Final Northern Cluster demonstrator evaluation report

D7.6

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About OneNet

The project OneNet (One Network for Europe) will provide a seamless integration of all the actors in the electricity network across Europe to create the conditions for a synergistic operation that optimizes the overall energy system while creating an open and fair market structure.

OneNet is funded through the EU's eighth Framework Programme Horizon 2020, "TSO – DSO Consumer: Large-scale demonstrations of innovative grid services through demand response, storage and small-scale (RES) generation" and responds to the call "Building a low-carbon, climate resilient future (LC)".

As the electrical grid moves from being a fully centralized to a highly decentralized system, grid operators have to adapt to this changing environment and adjust their current business model to accommodate faster reactions and adaptive flexibility. This is an unprecedented challenge requiring an unprecedented solution. The project brings together a consortium of over 70 partners, including key IT players, leading research institutions and the two most relevant associations for grid operators.

The key elements of the project are:

1. Definition of a common market design for Europe: this means standardized products and key parameters for grid services which aim at the coordination of all actors, from grid operators to customers;
2. Definition of a Common IT Architecture and Common IT Interfaces: this means not trying to create a single IT platform for all the products but enabling an open architecture of interactions among several platforms so that anybody can join any market across Europe; and
3. Large-scale demonstrators to implement and showcase the scalable solutions developed throughout the project. These demonstrators are organized in four clusters coming to include countries in every region of Europe and testing innovative use cases never validated before.

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Table of Contents

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

List of Figures

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 957739

List of Tables

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List of Abbreviations and Acronyms

Acronym	Meaning
aFRR	Automatic Frequency Restoration Reserve
API	Application Programming Interface
B2B	Business to Business
BESS	Battery Energy Storage System
CIM	Common Information Model
DEP	Data Exchange Platform
DER	Distributed energy resource
DMD	Dedicated Metering Device
DSO	Distribution system operator
ECP	Energy Communication Platform
EIC	Energy Identification code
EV	Electric Vehicle
FCT	Flexibility call for tender
FR	Flexibility Register
FSP	Flexibility Service Provider
HTTP	Hypertext Transfer Protocol
MARI	Manually Activated Reserve Initiative
mFRR	Manual Frequency Restoration Reserve
MMS	Market Management System
NOCL	Northern Cluster
PTDF	Power Transfer Distribution Factor
RES	Renewable Energy Sources
SFP	Single Flexibility Platform
SO	System Operator
T&D CP	TSO-DSO Coordination Platform
TSO	Transmission system operator
UC	Use Case
UI	User interface
VPP	Virtual Power Plant
WP7	Work Package 7

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Executive Summary

This document presents and summarizes the key results and achievements of the OneNet Work Package 7 (WP7) Northern Cluster Demonstrator covering the entire spectrum of energy flexibility for a harmonized operation of electricity markets and networks. It also evaluates the functionalities of the Northern Cluster (NOCL) demonstrations, by implementing and validating test scenarios, partners' IT platform integrations, data flows, and processes underpinning the design of a well-functioning common flexibility market solution. This universal market concept is envisioned through the multi-lateral interaction of stakeholders such as flexibility service providers (FSPs), market operators (MOs), system operators (SOs), as well as new identified system roles that include TSO-DSO coordination platform (T&D-CP), flexibility register (FR) and data exchange platform (DEP). The multilateral stakeholder interactions play a key role in setting up an architecture constituting a platform of platforms supporting an advanced multi-market environment, easing end-user market participation, and enabling inter-operability, and scalability of offered services.

The developed NOCL solution features an end-end process for harmonized, TSO-DSO coordinated, and market driven flexibility uptake to match the needs of multiple networks simultaneously, enabling value-stacking potential. This end-end approach yields a holistic solution from the perspective of all stakeholders in the value chain and follows respective use cases covering all phases of flexibility procurement, i.e. from resource registration and pre-qualification to the closing and financial settlement. The NOCL solution is aimed to break national-level barriers and country-market borders, which is substantiated by implementing and demonstrating the proof of concept using TSO-DSO pairs from Finland, Estonia, Latvia, and Lithuania, thus showcasing replicability of the solution under different stakeholders, geographies, and IT systems. The innovation lies in the development of a harmonized and near-real time coordinated process of flexibility procurement, removing market entry barriers via defining harmonized market products, and boosting availability and visibility of qualified flexibility by means of FR and T&D-CP.

The NOCL flexibility platform is easily extendable towards a regional or European level solution. In OneNet, it is accomplished through integration with OneNet middleware which enables connectivity with potential stakeholders across Europe. This connectivity is extremely necessary for connecting to market operators empowering bid collection and forwarding, thereby linking offers or bids across country borders and regions, and trade in a transparent and cost-effective way.

The individual functionalities and concepts of the NOCL components, flexibility enabling tools and associated processes have already been defined and explained in the respective deliverables. However, a summary of WP7 platforms and modules is provided for explaining the demo setup and flexibility market functioning.

In WP7 use cases, consideration is also given to flexibility resource owners (i.e. providers) and flexibility buyers (i.e. SOs). In this respect, real flexibility resources are piloted, and processes are designed to streamline

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the market participation through FSPs. NOCL also highlights the regulatory challenge when activation of flexibility affects the balance responsible party (BRP) and energy retailer of the flexibility resource provider. This aspect has been considered in the country-level demos. In addition, the value drivers for end-consumers to provide flexibility as well as for SOs to procure flexibility are also provided in this report as part of a previous WP7 deliverable D7.5.

Lastly, NOCL platform is used to seamlessly integrate stakeholders' IT platforms and demonstrate the automated end-end process of flexibility market operation for each of the country-demo. KPIs are used to evaluate the demonstration outcomes. Results prove that flexibility procurement by coordinated SOs in a joint market setting brings a significant benefit over fragmented market operation. T&D-CP has a great value-stacking potential such that it not only prevents further grid congestions but also increases resource utilization efficiency by activating flexibility that serves multiple needs of multiple operators. This type of value-stacking also brings socio-economic value for SOs enabling them to further reduce procurement costs by cost-splitting. Common tools generate value for both the flexibility sellers and buyers. However, lack of or access to sub-metering is concluded to be one of the major issues in customer engagement. While aggregation of resources addresses customer's privacy concerns, communication infrastructure to steer flexibility resource is another issue to be resolved.

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1 Introduction

This deliverable is an outcome of all tasks of OneNet WP7 Northern Cluster (NOCL) Demonstrator. It concatenates all the findings and achievements of WP7 that are accomplished during the execution of the OneNet project. In particular, this report details the setup and implementation of the NOCL universal flexibility market solution jointly developed by partners. In short, NOCL flexibility solution is an integrated effort to enable uptake of market-driven flexibility by coordinated networks through multiple markets where liquidity can be reached.

The solution is implemented in TSO-DSO pairs individually from Finland, Estonia, Latvia, and Lithuania assuring the replicability of the proposed solution. NOCL designed use cases to capture all market processes related to flexibility procurement, and map multiple networks' needs to harmonized flexibility products defined in OneNet. To do so, new roles such as flexibility register (FR) and TSO-DSO coordination platform (T&D-CP) are introduced that constitute an inherent part of NOCL architecture which is developed on top of achievements from previous collaborations. Such a platform seamlessly integrates IT systems of energy system stakeholders, e.g. flexibility service providers (FSPs), market operators (MOs) and system operators (SOs), enabling open competition supported by interoperability of services.

This form of market-clearing fosters a fair, transparent and competitive participation of stakeholders (FSPs and SOs) as well as enhance TSO-DSO-customer interoperability. Moreover, automating flexibility trading as well as stakeholders' processes for trading preparation form a unique functionality of the solution. To this end, the designed SUCs identified the following challenges to be solved in WP7:

- Develop open and scalable architecture and interfaces
- Single flexibility marketplace for FSPs and SOs
- Near real time coordination of electricity markets and networks
- Coordination between network operators
- Universal participation of stakeholders irrespective of physical location
- Data sharing, consent, and access management
- Compatibility with planned European level initiatives, e.g. MARI, PICASSO

The NOCL market solution addresses all the above-mentioned challenges by adopting an over-arching approach crafting an end-end mechanism that most-economically matches grid needs of multiple SOs with flexibility offers in a grid-safe manner and unlock value-stacking potential. This requires bid optimization and carried out with an optimization module inside the T&D-CP. NOCL develops further network information processing using PTDF matrices characterizing grid states to a granular level. Flexibility resources are first registered and pre-qualified by FR which also tags locational IDs to the qualified resources. Flexibility offers in marketplaces bears these geo-tags. Different SOs' needs in the form of purchase offers, network data, product requirements and flexibility bids are sent to this optimization module where grid-impact assessment is performed and qualified bids are optimally matched.

Considering different marketplaces ensures that the proposed solution is compatible with off-the-shelf market platforms and offer FSPs an improved visibility by offering willingness to trade in the common flexibility market or the marketplace business-as-usual processes. Moreover, the scalability of the proposed solution by contributing towards a regional and pan-European flexibility market is also an important factor. This issue is tackled by supporting direct integration of MOs to T&D-CP via standardized interfaces as well as through the integration of OneNet middleware protocols.

The NOCL architecture features standardized interfaces and communication protocols between stakeholders whenever possible. As such, it supports both standardized and proprietary interfaces. To administer access rights and consent management between stakeholders, a new entity called data exchange platform (DEP) is introduced. DEP ensures information sharing while complying with data protection concerns. The functionalities are embedded to the T&D-CP. The step-by-step information flow and data exchanges have been reported in detail in SUCs, that are included as parts of previous WP7 deliverables.

1.1 Objectives of the Work Reported in this Deliverable

The objective of the work reported in this deliverable is to concatenate the findings of the OneNet WP7, detail the entire implementation and set-up of country-level flexibility market demonstrations, validate the system use cases (SUCs) using test scenarios and evaluate the demonstration outcomes using NOCL KPIs reported in previous OneNet deliverables. In addition to these objectives, demonstrating proof of inter-operability, scalability and replicability of the proposed solution is an important cornerstone. The report also describes key features of country-level implementations including network modelling, involved stakeholders, piloted resources and participating FSPs. NOCL country-specific demos aim at demonstrating the complete end-end solution concept. However, the differences exist only in the TSO-DSO pairs, marketplaces and the flexibility products.

