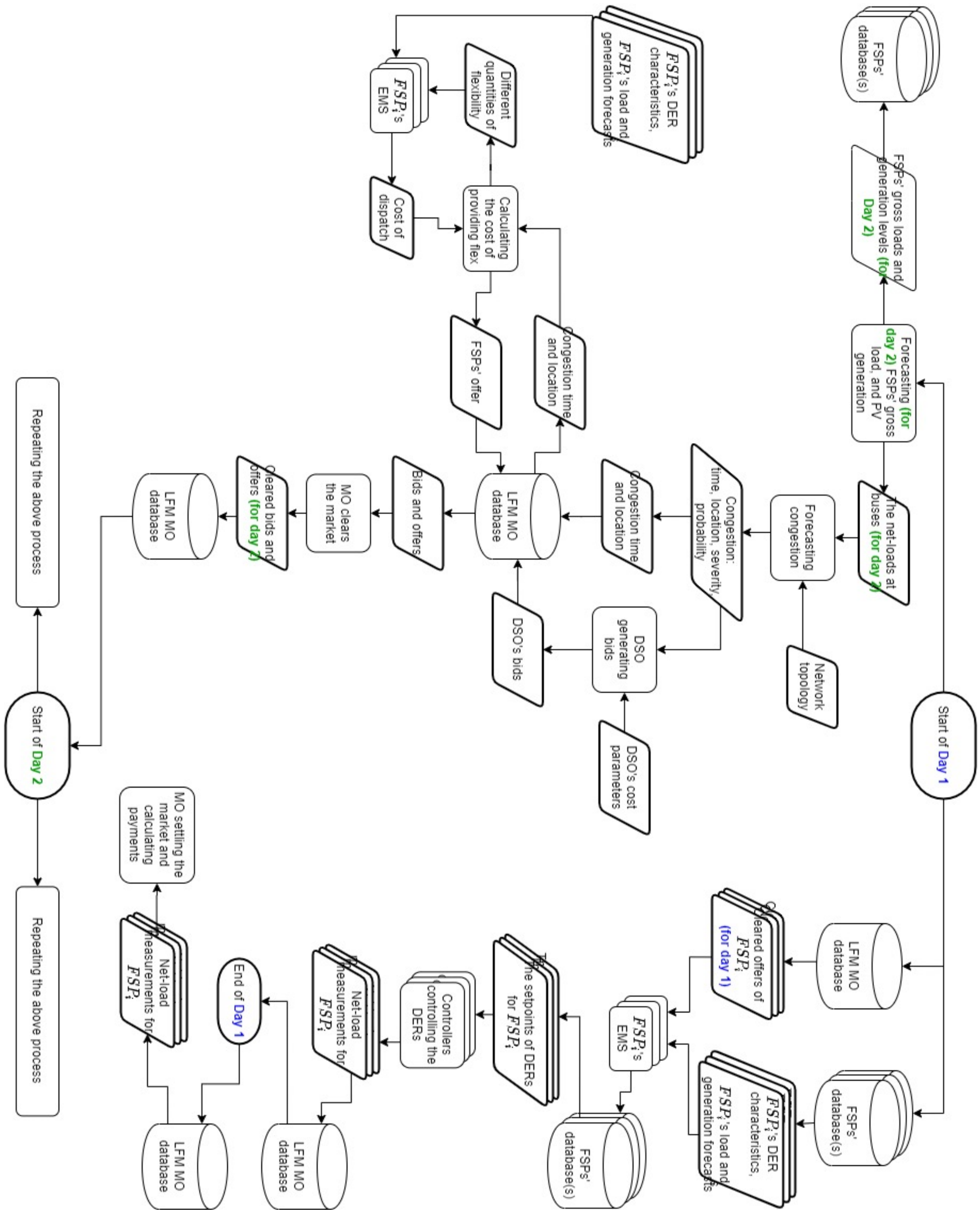

Figure 13 LFM demonstration flowchart for one day

Demonstration timeline:

The timeline in a day is as follows:

- **Every hour at minute 56:** The EMS of agents are run with a horizon of 24 hours and optimal setpoints of the next hour are sent to the DERs. If any flexibility is to be delivered in this horizon, it is considered in the
- **20:00:** DSO evaluates potential need for the flex for the next day and send its bids to the market operator if needed
- **21:00:** Agents ask the market operator for what hours and locations bids from the DSO is received. They place their offers for these hours and locations.
- **22:00:** Market is cleared and cleared quantities are communicated to the agents

There are limitations when deciding the above timeline. The LFM has to be run after the spot prices are announced on Nord Pool (i.e., 12:45 CET). This way the cost of providing flexibility can be more accurate. Moreover, the DSO can have a better forecast on how load profile of users would be, assuming a considerable share of flexible and active users in the future. The other limitation is concerning the availability of forecasts. In this demonstration, weather forecasts are available for up to 30 hours ahead. Therefore, the bidding for whole tomorrow is possible only after 18:00.

4.3. TC 6.3: Comparative case-study for LFM and LEM

This test-case includes a qualitative and quantitative comparison of LFM and LEM. In this report the qualitative comparison has been discussed in Section5.3. The qualitative comparison includes discussions about the following questions:

- What grid challenges do LEM and LFM address? Are these challenges the same?
- How do LEM and LFM concepts address the grid challenges?
- How can LEM and LFM concepts be adopted in the current energy system structure? What are the different alternatives?
- How is the economic efficiency of the markets?
- How is regulatory compliance? What adoption barriers exist?

The quantitative comparison will be conducted in D6.4. The quantitative comparison includes the full test of both markets except for sending the actual setpoints to the physical device. These markets are to be run in parallel in simulations for the same day to compare their impact. The impact can include economic and technical aspects such as costs/revenues for the agents, and voltage and currents in the grid (in simulations). This test case can provide a better understanding of the two market designs when it comes to comparing how they operate.

4.4. TC 6.4: Real-life demonstration case-study of exchange of services in LFM

This test-case includes demonstration of how an FSP can deliver its cleared flexibility by distributing it among its flexible assets. This test case is conducted as a part of TC6.2. In this section, we discuss how the cleared quantities on the flexibility market is transformed to setpoints for flexible assets.

The optimization algorithm used for transforming market clearing results to setpoints is elaborated in Appendix A. Using this algorithm, the cleared CL quantity from the market is included in the EMS and the flexible resource is dispatched accordingly. For this specific demo site, only one flexible resource has been available. However, if there were more resources at the site, a similar EMS could be used to divide the cleared CL quantity between different resources. If the flexible assets of an aggregator are located at different locations, an individual EMS needs to be run at each location.

4.5. TC 6.5: Real-life demonstration case-study of exchange of services by Akademiska Hus and Göteborg Energi

This test-case includes the demonstrations conducted by Akademiska Hus and Göteborg Energi in which Chalmers was involved. The demonstrations included a pilot test of Göteborg Energis LFM called "Effekthandel Väst" based on NODES market platform. The market is only in operation during the winter season when the electricity demand is high. Hence, initial demonstrations were conducted during January-March 2022. The flexibility resources that were used for the LFM was the CHP unit and the battery resources.

Market framework

The market framework is based on a traditional baseline product where the flexibility provision is calculated as deviation from a baseline. Both seller and buyer can submit bids to the market and the market is cleared continuously once there is a match between supply and demand bids.

Agents and bids

As mentioned, both sellers and buyers can submit bids to the market and the minimum bid size was set to 100kW with an hourly resolution.

Compared to the LFM demonstrated in TC 6.2, Akademiska Hus acted as a flexibility provider and aggregated its resources which was offered to the market. During the demonstrations Akademiska Hus was both accepting flexibility requests from the DSO Göteborg Energi as well as offering flexibility bids to the market that Göteborg Energi could respond to.

Both for Akademiska Hus and Göteborg Energi the demonstration was mainly to ensure the functionality and no optimal estimation of the bids was conducted.

5. Demonstration results and discussions

In this section, the preliminary results of the demos are presented and discussed. More extensive demonstrations alongside a more detailed evaluation are going to be conducted in D6.4. The structure of this chapter follows the described test cases in Chapter 4.

5.1. TC 6.1: Real-life demonstration case-study of LEM

This section summarizes preliminary results from a test on the 23rd of October. The market is cleared at 13:45 for the next 24 hours, based on the announced spot prices and the forecasts of load and PV production. The goal of the test is to verify that the algorithms and communication are functioning as expected.

Table 5-1 and

Table 5-2 show the cleared volumes for suppliers and buyers on the market. Due to the limited production of PV, most electricity demand is supplied by the retailer. Figure 14 shows the market clearing prices at each node. The prices at bus 07:8.1 are same as spot prices, which is the bidding valuations of the retailer. The prices at the other four buses are higher, reflecting the distribution cost for serving the electricity demand. Figure 15 shows the control commands sent to the battery. The commands are based on the agreed volumes of the corresponding agent. The battery is scheduled to charge during the hours when the market clearing price is low and discharge when the price is relatively higher.

The test shows that the algorithms for agent bidding and market clearing work properly. The execution of control commands has not been fully tested. More results will be collected and analysed in the next phase with a longer demonstration period and further tuned parameters.

Table 5-1 Cleared volumes for suppliers (h0 refers to 14:00 on Oct 23)

Agent	h0	h1	h2	h3	h4	h5	h6	h7	h8	h9	h10	h11
agent_BES_07:28	95	19	0	0	0	0	0	0	0	0	0	0
agent_PV_07:6	0	0	0	0	0	0	0	0	0	0	0	0
agent_PV_07:11	0	0	0	0	0	0	0	0	0	0	0	0
retailer	293	356	364	350	328	321	315	316	318	353	366	347
Agent	**h12**	**h13**	**h14**	**h15**	**h16**	**h17**	**h18**	**h19**	**h20**	**h21**	**h22**	**h23**
agent_BES_07:28	0	0	0	0	7	54	79	0	0	8	0	0
agent_PV_07:6	0	0	0	0	0	0	1	1	2	1	1	0
agent_PV_07:11	0	0	0	0	0	1	1	2	4	2	1	1
retailer	307	414	539	637	705	705	715	788	792	793	785	746

Table 5-2 Cleared volume for buyers (h0 refers to 14:00 on Oct 23)

Agent	h0	h1	h2	h3	h4	h5	h6	h7	h8	h9	h10	h11
agent_InflexL_T11.2_Idelara	12	11	5	5	4	4	3	3	3	3	3	3

agent_InflexL_T06.1_Bibliotek	21	18	16	16	16	18	18	19	20	15	19	24
agent_InflexL_07:28_Maskin	201	193	192	190	183	181	178	179	186	163	162	162
agent_InflexL_07:28_HB	7	7	6	6	6	6	6	5	5	4	4	5
agent_InflexL_T11.2_Edit	135	136	135	123	109	105	101	101	95	98	109	103
agent_InflexL_07:28_HA	13	10	10	10	10	8	8	8	8	8	8	7
agent_BES_07:28	0	0	0	0	0	0	0	0	0	60	60	44

Agent	**h12**	**h13**	**h14**	**h15**	**h16**	**h17**	**h18**	**h19**	**h20**	**h21**	**h22**	**h23**
agent_InflexL_T11.2_Idelara	3	4	8	11	13	14	14	14	14	14	15	15
agent_InflexL_T06.1_Bibliotek	27	50	60	67	71	80	82	82	84	81	76	71
agent_InflexL_07:28_Maskin	162	191	234	288	320	330	350	353	353	368	365	347
agent_InflexL_07:28_HB	5	7	15	20	20	24	22	17	21	22	19	16
agent_InflexL_T11.2_Edit	104	136	188	210	239	265	278	279	281	277	271	262
agent_InflexL_07:28_HA	6	26	34	42	49	48	50	47	44	42	41	36
agent_BES_07:28	0	0	0	0	0	0	0	0	0	0	0	0

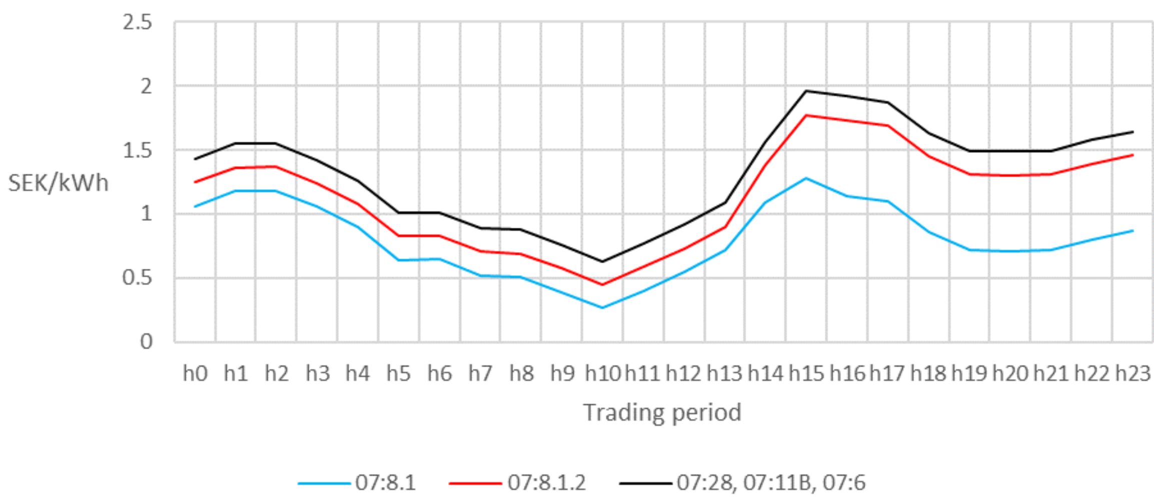

Figure 14 Market clearing price (h0 refers to 14:00 on Oct 23)

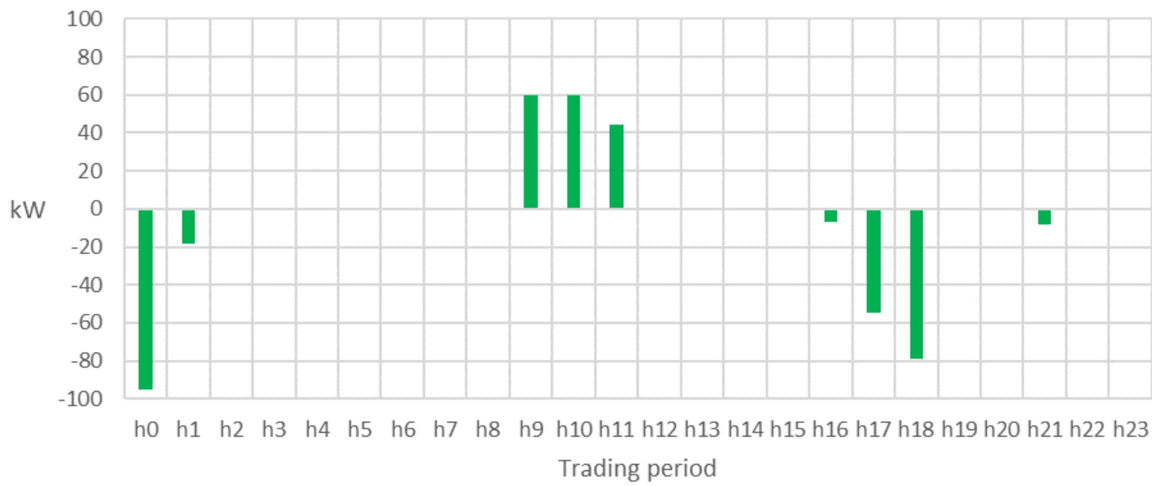

Figure 15 Control commands sent to BES (h0 refers to 14:00 on Oct 23)

5.2. TC 6.2: Real-life demonstration case-study of LFM

This section summarizes the preliminary results from a demonstration from 2022-09-26 20:00 to 2022-09-28 08:00. The timeline of the demonstration is as follows:

- **Every hour at minute 56:** The EMS of agents are run with a horizon of 24 hours and optimal setpoints of the next hour are sent to the DERs. The EMS of the agents at 2022-09-27 9:00-18:00 include a delivery of the flexibility product.
- **2022-09-26 20:00:** DSO evaluates potential need for the flex for the next day and send its bids to the market operator if needed
- **2022-09-26 21:00:** Agents ask the market operator for what hours and locations bids from the DSO is received. They place their offers for these hours and locations.
- **2022-09-26 22:00:** Market is cleared and cleared quantities are communicated to the agents

The probabilistic congestion forecast for 2022-09-27 is shown in Figure 16. The forecast is done at 2022-09-26 20:00. The widest grey zone covers 90% of the scenarios. The narrowest, darkest zone covers 10% of the scenarios. As show, there is a probability for congestions between hour 9:00 to 18:00. Therefore, CL-cap products are requested on the LFM for this period.