1.2 Outline of the Deliverable

This deliverable is organized as follows: Chapter 1 introduces the WP7 contributions, scope, objectives and discusses the structure of the deliverable. Chapter 2 provides an overview of the higher-level architecture of the NOCL common flexibility market solution along with partners' role. Chapter 3 provides a summary of NOCL platform components' functionalities and market processes in relation to the UCs. Chapter 4 explores customer-centric aspects for engaging and driving flexibility availability. An abstract of a detailed survey is also presented as a reference. Chapter 5 is dedicated to NOCL country-specific demonstration scenarios and results. Chapter 6 evaluates the NOCL demo results using KPIs, and value generation drivers. It also highlights the impacts of demo

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results on key stakeholders and summarizes the lessons learnt. Finally, Chapter 7 concludes the deliverable and Chapter 8 outlines future work.

1.3 How to Read this Document

This deliverable is not written against a specific task, but it summarizes and concatenates the whole WP7 findings including country-specific implementations and demonstration results. For a better understanding of the NOCL flexibility market concept, it is highly recommended to go through 'Report of flexibility availability' in D7.1, 'Flexibility register description and implementation' in D7.2 [1], 'Report on market functionality in D7.3 [2], 'T&D-CP module description and implementation' in D7.4 [3], and 'Report on TSO and DSO value generation drivers' in D7.5 [4].

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2 Northern Cluster demonstrator

Northern cluster demonstrator (NOCL) is the joint effort of 15 partners from different countries. Partners collaborated for this joint solution of universal flexibility market on top of the achievements in the previous collaborations. The solution is implemented in TSO-DSO pairs from Finland, Estonia, Latvia, and Lithuania. The developed solution features end-end process for harmonized, TSO/DSO coordinated, and market driven flexibility uptake and the proof of this concept is demonstrated in multiple use cases.

The architecture of NOCL, along with partners' roles, is presented in Figure 2.1. The Figure demonstrates key interactions for a well-functioning common flexibility market. The platform connects to SOs and FSPs and altogether connected to the flexibility marketplaces using harmonized market products. The NOCL solution creates fair and incentivizing conditions for significant participation of end customers and enables services for grid operators (flexibility buyers).

The solution is expandable from regional approach to pan-European solution using OneNet middleware, which is enabler of secure, standard, and scalable cross-platform data exchange between European energy sector stakeholders at all levels, from TSOs to DSOs, from small consumers to large producers regardless of physical location. The NOCL platform can maintain connectivity to marketplaces through middleware. This integration promotes competition among marketplaces driving innovation such that it can quickly adapt to evolving market changes. It also facilitates bid forwarding to T&D-CP for bid optimization and recommending optimal bids to relevant marketplaces.

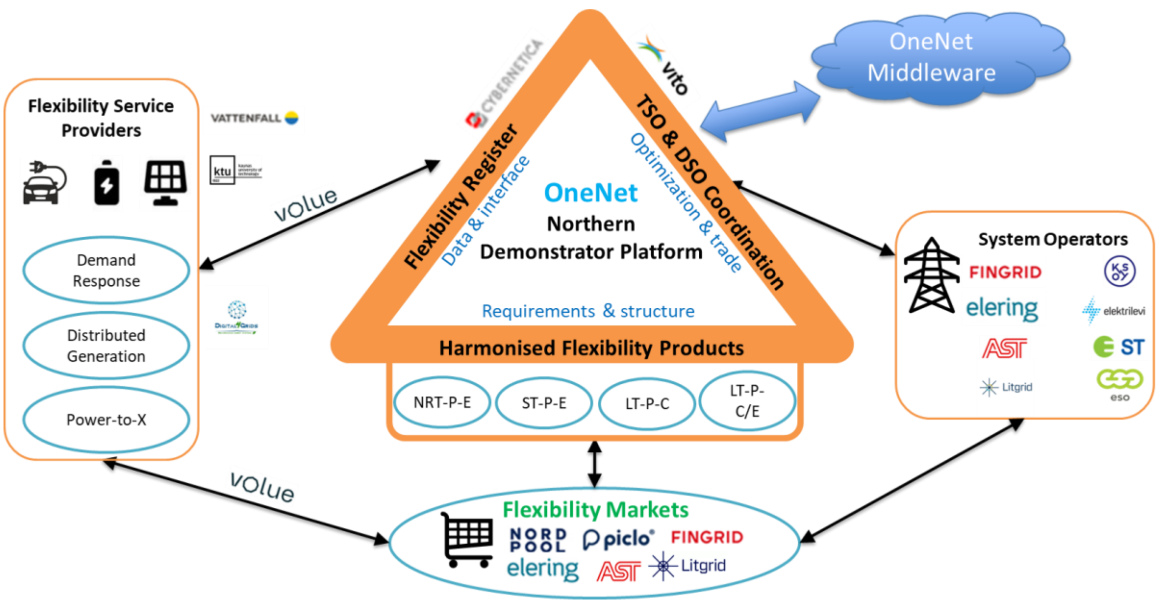

Figure 2.1: Northern Cluster architecture

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3 Northern Cluster Demonstrator Use Cases

3.1 BUC

In the very beginning of the project, Northern demonstrator decided to go forward with just one comprehensive business use case (BUC). The purpose of such approach was to indicate the:

1) Harmonized solutions for flexibility market in all countries participating in the NOCL;
2) Universal applicability of the use case to any flexibility needs and product;
3) Close interrelations of all processes from customer onboarding to settlement in the flexibility value chain.

Northern regional flexibility market BUC includes the high-level description of regional flexibility market processes, enabling seamless participation of multiple market actors and coordination of the system operators. The objectives of the BUC are to:

- develop seamless end-to-end process for market-based flexibility utilization for grid services;
- lower the entry barrier for flexibility by simplifying the process for flexibility service provider;
- ensure availability of short-term flexibility from multiple sources.

The BUC describes five scenarios: 1) customer onboarding process, 2) prequalification process, 3) flexibility procurement process, 4) secondary trading process. 5) verification and settlement process. BUC can be applied in provision and procurement of balancing, network congestion management and voltage control services. BUC includes new platforms, flexibility register (operated by Flexibility Register Operator) and TSO-DSO coordination platform (operated by Optimisation Operator). These platforms will have a role in management of flexibility resources and procurement related data and joint TSO-DSO coordination and network impact assessment.

The full NOCL BUC can be found in Zenodo repository [5].

3.2 SUCs

Based on the high-level BUC Northern demonstrator partners elaborated a number of system use cases (SUCs), which were explained in detail in deliverables 7.2 [1], 7.3 [2] and 7.4 [3]. However, the SUCs were subject to continuous updates according to the demonstrations' progress. Therefore, the final SUCs can be accessed in Zenodo repository [5].

3.2.1 Driving availability of flexibility

The increased electrification of society requires the introduction of new methods in the electricity market, one of them is an increased use of flexibility, coming not only from large production units but also from end customer sources. Private flexibility resources need to be aggregated, while commercial flexibility resources

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could achieve a relevant volume on their own. The different sources of flexibility available at the electricity consumers' level, the circumstances enabling the utilization and exploration of this flexibility, and the ways in which this flexibility can be unlocked comes with many challenges. The number and quality of resources with flexibility potential are increasing. The larger, most important, resources identified in the Northen Demo are heat pumps, hot water boilers, electric vehicle chargers, solar power and batteries.

By introducing the different roles of the Flexibility Service Provider, the link between the customers providing flexibility resources and the market for flexibility can be established. The main reason for customers to offer their flexibility is economic: The Flexibility Service Provider defines a rewarding mechanism which is attractive for the customer and a steering logic with minimal impact on the living comfort. The project has identified two main types of flexibility contracts, one which combines an electricity sales contract with flexibility and another which is for flexibility only.

The main drivers for market flexibility are from a Transmission System Operator's perspective, congestion management and balancing services, investment deferral and ancillary services. Similarly, the Distribution System Operator is also driven by congestion management and investment deferral. For the Flexibility Service Provider, the important aspects are economic value and market/system stability.

Although the current electricity system differs between the European countries, all the countries participating in the Northern Cluster Demonstrators see a similar development soon. The electricity demand will increase in all countries driven by the transition in heating, transport, and heavy industry. All countries have the potential and increasing flexibility to be utilised. EVs on the other hand constitute a transversal adoption trend which may unleash flexibility provision due to its distributed nature.

The flexibility provision in the Northern cluster demonstration finds that multiple resources for offering and using flexibility exist, with significant envisioned impact on the provision of system and grid services. However, the viability of large-scale implementation remains a challenge and is a long process.

3.2.2 Flexibility Register Module

Task 7.2 of the Northern demonstration cluster defined the functionalities of the Flexibility Register (FR), which is one of the important building blocks of the demonstration architecture. In a flexibility market setting, where the same flexible resources participate on multiple markets to offer different services, it is crucial to manage the information about the resources efficiently and enable relevant parties to have access to up-to-date information. This is the main function of the FR. It contains information about the resources, how they are pooled and which market participants have contracted them. The Northern demonstrator also specified that verification and settlement is a task of the FR. The FR is tightly integrated to the TSO-DSO Coordination platform and different market platforms, which enable an efficient flexibility market. The interaction of the FR with other components is depicted in the high-level architecture in Figure 3.1.

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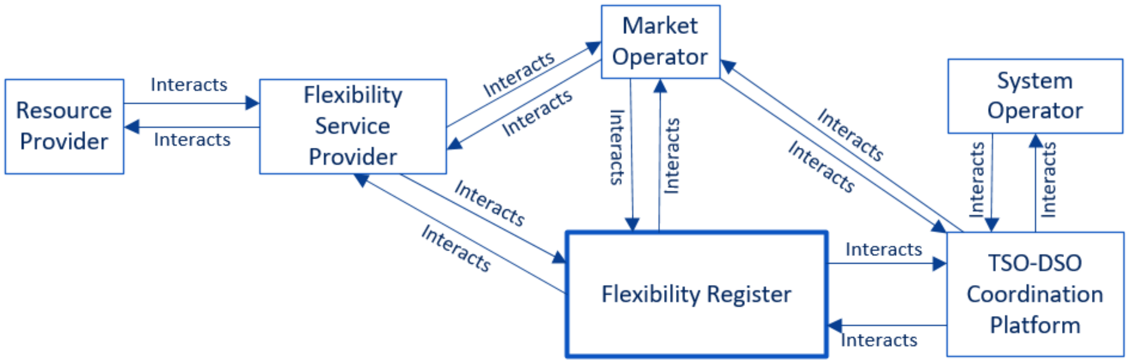

Figure 3.1: High-level architecture of the Flexibility Register.

The detailed definition of the Flexibility Register in the context of the OneNet Northern Demonstrator was described in the deliverable D7.2 *Flexibility register description and implementation* [1].