The loading of the line that is calculated using real measurements on 2022-09-27 are also shown in Figure 16. The loading is obtained using power flow calculations with real load, PV and battery measurements. The inputs to the load forecasts do not include any signal that can show how the battery could be forecasted. Therefore, the congestion forecasts are compared with the loading of the line with and without the battery measurements. As it can be seen, the congestion forecast of the line is relatively better without the BES measurements. Including input signals to the load forecast that can catch the dispatch of the battery can improve the congestion forecasts when compared with loading including the BES measurements. This has not been possible due to lack of historical data when the battery has been dispatch. The BES has not been dispatched historically based on cost minimization.

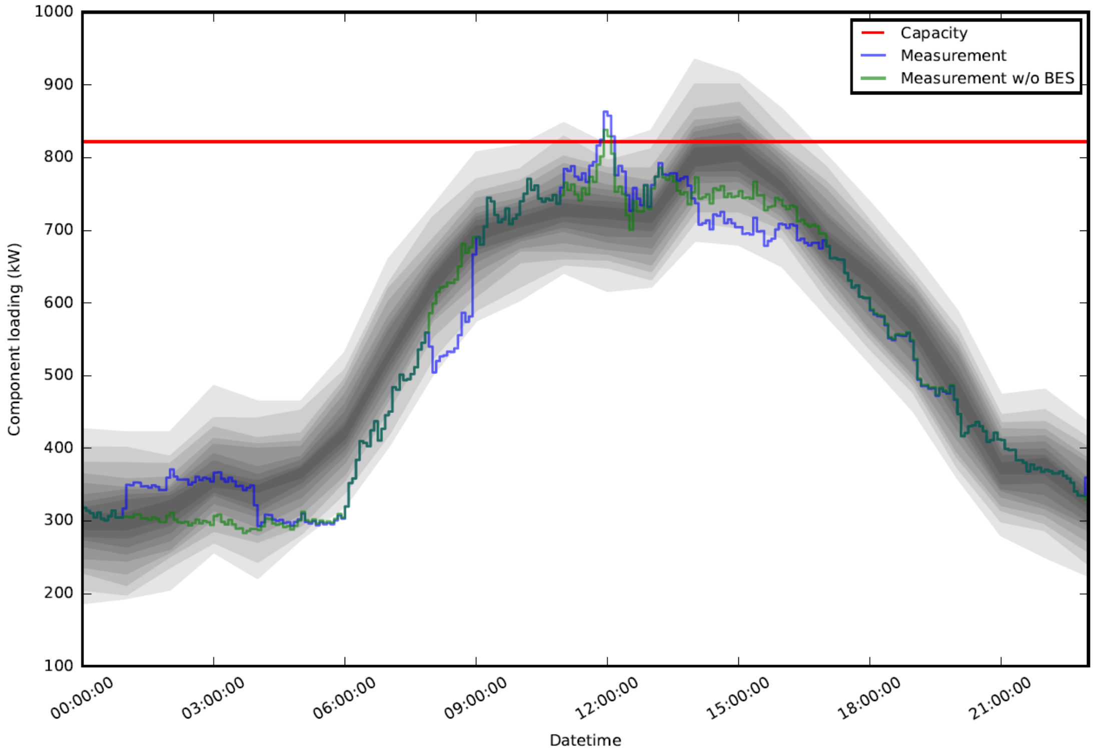

Figure 16 Congestion forecast for 2022-09-27. Loading of the line connecting bus 07:8.1.2 to bus 07:8.1.

Considering the congestion forecast, the DSO would place a bid on the market at 2022-09-26 20:00 using the probability-based method mentioned in section 3.4.2 of Deliverable 2.3. The FSP agents then check at 2022-09-26 21:00 at what hours and which locations the DSO has requested a request for 2022-09-27. Using their energy management system, the FSPs place their offer on the market for the requested hours and locations. As an example, the supply and demand curves based on the bids at 2022-09-27 13:00 are shown in Figure 17.

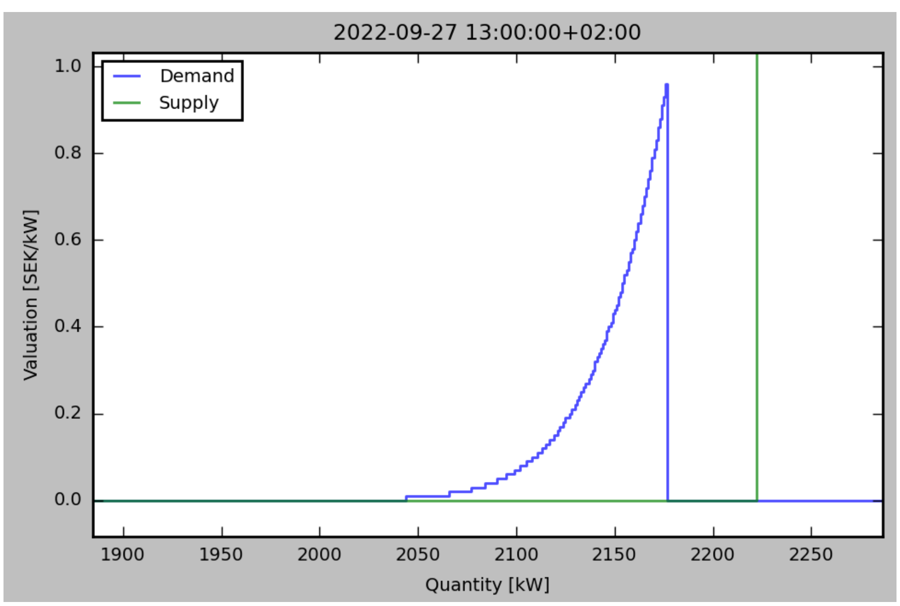

Figure 17 An example of the supply and demand curves: hour 13:00 on the 27th of September

The market operator clears the market at 2022-09-26 22:00 for every hour of 2022-09-27. On 2022-09-27 the agents optimize the assets' dispatch at every hour with a rolling horizon of 24 hours. If they were cleared in the market their connection capacity would be replaced by a market-imposed cap as shown in Figure 18, Figure 19, and Figure 20.

Among others, three observations can be made in the results. In Figure 18, it can be seen how the battery is dispatched according to the spot price (as an example, see 2022-09-27 8:00). The second observation is regarding the control of the battery in bld_07:28. In Figure 18, the expected/forecast netload ($\mathrm{P}_{\mathrm{imp}}^{\mathrm{fc}}$) is above the imposed cap by the market from 14:00-17:00. A potential reason can be that the battery could not be charged according to the sent setpoints in the period 11:00-14:00 and thus did not have enough energy stored to be discharged at t (Compare battery setpoint $\mathrm{P}_{\mathrm{bes}}^{\mathrm{fc}}$ with the real measurements from the battery $\mathrm{P}_{\mathrm{bes}}^{\mathrm{m}}$). The reason behind why the battery did not follow the setpoint is still unclear and need to be understood. However, this malfunction is not from the market and belongs to the physical layer of the demonstrations. In real-life, this malfunction could have potentially been corrected in the adjustment market horizon by the FSP agent purchasing a substitute amount of flexibility for not facing the potential penalties from the not delivering the service. The third observation is concerning the impact of the forecasts on the delivery of the flexibility service. In Figure 18, the forecasted load $\mathrm{P}_{\mathrm{load}}^{\mathrm{fc}}$ is lower than the measured load $\mathrm{P}_{\mathrm{load}}^{\mathrm{m}}$ that was realized. The EMS of the agents is a deterministic optimization and in these specific hours the dispatch had led to a net-load very close to the imposed cap. Therefore, the agent could not deliver the service and crossed the imposed cap, although its anticipated net-load $\mathrm{P}_{\mathrm{imp}}^{\mathrm{fc}}$ was below the imposed cap. This observation highlights the importance of utilizing stochastic or robust optimization for dispatching the flexibility which can be potential improvement for the future demonstration activities. A similar observation about the forecast errors can be made in Figure 19 and Figure 20. These two agents have sold back their unused connection capacity to the DSO between hours 9:00-18:00. However, due to forecast errors in their load and PV production, their net-load $\mathrm{P}_{\mathrm{imp}}^{\mathrm{m}}$ was realized to be higher than the expected value of $\mathrm{P}_{\mathrm{imp}}^{\mathrm{fc}}$ and thus have crossed the market imposed-cap in some periods between 9:00-18:00.