3.2.3 TSO-DSO coordination module

The TSO-DSO coordination module has two main tasks:

1) Qualification of flexibility resources from a grid capacity perspective;
2) optimising the clearing of the flexibility bids (i.e. generating the market clearing results) based on minimising total costs, reliably meeting the grid (TSOs and DSOs) need, avoiding causing further unintended issues in the grids, and enabling value-stacking of flexibility.

Grid impact assessment is a central activity of the grid qualification process. Grid qualification of a flexibility resource may take place in the prequalification, procurement, and activation phases. Qualification in the procurement phase is an integral part of the bid optimisation process. In the activation phase, grid qualification would not be feasible for near-real-time product due to time constraints. This is also not necessary in the case of capacity products. In the prequalification phase, two alternatives are possible. First, the concerned SO identifies the grid restrictions (constraints) by itself. The second alternative is that restrictions are calculated by the TSO-DSO coordination platform (T&D CP) based on input information like resource information, network topology and node limitations. The objective is to determine in which network node the activation of the resources would violate the node limitation.

For the bid optimisation process, an algorithm performs the bid optimisation for both capacity and energy products, and for the different time periods: long-term, short-term, and near real-time. Besides the flexibility bids submitted, also purchase offers and grid information from both TSO and DSO grids are necessary inputs for the algorithm that enables to perform bid optimisation and, thus, to generate the market clearing results. Optimising means choosing the optimal sets of bids (and portions thereof) to clear to meet the gird needs of the involved SOs (TSOs, DSOs, or multiple joint TSOs and DSOs) at the minimum possible cost while ensuring no

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network violations would be cause by the cleared flexibility. Thus, the optimization abides by the network limitations, the bid technical requirements (capacity limitation in case of fully divisible bids as well as other logical limitations captures using more complex bids, such as non-divisible bids, partially divisible bids, exclusive sets of bids, and multipart parent/children bids), and by the requirements indicated in the purchase offer (e.g. limits on the allowed impact on the system's balancing position, and total cost cap, if indicated, etc.). The optimization process, thus, meets the system needs (i) in the most economical way by capitalizing on synergies (value-stacking) across system needs (i.e. ability to contribute to multiple grid needs of potentially multiple SOs using one flexibility bid), and (ii) in a grid-safe way by ensuring that any combinations of bids purchased would not lead to any operational issues for any of the grids involved. As such, the optimization process concurrently performs bid qualification, grid qualification, and bid optimization within the market clearing step. If bids were not selected for congestion management purposes, they will be forwarded to relevant European balancing platform (e.g. MARI) after checking if such bids still comply with European balancing requirements and the requirements of the European platforms involved and if they would not cause internal congestions in local or national grids if they were to be cleared in the following balancing markets. The information about cleared bids as the result of optimisation will be sent to relevant MOs who interact directly with the FSPs. MOs are expected to request the FSPs to activate the resources exactly according to the optimisation results.

The detailed definition of the TSO-DSO Coordination Platform, including the bid optimisation algorithm in the context of the OneNet Northern Demonstrator was described in the deliverable 7.4 *TSO-DSO Coordination module description and implementation* [3] and in deliverable 7.3 *Report on Market Functionality* [2].

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4 Customer engagement

4.1 Survey results

4.1.1 Survey among Estonian customers

In first quarter of 2023 a dedicated online survey was organised among Estonian residential customers to find out their knowledge about their energy behaviour and the willingness to change, the layout of which is illustrated in Figure 4.1. Social media and local Saaremaa newspaper were used for disseminating information about the planned survey. In total, 98 responses were received. 43 persons have at least one home in Tallinn and 20 persons on Saaremaa island. Detached houses and flats are almost equally represented, many people having both options. Out of these, 94 persons said to be interested in their energy consumption and further 3 answered that additional increase of the energy costs would trigger their interest. Only one customer claimed not to care at all.

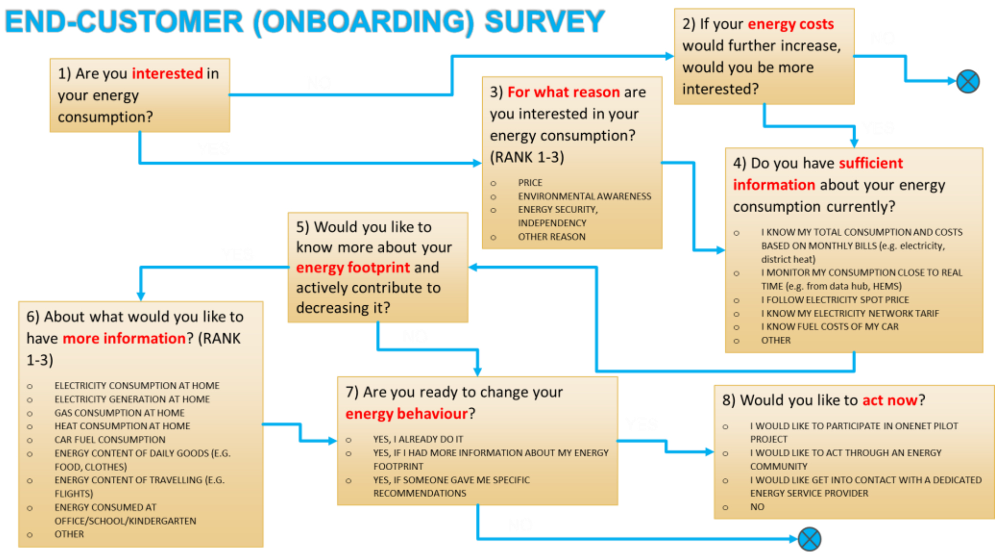

Figure 4.1: Estonian end-customers' survey

The majority of customers consider the price as most important factor determining their interest, but two thirds appreciate the importance of energy security and half of them environmental aspects also as listed in Table 4.1.

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Table 4.1: Factors triggering customers' interest about their energy consumption

	Energy price	Environmental awareness	Energy independence, security
Least important	2%	10%	5%
Medium importance	16%	42%	26%
Most important	82%	48%	69%

Figure 4.2 indicates the information sufficiency about the households' current energy consumption. More than 90% of the households are informed about their energy (e.g. electricity, district heat) consumption and costs through monthly bills from the utilities. About two thirds of the Estonian customers follow electricity spot price, know their electricity network tariff and know their transportation fuel costs. One third of the people uses tools (e.g. through data hub or home energy management system) to monitor the energy consumption close to real time. 40% of the households have information about their energy consumption at least from four different sources simultaneously. Only one person claimed to have no information at all.

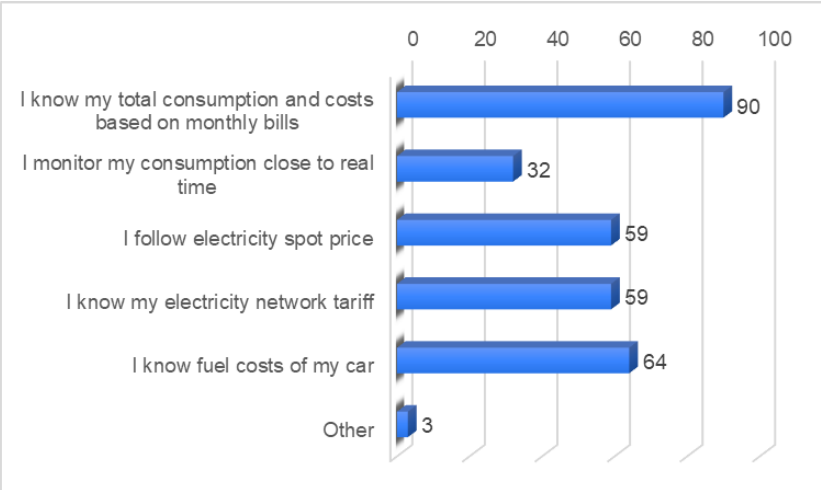

Figure 4.2: Number of customers with energy consumption information from different sources

According to the survey, 80 customers out of 98 would like to know more about their energy footprint and actively contribute to decreasing it. Though majority of households are well informed about their electricity consumption per Figure 4.2, still 60% of the respondents would prefer to learn more about their home electricity consumption. Quite surprisingly high number of customers are interested in the energy content of daily goods (e.g. food, clothes) - information about which is essentially not available at all today. Several other categories with equally high interest follow: heat consumption, energy content of travelling (e.g. flights), electricity generation at home, car fuel consumption, energy consumed at office/school/kindergarten.

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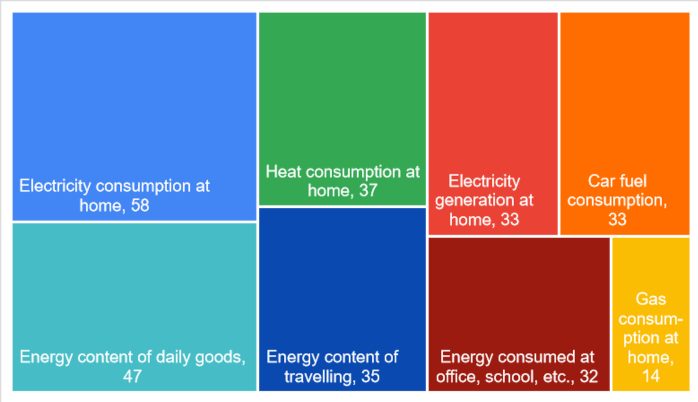

Figure 4.3: Number of customers with the need for more information

58% of households are already changing their energy behaviour (Figure 4.4). 19% would go for the change if receiving specific recommendations. Other 17% would need more information about their energy footprint in order to change. 33 respondents expressed their interest to participate in OneNet pilot project, while 14 would like to act through an energy community and 8 to contact a dedicated energy service provider.

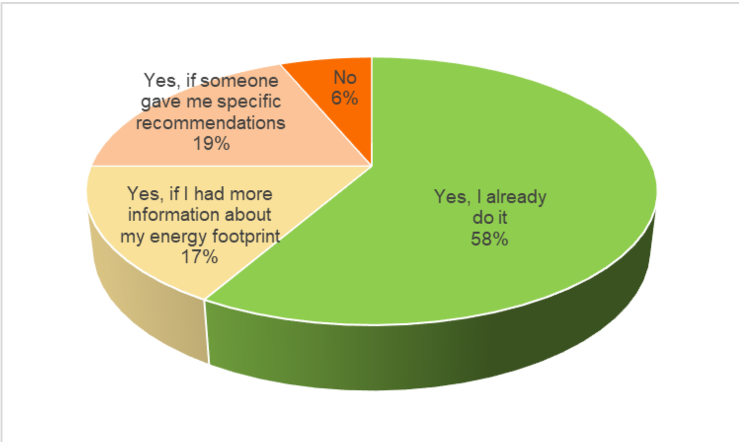

Figure 4.4: Percentage of customers willing to change their energy behaviour

4.1.2 Survey by Vattenfall among customers in five countries

Rising energy prices create problems for consumers in Europe. Therefore Vattenfall, as a large energy company in Northen Europe, wanted to gain an in-depth understanding of changes in consumption patterns regarding electricity and heating habits among European consumers in the long term.