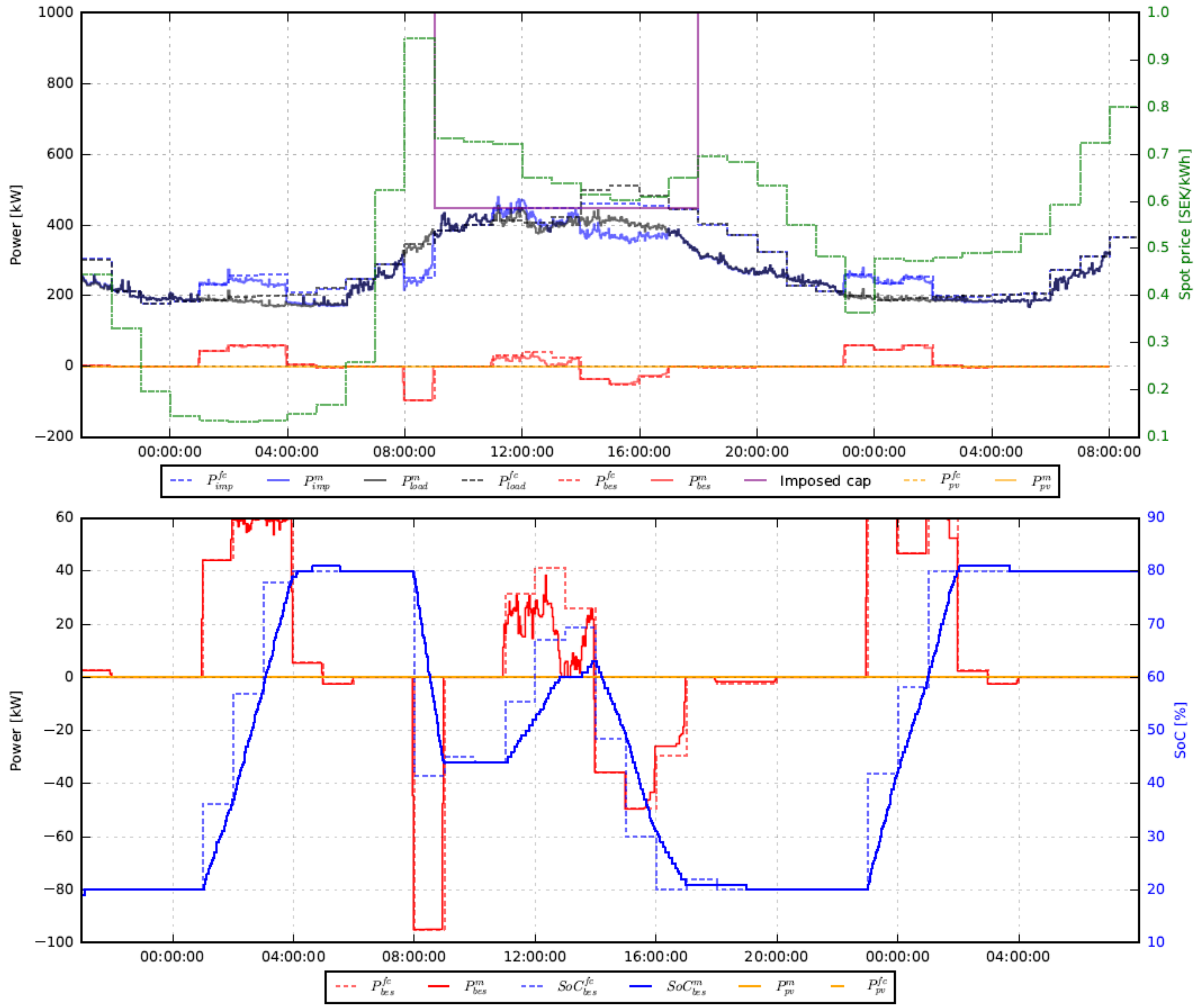

Figure 18 The dispatch of FSP agent bld_07:28 from 2022-09-26 20:00 to 2022-09-28 08:00.

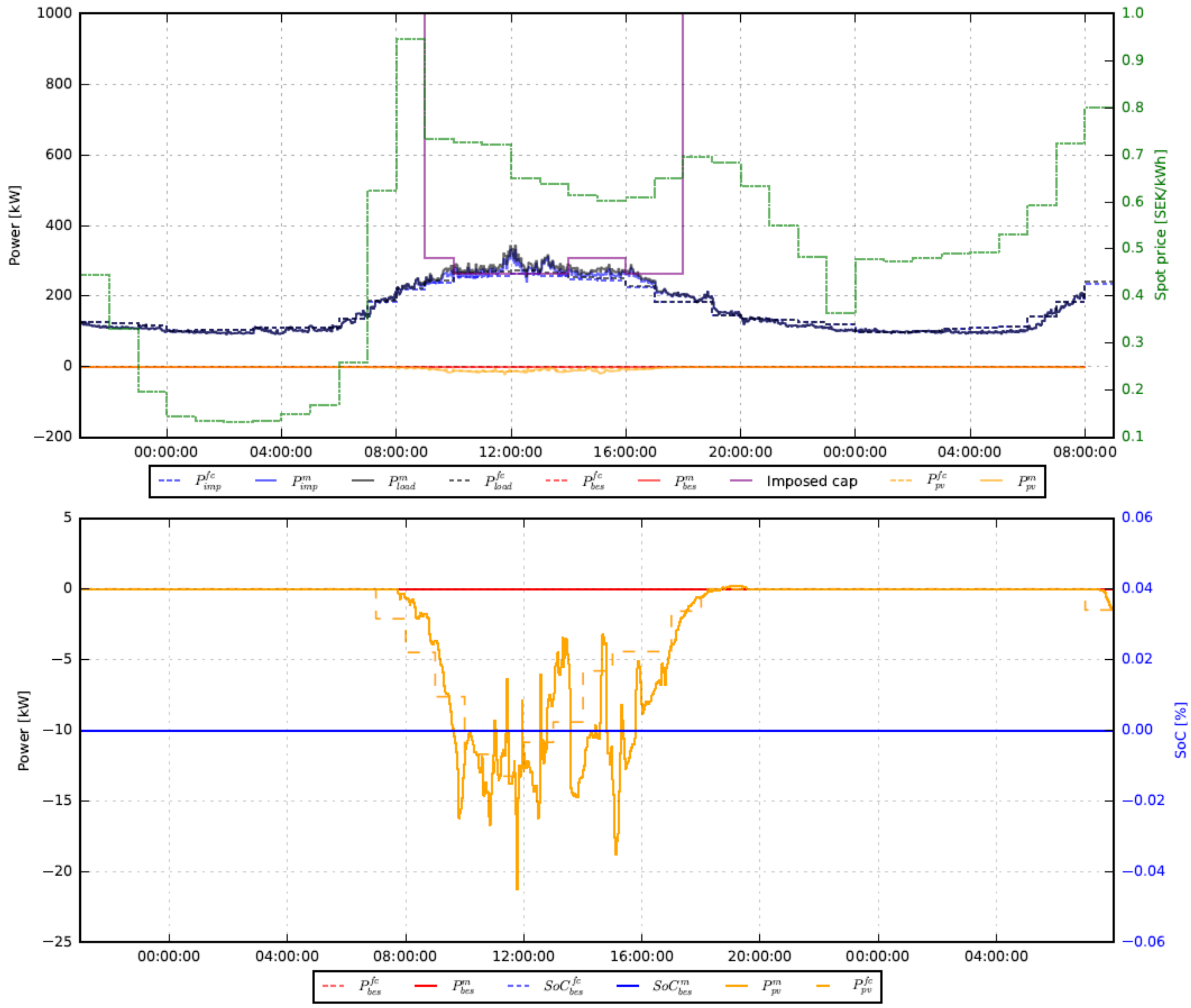

Figure 19 The dispatch of FSP agent bld_07:11B from 2022-09-26 20:00 to 2022-09-28 08:00