They conducted a large survey 2023, in 5 European countries where Vattenfall have household consumers (Sweden, Finland, Germany, Netherlands and France). This was an online survey with 1000 participants per country aged 18 years and older (representative for the respective country's housing population regarding gender, age and region). The survey was done three times: January 2023, May 2023 and November 2023. The study was made by Statista GmbH.

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The market research reveals insights into consumer behavior and attitudes in the area of energy consumption. The OneNet project could not add specific questions to the study, however some of the questions and analysis could put some light on customer attitudes towards flexibility and steering and the willingness from end customers to participate in flex markets. All tables below show data from the last survey (Nov 2023).

#1 - Flex as income/cost saver*:* Saving money is the highest motivator for reducing energy consumption see Table 4.2. This is stated by ~90% of the participants in all the countries. But since cost is the driver, it could encourage the customer to participate in the flex market and benefit from flex income to get a lower energy bill.

Table 4.2: Aspects that motivate consumers to reduce energy consumption

Q6 - Top2-Overview (detailed results below)					
To what extent do the following aspects motivate you to reduce your energy consumption?					
All respondents	Wave 3				
	Sweden	Finland	Netherlands	Germany	France
Base n =	1,000	1,000	1,000	1,000	1,000
To save money	89%	93%	91%	92%	91%
To save natural resources	73%	77%	69%	76%	79%
To support my country being less dependent on energy supplies from other countries	70%	76%	59%	62%	67%
To reduce climate change	68%	71%	69%	71%	77%
To ensure that current energy supplies last for all people	67%	72%	66%	67%	71%
Statista Q					

#2 - Acceptance for steering: Many customers also think it's relevant to adapt their consumption (e.g. lowering the thermostat) to reduce their energy consumption, see Table 4.3. Over 80% of consumers in all countries say it's rather relevant or very relevant. This shows that there is an acceptance for steering of heating systems even if it might have some impact on comfort. Thereby it seems possible to form relevant flex offers for end customers, especially since heating is a large asset which would provide good value to the flex market.

Table 4.3: Consumer relevance to reduce energy consumption in everyday life

Q5					
And how relevant is for you to reduce your energy consumption in your everyday life (e.g., lowering the thermostat, using less lights etc.)?					
All respondents	Wave 3				
	Sweden	Finland	Netherlands	Germany	France
Base n =	1,000	1,000	1,000	1,000	1,000
4=Very relevant	32%	39%	37%	46%	56%
3=Rather relevant	48%	47%	47%	44%	39%
2=Rather not relevant	16%	13%	12%	7%	3%
1=Not relevant at all	4%	2%	4%	2%	2%
Top2: Very / rather relevant	**80%**	**86%**	**84%**	**91%**	**95%**
Bottom2: (Rather) not relevant (at all)	**20%**	**14%**	**16%**	**9%**	**5%**
Statista Q					

#3 - Low-cost technology needed for flex: The customers also see a number of challenges in energy saving measures, see Table 4.4. The largest one is the investment costs for energy saving measurements which over half of them see as a challenge. This is probably true since different smart home products are rather expensive and only give limited energy saving back. Therefore, flex products need to find cost efficient solutions for measurements and control to be able to attract customers.

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Table 4.4: *Main consumer challenges when implementing energy saving measures at home*

Q1 - Wave 2 (Question added in W2)					
What are the main challenges when implementing energy-saving measures in your home?					
All respondents *Multiple answers possible*	Wave 3				
	Sweden	Finland	Netherlands	Germany	France
Base n =	1,000	1,000	1,000	1,000	1,000
Investment costs	55%	57%	62%	52%	62%
Technical conditions	34%	36%	23%	30%	27%
Constructional conditions	23%	37%	25%	39%	29%
Political framework conditions	10%	8%	11%	19%	11%
None of the above*	20%	15%	22%	20%	14%
**exclusive option* Statista Q					

#4 - Increased flex possibilities in the future: Many customers are willing to make energy related investments, see Table 4.5. Many of the respondents are willing to invest in Smart Home. Respondents owning a house are willing to invest in PV, between 27% and 64% (the Netherlands already have a large PV base (59%) and over 70% have invested in or are willing to invest in renewable energies (e.g. heat pump).

Table 4.5: *Innovations regarding reduction of energy consumption that is of consumer interest*

Q9					
Which of the following innovations did you or would you invest in to reduce your energy consumption?					
All respondents **All respondents who are house owners*	Wave 3				
	Sweden	Finland	Netherlands	Germany	France
New technologies for efficient energy use (e.g., smart home)	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**
I already made investments	22%	11%	25%	23%	17%
I have not made investments yet, but I am willing to invest in the future	57%	56%	55%	50%	49%
I would never make investments in this area	21%	33%	21%	27%	34%
Solar panels*	**343**	**267**	**471**	**286**	**439**
I already made investments	17%	16%	59%	36%	13%
I have not made investments yet, but I am willing to invest in the future	59%	64%	27%	45%	46%
I would never make investments in this area	24%	21%	14%	19%	40%
Heating based on renewable energies (e.g., heat pumps)*	**343**	**267**	**471**	**286**	**439**
I already made investments	55%	58%	19%	19%	28%
I have not made investments yet, but I am willing to invest in the future	36%	38%	61%	52%	44%
I would never make investments in this area	9%	4%	20%	29%	27%
**exclusive option (only relevant for house owners)* Statista Q					

Summing up, the insights regarding customer flex potential show that customers have a large focus on energy costs and thereby also as a customer a willingness to act in different ways to achieve cost savings. Recruitment of flex (FSP) customers therefore looks promising if the flex offerings is cost efficient to sign up to and gives some value back. But customers don't value only money, many also care about climate and sustainability.

4.2 Engagement in demos

4.2.1 OneNet Open Call

The OneNet project organized an Open Call for third parties to participate in the project activities and to evaluate and refine the results and implementation. Through this instrument, one company was granted funding to participate in the Northern Demonstration in Finland. This company, Northeast Flow Oy, developed its systems to connect to the Northern Demonstration platform and offer its flexible resources. The company builds computing units for various purposes and utilize the produced heat to provide heating in the building. During

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the project they used these units to provide flexibility in the pilot by controlling the power usage of the computing units based on the signals from the demonstrated market. Through this activity, one of Northeast Flow's units in a real customer environment was used.

Northeast Flow interviewed the customer after the trials. The customer had had some concerns about the heating capability of the system when flexibility was provided. Nevertheless, the trials didn't have negative effects on the heating and the customer was positive about the service that Northeast Flow was offering them, which decreased the gas consumption for the heating of the customer premises.

4.2.2 Flexibility providers in the Finnish demonstration

The Finnish project partners engaged other stakeholders to acquire real flexible assets to participate in the demonstration. This engagement happened after the Open Call which meant that only in-kind participation was possible. Yet, three different parties joined the demonstration by offering their flexible resource.

One of these external parties was acquired through the activities of another H2020 project called iFLEX. iFLEX organized a joint pilot with OneNet in which the heating demand flexibility of the iFLEX pilot residential building was offered to the NOCL platform. The iFLEX building was a typical customer case representing shared district heating facility and energy metering with limited customer enrolment.

In addition, Fingrid launched a campaign through its communication channels to find interested partners. As a result, two companies, namely, Comsel Systems Oy and Synergi Solutions Oy joined the demonstration. Comsel Systems Oy offers smart control services to end-customers and industrial companies. In the demonstration, Comsel directly controlled a total of 80 EV chargers, 80 heating units and 5 PV systems all located and widely distributed across Finland. The participation of Comsel Systems' resources is described in detail in Chapter 5.2.1.

Synergi Solutions Oy, on the other hand, connects directly to EVs and heat pumps through the vendor interfaces to monitor and control them. Synergi's B2B application is shown in Figure 4.5.

Synergi Solutions Oy provided detailed metering data for 250 EVs. The data was used to further test the baseline calculation model implemented to the FR. Using DERs to provide flexibility services is still in its infancy, thus it is relevant to learn more about their characteristics and behaviour. In the Northern Demonstrator, two alternatives were presented for reference value against which the metering data of the flexible resources were compared to verify the activation. Firstly, the FSP can submit a schedule for the resources before the activation as a reference value. Alternatively, if the schedule is not received by the FR, the statistical High 5 of 10 method is used to calculate the baseline. The baseline calculation model is most suitable for assets that behave with the predictable profile. Electrical heating is one example of a flexible resource for which this kind of model is well suited, since its load follows often a repeating pattern between days affected mostly by outdoor temperature.

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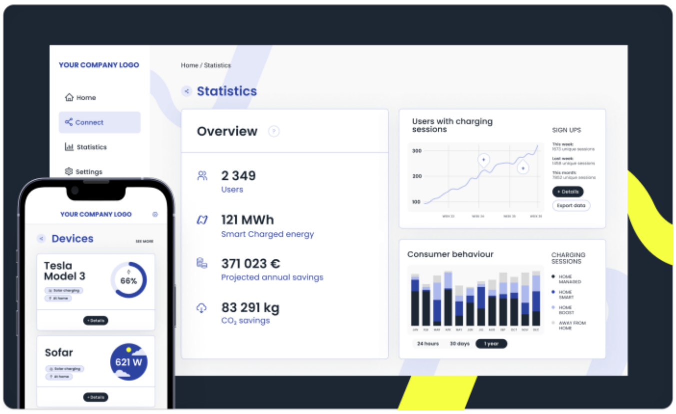

Figure 4.5: Synergi's B2B application.

In this case, the baseline calculation model was tested for EVs aggregated in groups of different sizes to find out the accuracy of the model with a real-world data set of EVs. Typically, the assumption is that the larger the aggregated pool the more accurate the estimation. With a larger group the deviations of single units are evened out by the behaviour of the others. the FSP is more suitable option. Table 4.6 presents the root mean square percentage error of the three pools.

Table 4.6: Results of a baseline calculation test for three groups of EVs.

Number of EVs	10	50	250
RMSE	122,5 %	65,6 %	58,3 %

Figure 4.6 shows the result of baseline calculations for three different aggregated pools of EVs by visualising the actual metering value and a calculated baseline value for the same time point.

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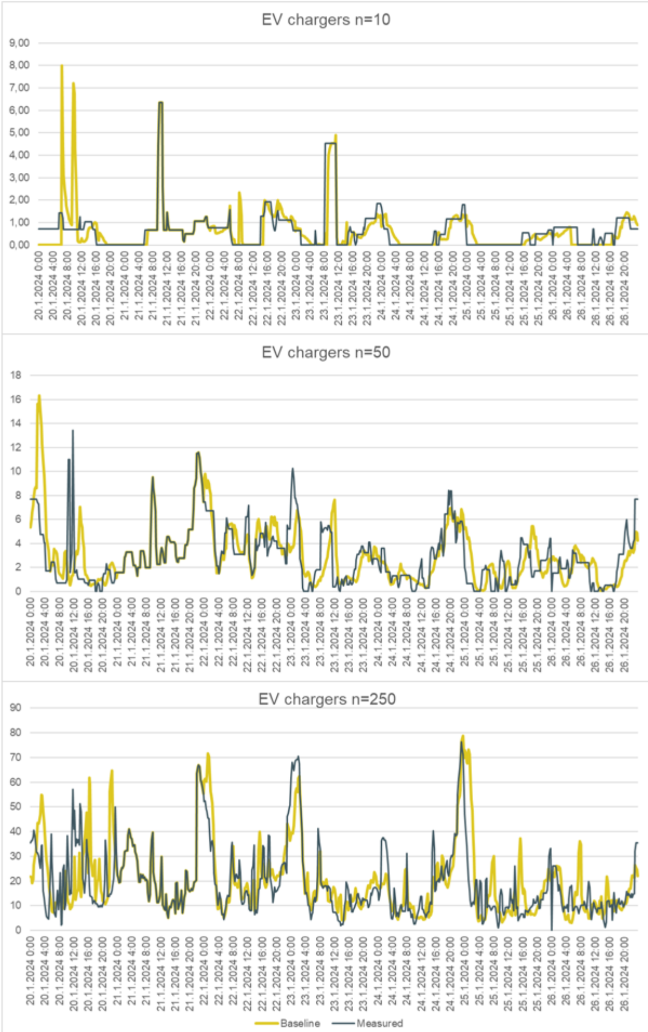

Figure 4.6: Calculated baseline for aggregated pools of 10, 50 and 250 electric vehicles.

4.2.3 Flexibility providers in the Estonian demonstration

In Estonian demonstration three parties were engaged in the role of flexibility service provider: Estonian companies R8 Energy and Futugrid, and French company Digital4Grid (D4G). While R8 relied on the flexibility coming from commercial building and Futugrid applied simulated water boilers, D4G engaged with real residential customers. Some of those customers are located in France and some across Estonia, however the flexible resources of these customers were attached to specific Estonian grid nodes for the purpose of demonstration.

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Figure 4.7: Examples of Estonian residential flexible resources – ground source heat pump, heat exchanger, air-water heat pump

The purpose of D4G has been to demonstrate a new generation multisided platform for the real-time orchestration of Residential Distributed Energy Resources (referred to as DERs) targeting residential prosumers equipped with several DER equipment behind their home utility meter.

While Digital4Grids original platform had originally been launched for the monitoring and control of 5 single phase residential homes located in France (as part of the INTERRFACE cascading funding), the objective of OneNet demonstration has been to expand the platform to 3-phase homes located in Estonia while testing the feasibility to use standardized APIs derived from IEC62325 European Style Market profiles through real-time data exchanges.

The new D4G platform has been designed on one side to enable consent-based management of real-time home energy data acting as a data and service provider to residential homeowners as well as on the other side to automate DER flexibility transactions leveraging new IoT-edge and cloud data exchanges integrating dedicated measurement devices and DER control units.

The demonstration has proved the possibility to automate flexibility transactions bottom up from prosumer setting their price sensitivity across DERs in their homes – typically defining higher price sensitivities for DER controls having more impact on their comfort or requiring manual transactions – into the self-nomination of DER baseline operating schedules near real-time, the automated calculation of associated DER flexibility every 15 minutes, as well as associated bidding and DER activation down to the real-time monitoring of deviations against baselines using submetering data collected from dedicated measurements associated to DERs.

4.2.4 Flexibility providers in the Lithuanian demonstration

In the Lithuanian demonstration, one partner was involved in the role of flexibility service provider: Kaunas University of Technology (KTU). KTU's resources include a solar power plant, heat pump, heat accumulator and controllable electric load, these resources are connected to the DSO's grid. Additionally, a battery energy storage

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system owned by Litgrid that is connected to the TSO’s grid was managed by KTU. These resources were treated and dispatched as a single Virtual Power Plant connected at different grid nodes as depicted in Figure 4.8.

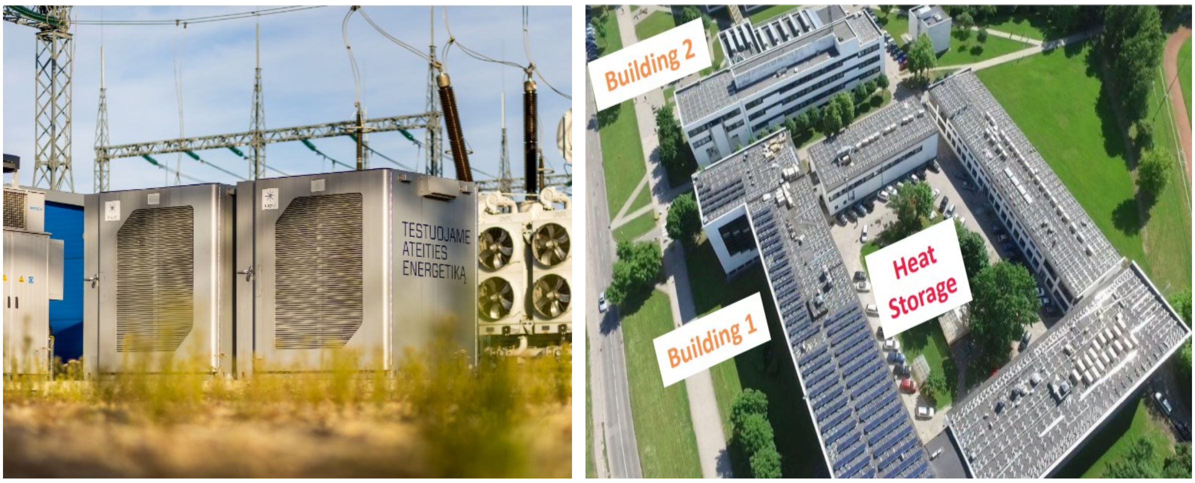

Figure 4.8: Example of Lithuania flexibility provider. Left side 1MWh Litgrid battery storage, right side KTU assets including solar PV, heat pump, residential loads.

The Virtual Power Plant spans across two buildings with different power generation and heat load profiles. Building 1 includes an underground heat energy storage, while Building 2 houses a Computer Centre demanding significant power for servers cooling. By constantly cooling the servers, a lot of wasted heat is produced. The Virtual Power Plant utilizes this heat by efficiently storing it by using a heat exchanger. This allows immediate or delayed use of generating hot water or providing heating to building 1. The system operates in two distinct modes depending on the temperature within the heat storage, these modes are simplified and correlate with heating and non-heating seasons. The flexibility can be provided during the heating season, during which the demonstration took place, further details can be found in Resources in Demonstration group 2.

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5 Northern Cluster demonstration

5.1 Regional demonstration setup

5.1.1 Common approach

The Northern cluster is creating technical software solution to implement flexibility process flow called NOCL Single Flexibility Platform, as shown in Figure 2.1. Solution contains both standard and proprietary technical components. Internal business logic, together with optimized bid selection algorithm is following proprietary business use cases that are worked out by demogroup partners. Integration to external systems of regional stakeholders is implemented via 'REST API's.

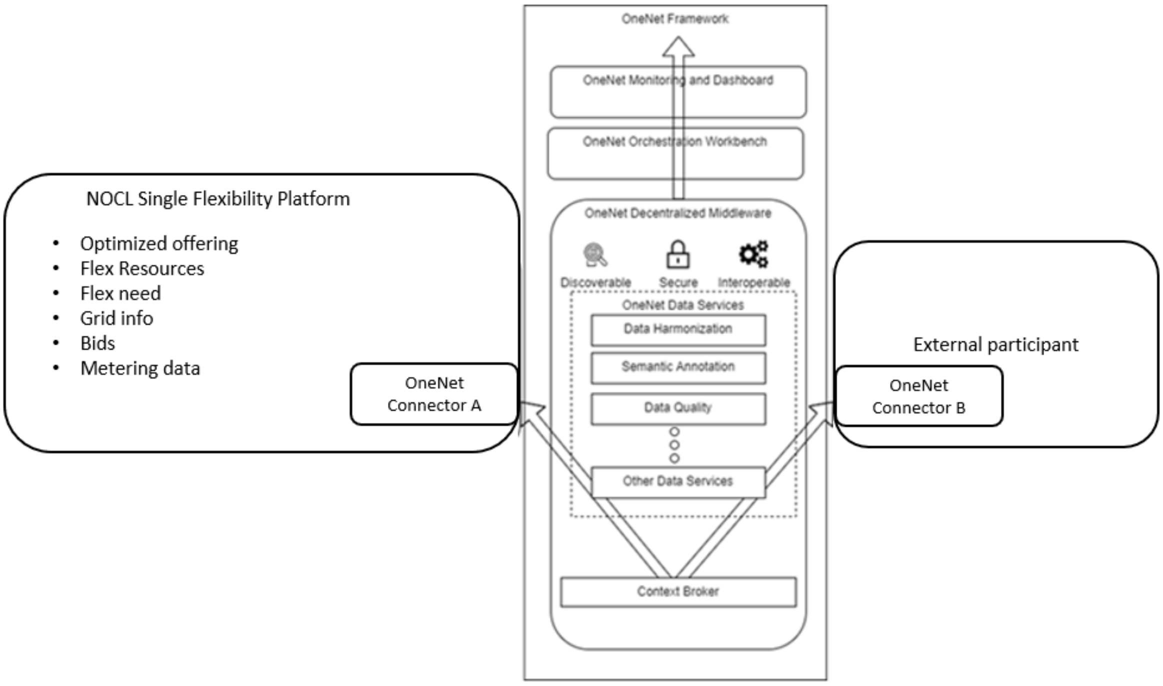

Figure 5.1: NOCL Connectivity with OneNet Framework

The logical Data Model format that is used in communication to regional stakeholders are either standard CIM based or proprietary [6], dependent on communicating stakeholders existing internal IT system. As an example, the market operator Nord Pool has its existing proprietary communication data model as changing it was not neither objective the scope of the project nor the objective of the Nord Pool itself. Similarly, transmission system operator 'Elering' has existing IT system supporting standard CIM communication. Based on this, the coordination platform software solution created during the project was able to utilize the existing system operator IT system. In a nutshell, the NOCL solution developed the capability to demonstrate flexibility use cases for communicating with platforms that are implementing not only standardized but also proprietary

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IT systems. However, preference would be to use standardized CIM format whenever it is possible. Both XML and JSON data exchange formats are supported in the implemented communications.