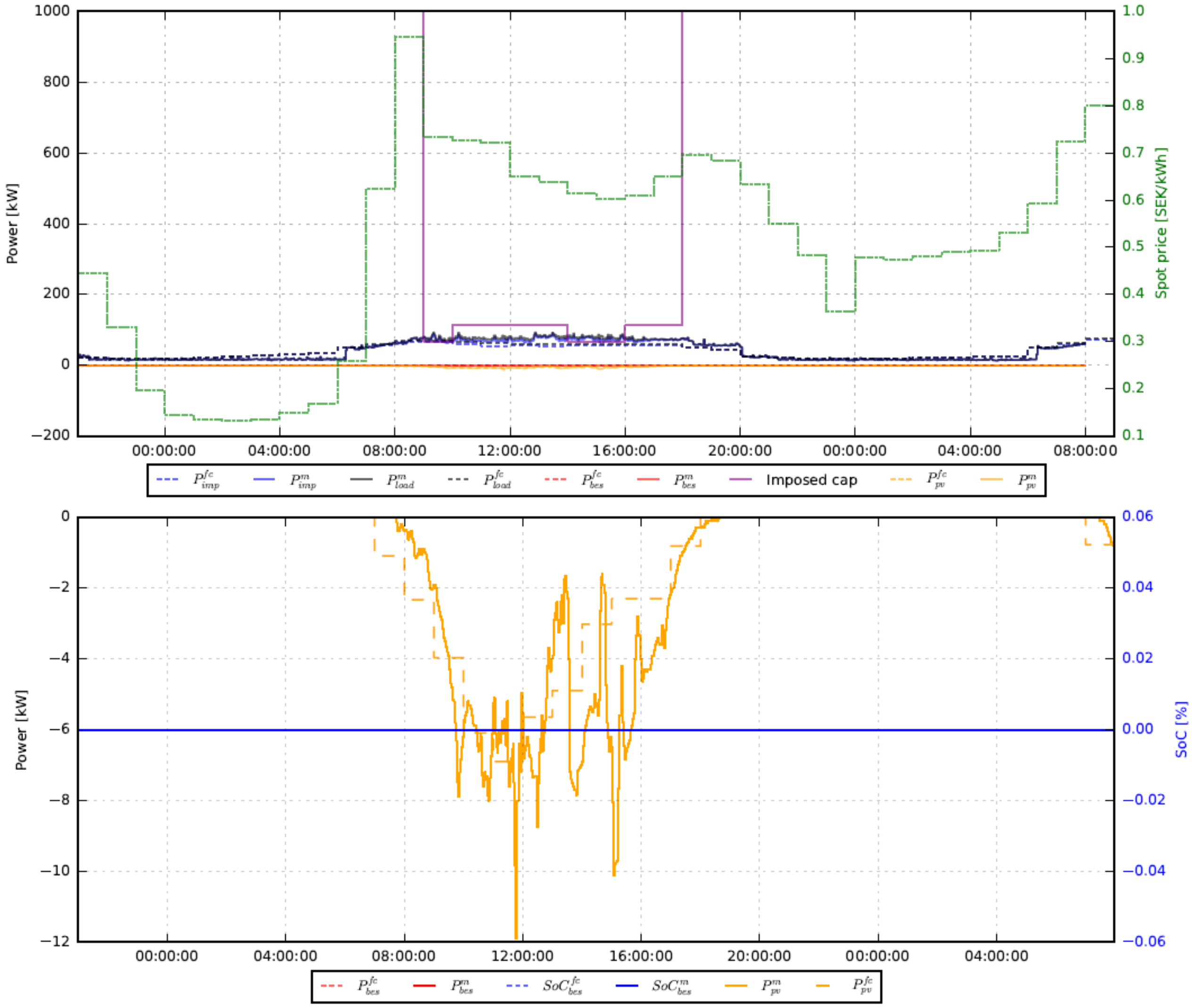

Figure 20 The dispatch of FSP agent bld_07:6 from 2022-09-26 20:00 to 2022-09-28 08:00

5.3. TC 6.3: Comparative simulation case-study for LFM and LEM

As part of TC 6.3, the LFM and LEM designs have been compared qualitatively. The market design aspects such as market organization, bid structure, market clearing and settlement for these two markets have been explained in Section **Error! Reference source not found.**. In this section, they are compared from a t echnology adoption perspective by answering the questions proposed in 4.3.

5.3.1. What grid challenges do LEM and LFM address? Are these challenges the same?

Both market models aim to address the challenges faced by the electric power system nowadays, which are caused by larger share of variable renewable energy, increasing demand of electricity and grid bottlenecks. As illustrated in **Error! Reference source not found.**, different measures and approaches can b e used for accessing flexibility and improving the effectiveness of grid utilization on the distribution level. LEM and LFM are both market-based approaches. There are various designs suggested for LEM and LFM.

Different designs lead to different capabilities of these markets. In this comparison, we have focused on the designs presented in this report. The proposed **LEM** design contributes to local balancing of production and consumption while stimulating a more efficient utilization of distribution grid. The proposed **LFM** design is tailored for congestion management in local grids that are often radial.

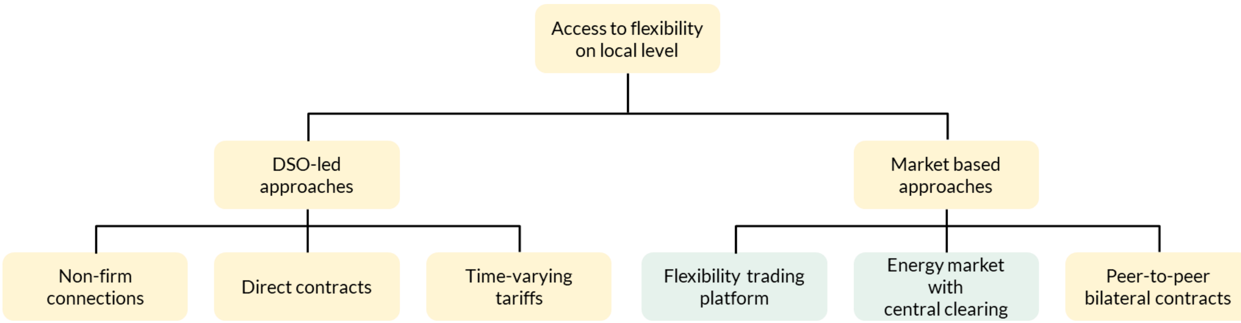

Figure 21 Different approaches to access flexibility in distribution grids [6]*Click or tap here to enter text.*

5.3.2. How do LEM and LFM concepts address the grid challenges?

LEM and LFM use different approaches to tackle with the similar challenges in the distribution network.

LEM: Compared with the current wholesale electricity market, the LEM intends to introduce a finer spatial and temporal resolution, and to enhance the ability of the market price to reflect the true costs. It addresses the challenges with a new marketplace where the local producers and consumers submit bids reflecting their willingness to sell or buy. The market optimizes the power flow to ensure the capacity limits of the grids are not exceeded. Based on the FED local energy market model, a status-based grid tariff is proposed and integrated with the new market model to enhance the efficient utilization of the distribution capacity. The market clearing price internalizes both electricity supply price and distribution cost, and consequently reflects the actual marginal cost for electricity demand. The geographically diversified prices can be considered as an incentive for a more efficient investment in distributed resources.

DSO does not directly participate in the **LEM** trading as a bidder. As the operator of the local distribution grid, it provides information to the market operator about the limits of the grid components and grid tariff. The limits of the grid components are considered as constraints in power flow optimization, while the grid tariff is used to quantify the grid cost in the market clearing function. After the market is cleared, DSO receives payments according to pay-as-bid principle to cover the operation cost.