The reasons for several proprietary solutions are derived by needs of demo partners' existing systems. Each of the systems needs to be interfaced separately which diminishes common interoperability of platform. To resolve this barrier the existing systems should implement some common data structure standard.

By applying and implementing both standardized and some proprietary solutions, the NOCL has acquired necessary capability in cross-platform communications in the flexibility value-chain. Considering this, NOCL has achieved a fair level of interoperability in the developed coordination platform software. Further proprietary systems can be interfaced with a reasonable effort.

The platform is opened also for external Pan European Market Operators through OneNet Middleware implementing IDSA FIWARE communication stack as depicted in Figure 5.1. OneNet Framework and Middleware provide rich set of features for data transfer, security and quality. To communicate through OneNet Framework the OneNet Connector instances must be deployed and registered in both ends of communication chain. Once external partner connector is configured the NOCL SFP assets as Flexibility resources, Bids, Flexibility Needs etc. could be accessible through standardized CIM data formats.

NOCL has demonstrated MO role activities through OneNet Framework. NOCL Single Flexibility Platform has interfaced with OneNet Connector provided by OneNet Framework to receive and send common CIM format messages as listed in Table 5.1.

Table 5.1: Interfacing CIM with OneNet Connector in NOCL demo

COMPONENT	SERVICE CODE	API DATA MODEL	DATA CONTENT TYPE
OneNet Middleware	MO-T2-CLEARED-BID	um:iec62325.351:tc57wg16:451-x:flexbid:1:0	application/xml
OneNet Middleware	MO-T1-BID	um:iec62325.351:tc57wg16:451-x:flexbid:1:0	application/xml

5.1.2 Standardized products

One of the main goals of the Northern Cluster was to propose and test a set of new flexibility products – however, keeping the number of products as low as possible and by relying on existing products like mFRR or intraday trading product. This means that the same product can be used by both TSO and DSO and for different needs (balancing, congestion management) and thereby FSPs' access to market should be simplified and the liquidity in the market should increase. Table 5.2 includes the comparison of attribute values of ST-P-E (short-term active energy), NRT-P-E (near real-time active energy), LT-P-C/E (long-term active combined capacity and energy), ST-P-C (short-term active capacity and LT-P-C (long-term active capacity) products. The attributes are defined in deliverable 7.5 *Report on DSO & TSO value generation drivers* [4].

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Table 5.2: Comparison of attributes of Northern Cluster flexibility products

Attribute	NRT-P-E value	ST-P-E value	ST-P-C and LT-P-C values	LT-P-C/E value
Product type	Energy	Energy	Capacity	Capacity /energy
Link to energy product	n/a	n/a	NRT-P-E / ST-P-E / n/a	n/a
Quantity unit	MW	MW	MW	MW
Activation type	Scheduled activation / Direct activation	n/a	n/a	n/a
Preparation period	≤7 min	Defined in tender	≤7 min	360 min
Ramping period	≤12 min	Defined in tender	≤12 min	n/a
Full activation time	≤12.5 min	Defined in tender	≤12.5 min	60-360 min
Delivery period	15 min	15-60 min	15 min	60 min
Minimal duration of delivery period	≤5 min	Defined in tender	≤5 min	n/a
Deactivation period	≤10 min	Defined in tender	≤10 min	n/a
Mode of activation	Manual	Manual	Manual	Manual
Minimum quantity	0.01	0.01	0.01	0.001
Quantity step	0.01	0.01 MW	0.01	0.001
Symmetry	Asymmetric	Asymmetric	Symmetric / Asymmetric	Symmetric / Asymmetric
Pricing method	Pay-as-bid	Pay as bid	Pay-as-bid or marginal	Pay as bid
Price unit	EUR	EUR	EUR	EUR
Price resolution	0.01	0.01	0.01	0.01 EUR/unit
Validity	15 min	When the intraday market is open	15 min	n/a
Gate closure time	25 minutes	Before NRT products	Defined in tender	Defined in tender

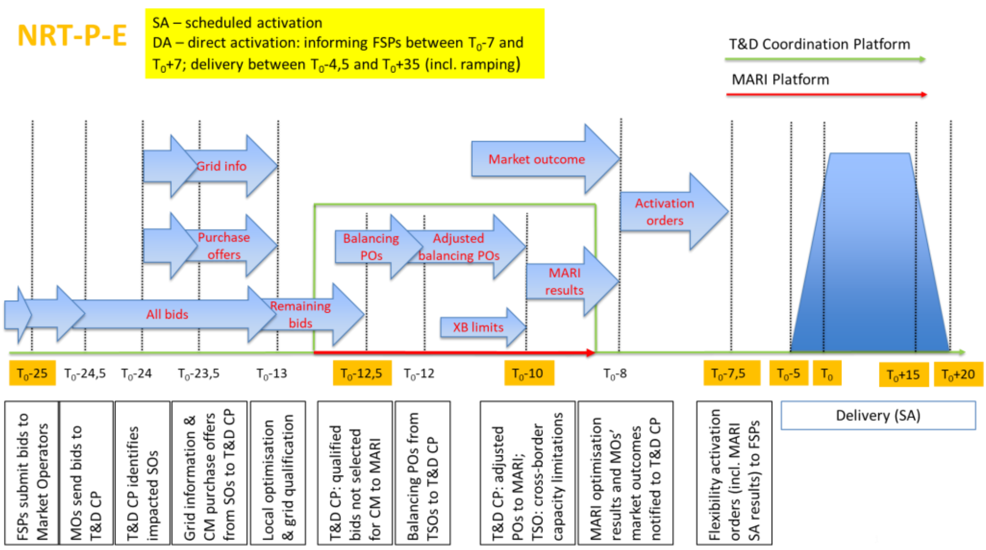

Figure 5.2: Timeline of NRT-P-E product

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Figure 5.2Figure 5.3, Figure 5.4Figure 5.5Figure 5.6 illustrate the flexibility products elaborated and demonstrated in NOCL.

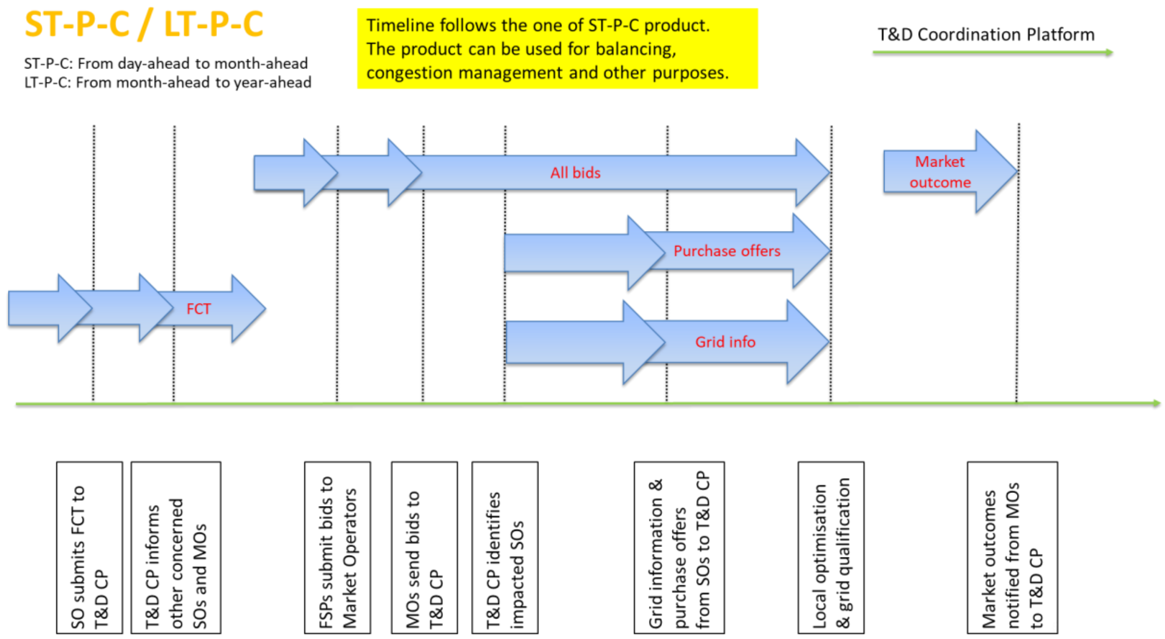

Figure 5.3: Timeline of ST-P-C and LT-P-C products

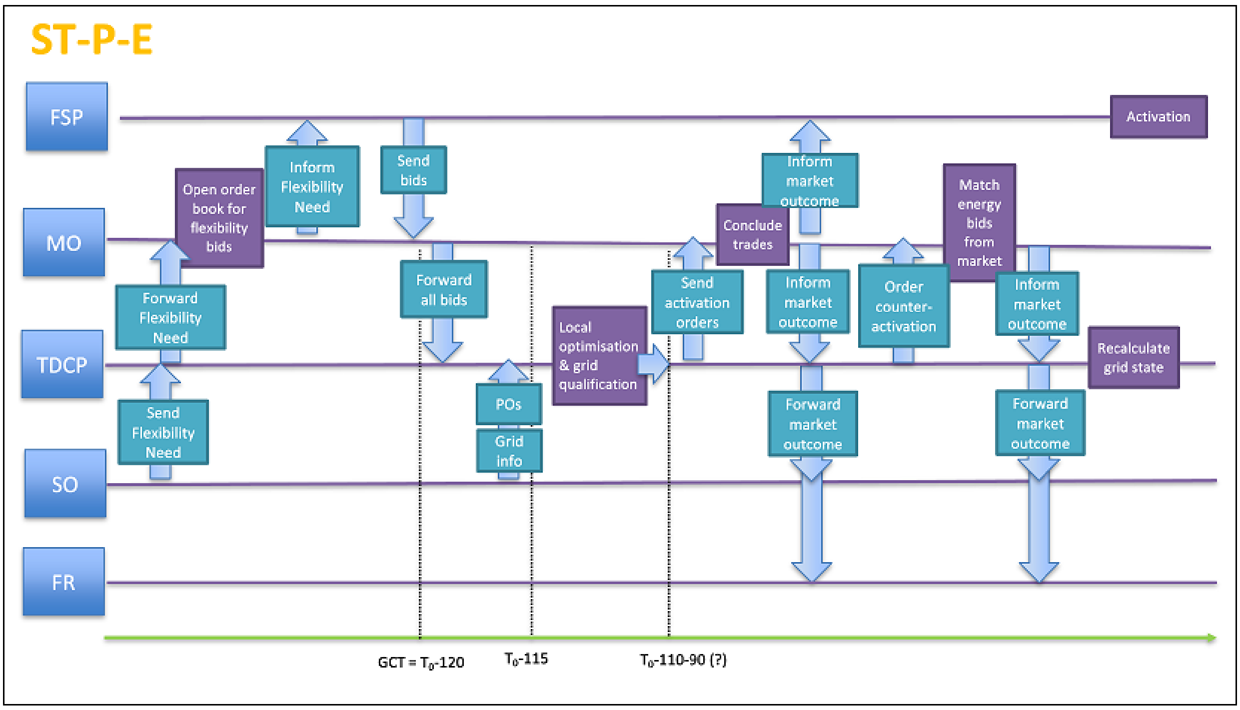

Figure 5.4: Timeline of ST-P-E product

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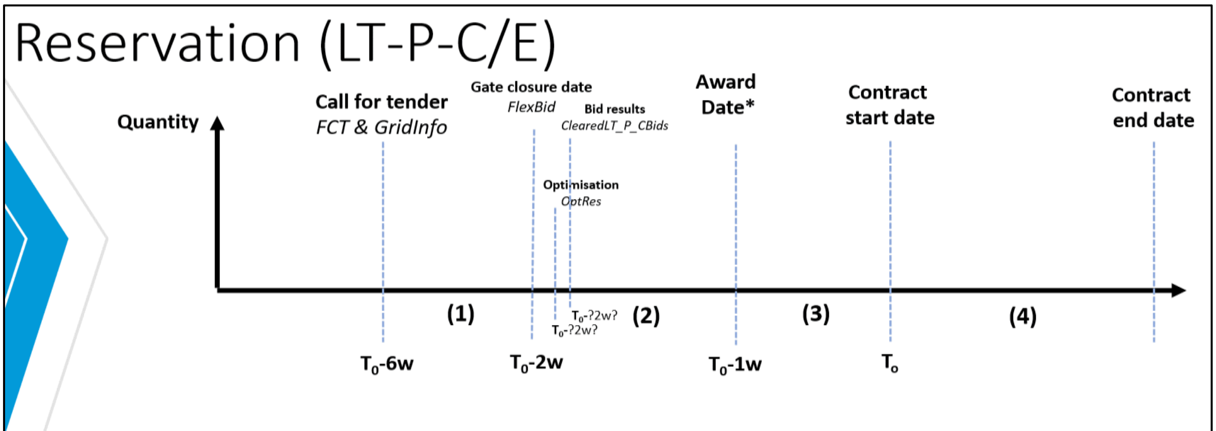
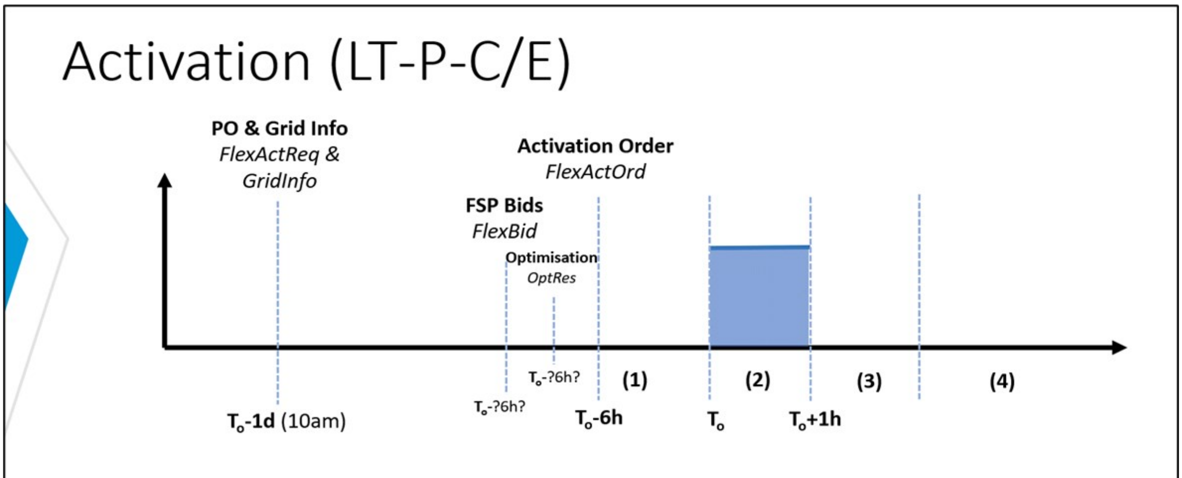


Step	Definition	Value	Comments on value
(1)	Bid submission	4 weeks	
(2)	Award time*	1 week	Time for SO to review results and award FSPs
(3)	Contract signing*	1 week	Signed contract by FSP (probably automated in the future)
(4)	Contract duration	Defined in tender	1 week to 6 months

*can be removed from demo if necessary

Figure 5.5: Timeline of LT-P-C/E product reservation



Step	Definition	Value	Comments
(1)	Preparation period	6h	Includes ramping time
(2)	Delivery period	1h	
(3)	Deactivation period	0h	No requirement to return to the previous setpoint
(4)	Recovery period	Defined in tender	

Figure 5.6: Timeline of LT-P-C/E product activation

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5.1.3 Marketplaces

5.1.3.1 Nord Pool Intraday

Nord Pool is Europe's leading power market and offers trading, clearing, settlement and associated services in both day-ahead and intraday markets across 16 European countries. We have been pioneering power markets for over 30 years and will continue doing so as the energy system is transforming into a decarbonized one. Nord Pool provides liquid, efficient and secure day-ahead and intraday markets and we are committed to simple, straight-through trading, expanding across all timeframes, for all our customers regardless of their size or where they trade from. Our primary product is a transparent and reliable power price produced within our markets every hour, every day.

What is the Intraday market

This is a continuous market, with trading usually taking place every day around the clock until one hour before delivery, and in some cases right up until the delivery period starts. Prices are set based on a first-come, first-served principle, where best prices come first – highest buy price and lowest sell price.

The intraday market works together with the day-ahead market to help secure the necessary balance between supply and demand, as you can trade closer to the physical delivery within the intraday markets.

Being balanced on the network closer to delivery time is beneficial for market participants and for power systems alike by, among other reasons, reducing the need for reserves and associated costs. In addition, the intraday market is an essential tool that allows market participants to take unexpected changes in consumption and outages into account.

Access to market

To gain access to Nord Pool's Intraday market, market participants need to be a member at Nord Pool. Trading usually takes place through a dedicated User Interface (UI) or an Application Programmable Interface (API). Once the membership and user access to the trading system has been established, traders can view market information either through the trading UI or API and are able to place orders to the market.

Trading on the Intraday market

Intraday market trading takes place by submitting orders to the market for specific contracts that each contain a dedicated delivery period. All orders must contain a quantity the trader is willing to sell or buy and a price.

Trading of flexibility through Nord Pool's Intraday market

In the OneNet project, Nord Pool enhanced its Intraday market trading platform to facilitate also the trading of flexibility. This was achieved by including additional order attribute to the order placements process, where

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traders would include a flexibility asset identification (flexibility asset ID) to their Intraday market bids to highlight the association of a specific bid with a flexibility asset. Requirement for obtaining a flexibility asset identification is a successful preregistration to the flexibility registers with the purpose of offering the flexibility asset(s) as 'short-term active energy' (ST-P-E) flexibility.

In practice, placing a sell order associated with a flexibility asset ID to Nord Pool's Intraday market signals the willingness to offer up regulation in specific location of the flexibility asset. This is achieved either by increasing output towards the grid by injecting more electricity into it (e.g. by discharging an energy storage or increasing production) or by reducing outtake of electricity in that specific location e.g. by consuming less electricity.

Down regulations would then be offered to the market by placing a buy order to the market in similar fashion. Outcome would in this case be reduced output to the grid or increase outtake.

The actual order placement in the solution developed in the OneNet project takes place through Nord Pool's Intraday market trading API by wither utilizing a third-party trading software or a trading algorithm solution. using the trading API allows full automatization of the trading process, reducing need for manual interaction and allowing a fully automatized flexibility asset optimization process.

All flexibility asset ID containing order on Nord Pool's Intraday market were in the northern demonstration forwarded also to the join coordination platform of the transmission and distribution system operators. Once the SOs had selected the flexibility orders they would like to activate and request for activation were sent to Nord Pool. After receiving the request for activation, Nord Pool checks if the associated flexibility order still remained on the market as the order could have already been traded on the Intraday market or have been cancelled. If the order were still available for trading, the order would be matched against the activation request from the SOs and cancelled from the Intraday market. As a result a trade notification is sent to the flexibility service provider and the SOs to signal that an agreement of flexibility asset activation was made between the parties (the SO and the FSP).

Trade result notification and activation

As the trading of flexibility is to take place relatively close to real time, all trade results are considered also to be direct requests for activation for the specific delivery period of each traded contract and the underlying flexibility asset.

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5.1.3.2 Piclo

What is Piclo?

Piclo is the leading end-to-end marketplace for local flexibility. Established as the industry's leading marketplace for local flexibility in six countries, Piclo Flex is the only commercially proven, end-to-end solution, for flex buyers (system operators) worldwide.

Piclo Flex is the marketplace that supports SOs in the process of procuring and operating flexibility. The platform is composed of a series of functional modules which SOs can subscribe to, based on flexibility needs and the required degree of process automation. FSPs can create an account and participate in the competitions created by the SOs, who advertise their flexibility needs and access the ecosystem of FSPs to build capacity rapidly.

Piclo integration in OneNet

A Piclo Flex account was created for FSP, so that all flexibility assets can be registered. The interested parties could complete a virtual registration process through Piclo Flex platform using Asset Upload Excel template. Since some of terminology is different from OneNet business object ResInfo, the mapping of attributes is provided in Table 5.3.