LFM: Relieving congestion by LFM happens using direct trading of capacity-limitation products. This is different compared to methods that send energy price or tariff signals to affect the behaviour of end-users. The difference can be explained further using the following bipolar dimensions: direct/indirect, dynamic/static, rebate/penalty. The proposed LFM enables a direct trade of service for congestion relief compared to tariff or price signals that aim to indirectly relieve congestion in the corresponding hour. LFMs are dynamic and can adapt to unforeseen events using the intra-day adjustment market. Solutions including tariff signals can be both dynamic and static. How dynamic they are depends on how frequent the tariff is recalculated. The last bipolar dimension is the rebate/penalty. LFM is a rebate/compensation mechanism that rewards the flexible end-users while tariff-based solutions are penalty-based mechanisms. This can affect end-users' resistance towards the adoption of a new solution.

DSO participates directly in the **LFM** as the buyer of the flexibility products.

5.3.3. How can LEM and LFM concepts be adopted in the current energy system structure? What are the different alternatives?

LEM: For LEM, the overlay market is the wholesale electricity market for the specific price area where the LEM is located in. There could be alternative ways for coupling the LEM with the overlay market. One way is to consider the LEM as a supplement layer to the wholesale market, with the electricity retailers as the interfaces and intermediaries between the two markets. The retailers' transactions on the wholesale market depends on the net import/export electricity to/from the LEM. The length of trading period can be adapted to align with wholesale markets. LEM could run in parallel with the wholesale market with either same or different clearing frequency e.g. clears daily, hourly or quarter hourly. The balance responsible of customers in the local grid could be taken by the retailers, similar as the set-up in nowadays. Alternatively, the operator of LEM could take the balance responsible for the entire local market. An advantage of market operator as balance responsible player is that the imbalance cost could also be considered in the market clearing function. As described in [3], there is a potential for the market operator to minimize the imbalance settlement cost by utilizing the available flexibility.

LFM: For LFM, there is no existing overlay market for congestion management. However, the wholesale electricity and the balancing markets are closely related. The proposed LFM is cleared after the wholesale market prices are published. Therefore, the bids and offers on the LFM are affected by the whole electricity prices. In addition, the cleared values on the LFM might impact the portfolio of the balance responsible parties (BRPs) in the wholesale energy market. LFM can coexist in the current structure of the electricity system. For integration in the system, there are two important questions that need to be further studied. One is the relation of the flexibility providers with the balance responsible parties and the second is the competition/coordination of local flexibility markets with the balancing markets.

5.3.4. How is the economic efficiency of the markets?

LEM: the economic results of different actors in the demo will be evaluated after further tests. According to a previous study in [3], the total cost for customers in a local grid (including both electricity supply cost and distribution cost) can be reduced with the proposed LEM model compared to the case without the LEM model. It is achieved by the cost minimization in the market clearing function, which optimally utilizes the available flexibility in the grid. The economic results of the local actors depend on how the market surplus is handled and distributed among the actors. Considering different expectations of the cost reduction or potential revenue, this may influence the interest and willingness for the local actors to participate in the local energy market, invest in DERs and provide their flexibility. Moreover, the marketplace shall be organized and operated efficiently to ensure that the market is functioning well with a reasonable operation cost. The high requirement on the local market operators also brings uncertainties to rolling out LEM in a larger scale [3].

LFM: Economic efficiency can be seen from two perspectives. One is from a mechanism design perspective that efficiency of a mechanism is about maximizing the social welfare of its participants considering their revealed preferences [7]. The efficiency of the long-term reservation and short-term activation markets is theoretically proven from a mechanism design perspective since they are double-sided call-auctions, and thus, they can maximize the social welfare given the revealed costs and utilities [8], [9]. Economic efficiency can also be seen from the perspective of if LFM is a cost-effective solution for addressing the local congestions or not. This can be seen from the group rationality property from mechanism design literature. Group rationality indicates that a desirable mechanism should be designed in a way that no individual or group of participants would be willing to separate from the market to obtain larger benefits. The result of such a property is the stability of the mechanism [7]. There are different challenges with LFMs that can impact this property. Examples are low market liquidity, reliability concerns around availability of demand or supply, potential gaming, transparency issues, and conflict of interests due to challenges with baseline-based flexibility products, and forecast errors at low aggregation levels leading extra costs due to failures in delivery, or wrong estimations for the required/available service quantity concerning. These aspects need to be further analysed and tested in real pilots to assess the cost-effectiveness of LFM as a solution.

5.3.5. How is regulatory compliance? What adoption barriers exist?

Both LEM and LFM are in line with Swedish Energy Market Inspectorate (Ei) 's vision to promote demand-side flexibility in electricity market. They comply with Ei's strategies [10] in terms of:

- Enable effective and correct pricing of flexibility services and enable the price signals to reach customers
- Stimulate grid companies to efficiently utilize and expand the electricity grid
- Facilitate and promote customers to contribute flexibility

LEM: However, the proposed LEM is not entirely aligned with existing regulations for the electricity market. The model introduces a stepwise grid tariff to reflect the actual distribution cost which may vary under different load status. This implies that customers in the same grid area may face different tariffs depending on their locations in the grid. On the other hand, the current regulation requires that tariffs must be non-discriminatory within a network area. The dynamic and geographically diversified grid tariff can be considered deviating from the regulation. Furthermore, both energy and infrastructure are integrated in the proposed market model. The market clearing price internalizes the marginal cost for both electricity supply and distribution i.e., the electricity cost and grid cost are not separated. The purpose is to provide consistent signals for allocating the DERs and to incentivize more efficient utilizations of the network and flexible resources. This, however, deviates from the principle that the network operation and energy trading shall be separate businesses to avoid the grid companies exercising market power. Therefore, a regulatory sandbox would be needed for demonstrating the market model with wider customer groups. More discussion about the regulatory compliance of the LEM model can be found in studies [3], [6].

LFM: The regulatory compliance and related adoption barriers are extensively discussed in Deliverable 2.4. Some of the main regulatory barriers mentioned in D2.4 are missing regulations about product prequalification, standardisation, and baseline design of flexibility product, lack of regulatory adaptation regarding data security, data exchange, data access, contractual agreements, bidding and market settlements. Interested readers can check that deliverable for further details.

5.3.6. Summary

Based on the explanations of the two market models in Section **Error! Reference source not found.** and d iscussions in section 5.3.1 - 5.3.5, **Error! Reference source not found.** summarizes the commons and differences between the two market models.

Table 5-3 Comparison between LEM and LFM models

	LEM	LFM
Addressed grid challenge	Balance the electricity supply and consumption in the local grid; relieve local congestion and stimulate efficient grid utilization	Local congestion
Commodity on the market	Electricity [kWh]	Flexibility: the temporary limitation of subscribed connection capacities[kW]
Market organization	Centralized double-side auction	
Suppliers	Retailer(s), local producers and prosumers	Flexibility service providers
Buyers	Consumer and prosumers	DSO
Trading horizon	The market could be cleared day-ahead, hour-ahead or quarter hour- ahead.	Triple-horizon structure: long-term reservation market (t-years); short-term activation market (t-day): continuous adjustment market on real-time.
Interaction with overlay market	Retailers act as the intermediaries between LEM and the wholesale market, according to the net import and export of the LEM	FSPs can potentially participate in LFM, balancing, and wholesale electricity markets. The system operators need to coordinate over the flexible resources of FSPs. Moreover, the relation of the flexibility providers with the balance responsible parties needs to be clarified.
Imbalance settlement	There could be different solutions e.g. retailers take the balance responsible as nowadays, or the LEM operator takes the balance responsible for all customers in the local market.	N/A
DSO's role	Provide information about grid capacity and grid tariff	Buyers of flexibility services
Pricing scheme	Pay-as-clear for local suppliers or buyers where the market clearing price internalizes the marginal costs for electricity production and distribution; pay-as-bid for retailers according to the bid price; pay-as-bid for DSO according to the actual distribution cost.	Pay-as-bid for all the horizons
Market operator	Neutral third-party	

Economic efficiency	Advantages: Reduced cost for electricity supply and distribution. Uncertainties: - More discussion is needed regarding the distribution of market surplus among local actors. - Measures are needed to ensure efficient operation of the local marketplace.	The long and short-term market horizons are efficient from a mechanism design perspective. Economic cost-effectiveness or group rationality need to be further assessed.
Regulatory compliance	Advantages: Concern effective pricing, efficient grid utilization and unlocking flexibility in the market design. Uncertainties: - Regulatory barriers due to the incompliance with existing legislations i.e. non-discriminatory tariff and unbundling rules.	Missing regulations: product prequalification, standardisation, and baseline design of flexibility product. Needs adaptation to LFM: data security, data exchange, data access, contractual agreements, bidding and market settlements

5.4. TC 6.4: Real-life demonstration case-study of exchange of services in LFM

The algorithm is Section 4.4 is utilised to dispatch the cleared CL quantity from the market. As mentioned before, in the current demonstration only one battery has been available as a flexible resource. Therefore, the cleared CL quantity has only been dedicated to this battery. However, in the case of more resources, a similar approach can be used. More batteries and other flexible resources can be added to the EMS and the CL constraint can be utilised to incorporate the market clearing results. This test-case can be expanded with more resources in the coming Deliverable 6.4.

5.5. TC 6.5: Real-life demonstration case-study of exchange of services by Akademiska Hus to Göteborg Energi

This section summarizes the results from the pilot demonstration on Göteborg Energis local flexibility market “Effekthandel Väst” where Akademiska Hus was one of the flex providers.

During the demonstration 3 flexibility offers was accepted as shown in Figure 20. The traded volume ranged from 105-300 kWh/h and the delivered flexibility was above the traded volume for two occasions while it was below the agreed volume in one case.

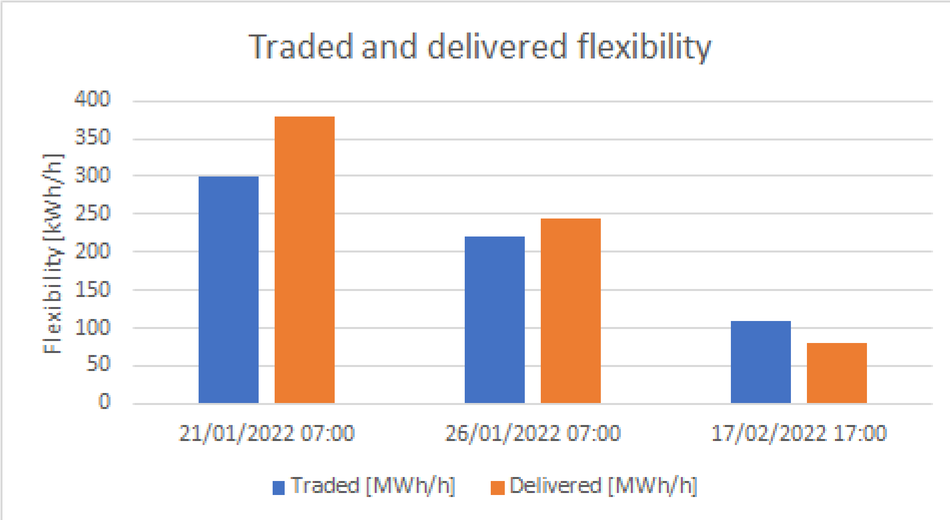

Figure 22 Traded and delivered flexibility from Akademiska Hus to Göteborg Energi.

As mentioned, both battery and CHP unit were included and the agreed baseline for the battery was 0 kW while the baseline for the CHP unit depend on the heat demand.

Although the market was cleared and settled automatically, both the bidding and activation were done manually which required that resources was allocated to the trading. The market platform support automated communication and information exchange via their API interface. During the coming winter season, the framework of LESOOP will be used to automatically estimate the bid price and activation of the resources.

6. Conclusions

In this report, an overview of the testbed and the chosen demonstration site, measurement system and controllable devices, the IoT local platform, and the common platform used for comparison of the markets were presented. Moreover, an overview of the improved designs for LEM and LFM. The designs were tested in different test cases, and the preliminary results were presented and discussed.

The test cases include real-life demonstration case-studies of the LEM and LFM designs, a comparison of LEMs and LFMs, exchange of services in the LFM, and exchange of services in a commercial LFM between Akademiska Hus and Göteborg Energi.

The test cases for LEM and LFM show that the integrated local IoT platform is functioning as expected. The algorithms and communications enable the demonstration of the two market models, in terms of reading measure points from DERs, generating forecasts for local consumption and production, defining bids on LEM and LFM, clearing the markets, converting the market clearing results to command commands and sending the commands to the controllable devices.

In the preliminary tests of LEM, the market operator is scheduled once per day to collect bids from agents, clear the market and convey the clearing results to the agents. The agents submit bids according to the required bid formats on behalf of local DER owners and the retailer. The bids are based on the forecast of production, consumption, and spot prices. After receiving the bids, the market is cleared by matching the supply and demand bids while maximizing the social utility. The market clearing prices reflect finer spatial resolution by integrating both supply cost and distribution cost, where the distribution cost is estimated based on the status-based tariff. The control commands for the flexible resource, i.e., BES in the demo, are converted from the market clearing results. The execution of commands will be further tested during the next phase of the demonstration.

In the LFM tests, a full cycle demonstration of the short-term activation market is tested in an automated manner. The preliminary results from the LFM test show that agents' bidding and control algorithms are interconnected with the forecasts, IoT platform, and the market clearing algorithm. Moreover, the preliminary results indicate the impact of forecast errors on failures in the delivery of the flexibility products and thus the importance of utilising continuous adjustment horizon and stochastic or robust optimization algorithms for dispatching the flexibility.

A qualitative comparison between LEM and LFM is made by discussing their commons and differences regarding market organization, bid structure, market clearing, interconnection with overlay market, compliance of regulatory frameworks, etc. For tackling the similar challenges on the distribution level, the two models adopt different market approaches and focus on different aspects of the challenges. There are alternative ways to integrate them with the existing overlay market, although with regulatory barriers to different extents.The provision of services to Göteborg Energis flexibility market using Akademiska hus flexibility resources gave good insights in the market operations and showed the importance of setting up solutions that automatically dispatch the resources.

The presented results have been preliminary. These results show that the demo site, the IoT platform and the algorithms are interconnected and functional. Further demonstrations and evaluation of the test-cases will be conducted and presented in the coming Deliverable 6.4. The future activities include:

- Longer real-life demonstrations of the LFM and the LEM
- A more thorough qualitative and quantitative comparison of the LFM and LEM designs
- An automated demonstrations in the commercial LFM of NODES using agent algorithms in LESOOP
- The assessment of adding other flexibility resources such as heat pumps and ventilations system in the demonstration activities

Appendix A

In this section, the agents' optimization algorithm in the LFM test is presented. It is used in bidding and dispatch of flexibility in the LFM test-case.

The dispatch of batteries for each FSP is decided individually by a cost minimization algorithm that is presented in Eq. (A2). The optimization algorithm runs every hour and decides the dispatch for the next 24 hours ($\mathcal{T}$). The objective function Eq. (A2a) includes power costs ($\mathrm{C}^{\mathrm{power}}$), energy import costs ($\mathrm{C}^{\mathrm{imp}}$), and energy export revenues ($\mathrm{R}^{\mathrm{exp}}$). The revenues from LFM are not included to extract the truthful cost curve for providing CL product. The fees for energy import (ρ_t^{imp}) and export (ρ_t^{exp}) are shown in Eq. (A1). The fees include spot-market prices (ρ_t^{spot}), power tariffs ($\rho^{\mathrm{P_{tariff}}}$), grid energy tariffs ($\rho_t^{\mathrm{gridtariff}}$), energy tax ($\rho_t^{\mathrm{tax}}$), and tax returns ($\rho_t^{\mathrm{taxreturn}}$) in the case of export of energy to the grid.

$$\rho_t^{\mathrm{imp}} = \rho_t^{\mathrm{spot}} + \rho_t^{\mathrm{gridtariff}} + \rho_t^{\mathrm{tax}} \qquad \text{Eq. (A1a)}$$

$$\rho_t^{\mathrm{exp}} = \rho_t^{\mathrm{spot}} + \rho_t^{\mathrm{taxreturn}} \qquad \text{Eq. (A1b)}$$

The decision variables of the algorithm are $\Xi = \{p_t^{\mathrm{imp,fc}}, p_t^{\mathrm{exp,fc}}, p^{\mathrm{max}}, p_t^{\mathrm{BES,ch,fc}}, p_t^{\mathrm{BES,dch,fc}}, z_t^{\mathrm{BES}}, e_t^{\mathrm{BES}}, p_t^{\mathrm{PV,fc}}, p_t^{\mathrm{PV,curt}} \mid \forall t \in \mathcal{T}\}$. $p_t^{\mathrm{imp,fc}}$ and $p_t^{\mathrm{exp,fc}}$ are the expected imported and exported power at each time step. They will not occur at the same time because it would lead to higher power costs and also ρ_t^{imp} is always larger than ρ_t^{exp} that leads higher costs than revenues. p^{max} is the maximum net-load of the optimization problem. It is compared with the maximum historical value and the larger value will be used in calculating the power cost C^{power}. $p_t^{\mathrm{BES,ch,fc}}$ and $p_t^{\mathrm{BES,dch}}, fc$ are charging and discharging power of the battery that can be used as the setpoints to be sent to the device. z_t^{BES} is a binary variable indicating charging mode when 1, and discharging mode when 0. e_t^{BES} is the energy content of the battery. $p_t^{\mathrm{PV,fc}}$ is the final PV production after considering the potential curtailment $p_t^{\mathrm{PV,curt}}$.

$$\min_{\Xi} C^{power} + \sum_{t\in\mathcal{T}} C_t^{imp} - R_t^{exp} \quad = \rho^{P_{tariff}} p_{max} + \sum_{t\in\mathcal{T}} \rho_t^{imp} p_t^{imp,fc} - \rho_t^{exp} p_t^{exp,fc} \qquad \text{Eq. (A2a)}$$

$s.t.$

$$\xi \geq 0 \quad \forall \xi \in \Xi \qquad \text{Eq. (A2b)}$$

$$z_t^{\mathrm{BES}} \in \{0,1\} \quad \forall t \qquad \text{Eq.(A2c)}$$

Balance constraint:

$$p_t^{\mathrm{load,\,fc}} + p_t^{\mathrm{exp,fc}} + p_t^{\mathrm{BES,ch,fc}} - p_t^{\mathrm{PV,fc}} - p_t^{\mathrm{BES,dch,fc}} - p_t^{\mathrm{imp,fc}} = 0 \quad \forall t \qquad \text{Eq. (A2d)}$$

BES constraints:

$$p_t^{\mathrm{BES,ch,fc}} \leq \overline{p}^{\mathrm{BES}} \quad \forall t \qquad \text{Eq. (A2e)}$$

$$p_t^{\mathrm{BES,dch,fc}} \leq \overline{p}^{\mathrm{BES}} \quad \forall t \qquad \text{Eq. (A2f)}$$

$$P_t^{\mathrm{BES,ch,fc}} \leq z_t^{\mathrm{BES}} M \quad \forall t \qquad \text{Eq. (A2g)}$$

$$P_t^{\text{BES,dch,fc}} \leq \left(1 - z_t^{\text{BES}}\right) M \quad \forall t$$ Eq. (A2h)

$$\overline{e}^{\text{BES}} SoC_{\min} \leq e_t^{\text{BES,fc}} \leq \overline{e}^{\text{BES}} SoC_{\max} \quad \forall t$$ Eq. (A2i)

$$e_t^{\text{BES,fc}} = e_{t-1}^{\text{BES}} + \eta p_t^{\text{BES,ch,fc}} - \frac{1}{\eta} p_t^{\text{BES,dch,fc}} \quad \forall t$$ Eq. (A2j)

Maximum power constraint:

$$p^{\max} \geq p_t^{\text{exp,fc}} + p_t^{\text{imp,fc}}$$ Eq. (A2k)

PV constraint:

$$p_t^{\text{PV,fc}} = p_t^{\text{PV,gen}} - p_t^{\text{PV,curt}} \quad \forall t$$ Eq. (A2l)

CL product constraint:

$$p_t^{\text{imp,fc}} \leq \overline{p}^{\text{imp}} - P_t^{\text{CL}}$$ Eq. (A2m)

The optimization is subjected to a few constraints. The balance constraint Eq. (A2d) makes sure the input and output energy is in balance in each hour. Constraints Eq. (A2e) and (A2f) limit the charging and discharging power of the battery to its nominal values ($\overline{\mathrm{p}}^{\mathrm{BES}}$). Constraints in Eq. (A2g) and Eq. (A2h) make sure charging and discharging cannot happen at the same time using the big-M method. Constraint Eq. (A2i) limits the energy content of the battery to a minimum and maximum state of charge (SoC) to reduce degradation in the battery. $\overline{\mathrm{e}}^{\mathrm{BES}}$ is the nominal energy capacity of the battery in this constraint. Constraint Eq. (A2j) is the inter-temporal constraint of the battery linking the energy content of the battery to its previous step energy content while considering charging and discharging efficiencies. Constraint Eq. (A2k) finds out the largest net-load of the FSP in each time horizon. In constraint Eq. (A2l), the power from the PV is calculated from the expected generation based on the weather $p_t^{\text{PV,gen}}$ and the potential curtailed power ($\mathrm{p}_\mathrm{t}^{\mathrm{PV,curt}}$). Lastly, constraint Eq. (A2m) limits the imported power by the sold CL quantity ($\mathrm{P}_\mathrm{t}^{\mathrm{CL}}$) with respect to the nominal connection capacity ($\overline{\mathrm{p}}^{\mathrm{imp}}$).

References

[1] S. Rydberg and J. S. Park, “FED Technical Final Report.” Accessed: Oct. 31, 2022. [Online]. Available: https://www.johannebergsciencepark.com/sites/default/files/FED Technical Final Report - v1-2020-01-16.pdf.

[2] M. Brolin and H. Pihl, “Design of a local energy market with multiple energy carriers,” *Int. J. Electr. Power Energy Syst.*, vol. 118, p. 105739, Jun. 2020, doi: 10.1016/j.ijepes.2019.105739.

[3] M. Brolin, “Marknadsplats för handel med energi i det lokala energisamhället,” 2022, Accessed: Oct. 31, 2022. [Online]. Available: www.energiforsk.se.

[4] “Why baselines are not suited for local flexibility markets,” *Renew. Sustain. Energy Rev.*, vol. 135, p. 110357, Jan. 2021, doi: 10.1016/j.rser.2020.110357.

[5] Göteborg Energi, “Elnätspriser Göteborg 2022,” 2022. https://www.goteborgenergi.se/foretag/vara-nat/elnat/elnatsavgiften (accessed Oct. 31, 2022).

[6] H. Pihl, W. Tobiasson, and M. Brolin, “D5.3 Report on market design for micro-grid markets including interaction with the surrounding system and market,” 2019. Accessed: Oct. 31, 2022. [Online]. Available: https://www.ei.se/download/18.6f9b6b2617714873b45f1634/1613487758406/Energimarknadsinspektionens-strategi-för-flexibilitet-i-elsystemet.pdf.

[7] L. Mitridati, J. Kazempour, and P. Pinson, “Design and game-Theoretic analysis of community-Based market mechanisms in heat and electricity systems,” *Omega (United Kingdom)*, vol. 99, Mar. 2021, doi: 10.1016/J.OMEGA.2019.102177.

[8] R. Scharff and M. Amelin, “Trading behaviour on the continuous intraday market Elbas,” *Energy Policy*, vol. 88, pp. 544–557, Jan. 2016, doi: 10.1016/J.ENPOL.2015.10.045.

[9] F. Ocker and V. Jaenisch, “The way towards European electricity intraday auctions – Status quo and future developments,” *Energy Policy*, vol. 145, Oct. 2020, doi: 10.1016/J.ENPOL.2020.111731.

[10] J. Rosenlind and E. Broström, “Ei:s strategi för flexibilitet i elsystemet,” 2020. Accessed: Oct. 31, 2022. [Online]. Available: https://www.ei.se/download/18.6f9b6b2617714873b45f1634/1613487758406/Energimarknadsinspektionens-strategi-för-flexibilitet-i-elsystemet.pdf.