Piclo Flex introduces asset topologies and asset sub-categories. All Demand Side Response assets fell into Commercial or Industrial sub-category, while Renewable category assets are either biomass combined heat & power (CHP) plants or biogas CHP plants. The UPWARD flexibility of CHP plants arises from the range of operation between cogeneration mode (maximum heat generation) and full condensing mode (no useful heat generation at all but maximum electricity generation). As normal CHP operation is at full cogeneration mode, it gives the asset owner flexibility to ramp up power generation until it reached full condensing mode.

A limitation with the asset qualification is linked to the current set up on the Piclo Flex end, which requires to pre-define the support direction (UPWARD or DOWNWARD). Meanwhile, a submission to T&D CP can accept bids in both directions and determine which of them are compliant with the Flexibility Call for Tender (FCT) requirements and can help resolve the expected congestion. In DEMO scenarios, only assets with UPWARD regulation capability can be submitted and will qualify to the competition, and their UPWARD bids will be accepted if successful following the optimization results.

Finally, operational limits were set for each flexibility asset. For example, Sadales Tikls intends to use LT-P-C/E as a day-ahead product informing the selected FSPs about the planned activation at 11am on the current day based on the most recent weather and load forecasts. Letting all FSPs know about SO's plans for LT-P-C/E activation at 11 am, would give enough time for FSPs, retailers or the asset owners to adjust their day-ahead energy bids in Nord Pool (if needed).

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Table 5.3: Attribute mapping between Piclo Flex and ResInfo business object.

Piclo Flex	*ResInfo* Business Object
Asset Ref (anonymized EIC)	Main metering point ID (anonymized EIC)
Asset Name	n/a
Asset Status	n/a
Asset Category • Demand Side Response • Energy Efficiency • Interconnector • Low Carbon • Renewable • Storage • Thermal	Resource Type • Load • Generation • Storage
Asset Type (subcategory) *Demand Side Response* • Commercial • Industrial *Renewable* • Biogas CHP • Biomass CHP	n/a
Voltage Level • 0,4; 6; 10; 20	n/a
Active Generation Turn-up details (MW)	Flexibility Active Power (MW) (Flex direction specified in the bid)
Active Generation Turn-down details (MW)	Flexible active power (MW) (Flex direction specified in the bid)
Active Demand Turn-up details (MW)	Flexible active power (MW) (Flex direction specified in the bid)
Active Demand Turn-down details (MW)	Flexible active power MW) (Flex direction specified in the bid)
Response time (Excel time format)	Full Activation time (minutes)
Maximum run time (Excel time format)	Maximum duration of delivery period (minutes)
Minimum run time (Excel time format)	Minimum duration of delivery period (minutes)
Recovery time (Excel time format)	Deactivation period (minutes)
Location Details (GeoJSON file)	Localization Factor (EIC)

After the grid topology is set up and FSP data has been provided, the SO submits a Flexibility Call for Tender on the marketplace – for this either Piclo Flex's UI or OneNet T&D Coordination Module, Call for Tender API method can be used. To create a new competition in the Piclo Flex web portal, it is required to use Competition Template (CSV file) with pre-defined FCT attributes. However, there are also additional attributes that were not specified for the LT-P-C/E product but can be provided to FSPs as additional information. For example, Area

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Buffer requires to set the furthest distance outside the competition area that can make a flexibility asset eligible for participation a flexibility tender.

Piclo Flex Competition Template consists of three sections with relevant attributes. As before, it is important to align Piclo Flex attributes with LT-P-C/E attributes. The details of all attributes and mapping are given in Table 5.4. A single Competition Template could be used to set up competitions for all grids – one line per competition.

It must be noted that the flexibility requirement logic in Piclo Flex slightly differs from OneNet product attributes. Expected Number of Hours of Activation for LT-P-C/E product is the total number of hours of all dispatch events summed up. In Piclo Flex, this is defined separately as Estimated Duration of Dispatch Event (average) and Estimated Number of Dispatch Events.

FCT and Piclo Flex also expect that the inputs will contain information on the maximum bidding price for either reservation or activation.

Table 5.4: Attribute mapping between Piclo Flex Competition Template and FCT business object

Piclo Flex	*FCT* Business Object
1. Competition	
Competition Reference (shown on web portal)	Document ID
Competition Name (shown on web portal)	n/a
Area Buffer • set to 250m	n/a
Qualification Open Qualification Close • for DEMO, past dates were selected as all expected flexibility assets were already registered in the previous step.	n/a
Minimum Voltage Connection • 0.4kV	n/a
Maximum Voltage Connection • 20kV	n/a
Power Type • Active Power	n/a
Need Type • Reinforcement Deferral (selected as the closest option to the meaning of LT-P-C/E product).	Product name • LT-P-C/E
Need Direction (Deficit/Excess) • Always Deficit for Sadales Tikls DEMO	Direction (UP/DOWN) • Always UP for Sadales Tikls DEMO
Maximum Budget	Total Cost Cap
Competition Open	Opening Date
Competition Close	Closing Date
Competition Type • Availability & Utilization	n/a
Price is Fixed	n/a (fixed as pay-as-clear by default)

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• No	
2. Competition Boundaries	
Area Refs (requires adding the ID of the congested area, which has to be uploaded to Piclo Flex in advance).	Localization factor
3. Service Windows	
Service Period Start	Start of service date and time
Service Period End	End of service date and time
Window Name	n/a
Window Start Time • 07:00 Window End Time • 23:00 This was an additional attribute that was useful for FSPs. It was known that congestion was never forecast between 23:00-07:00. Therefore, this is additional information that can be provided to FSPs.	n/a
Service Days • Monday to Friday Similarly, Piclo Flex also allowed to specify on which days the service may be activated. Sadales Tikls forecast shown that only weekdays are at the risk of congestion.	n/a
Public Holidays Handling • Set to NO since UK holidays are in the database	n/a
Maximum Capacity Required • As per Sadales Tikls forecast	
Minimum Aggregate Asset Size • 0.01MW	
Minimum Runtime • Set to 1h as per smart metering reading interval	Minimum delivery period
Required Response Time • 20 hours (between activation announcement on D-1 and first possible activation at 07:00 on D-0.)	
Dispatch Duration • 3 hours Estimated Duration of Dispatch Event • 5-41 depending on the grid Here is a discrepancy between Piclo Flex inputs and FCT parameters. In order to set up a competition in Piclo Flex, it was needed to calculate the average duration of each event dividing the Expected Number of Hours of Activation by the Estimated Duration of Dispatch Events.	Expected Number of Hours of Activation (as a product of the number of dispatch events and the duration of each dispatch event).
n/a	Maximum consecutive delivery hours • 6 hours (as per long-term forecasts)
n/a (Piclo Flex accepts only Fully Indivisible bids. Therefore, all assets are considered as Fully Indivisible.)	Bid Types • Fully Divisible • Fully Indivisible • Partially Divisible

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After providing the values in Excel Competition Template, the Excel file shall be uploaded on Piclo Flex platform. SO will receive a notification after the file is uploaded on Piclo Flex (Figure 5.7) if it contains an error. For each error line, an explanation is given. The correction is done on the same Excel file offline. In the example below (Figure 5.7), wrong Competition Open and Competition Close dates were entered.

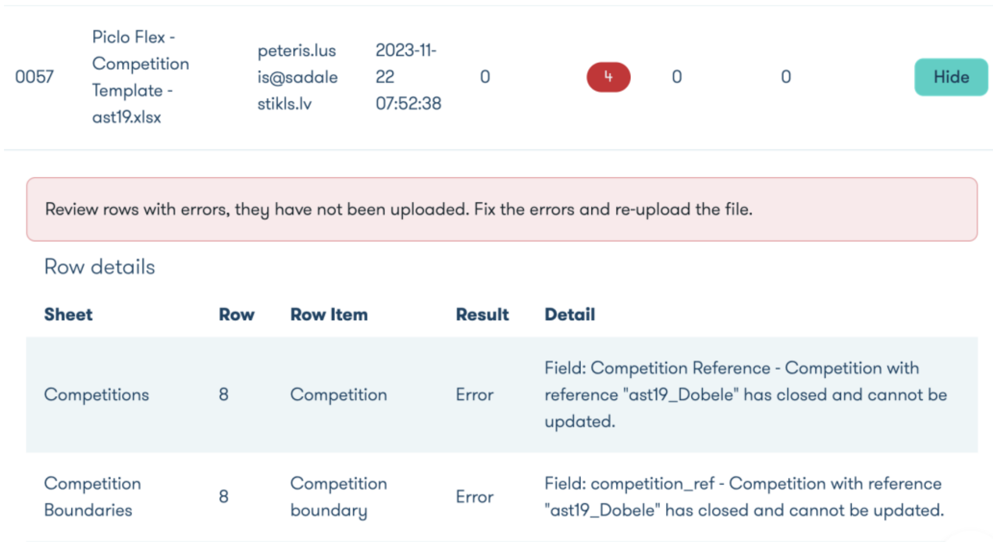

Figure 5.7: Example of wrong entry data for Flexibility Call for Tender

Figure 5.8: FSP's bidding strategy for Roja A/st.40

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FSPs submit bids within the defined procurement window (including long and short-term markets). All FSP bids are considered fully indivisible, but FSP can create a split bid, specifying the marginal price of each asset. At the same time, FSP must manually ensure that the total capacity of all split bids do not exceed the FCT requirement. As an example, all four assets in Figure 5.8 were arranged in merit order according to Activation Price as Reservation Price is set equal. If Reservation Price differed, this task would become more challenging. The Maximum Runtime is six hours since all assets are of category Industrial or Renewable.

After bid submission, the FSP must wait for the outcome.

While the Piclo Flex platform gives SOs the ability to clear bids directly in the platform, either by manual selection or a price-based algorithm, bids can also be forwarded to an external clearing tool such as the Cybernetica Coordination Platform. For the OneNet project, bids are forwarded to the Coordination Platform via API, cleared, and then the bid results are returned automatically via API. The outcomes of the bids are visible on the Piclo platform and FSPs are notified of the outcome.

Piclo Flex traditionally supported long-term flexibility products and was therefore a good fit to demonstrate the LT-P-C/E product in the demo. The platform allows for both energy and capacity portions to be included in a bid over a season or multiple years. Contracted bids then be triggered and notified later through Piclo Flex when dispatch is required.

5.1.4 Summary of the architecture

The uptake of flexibility markets requires several new functionalities that don't yet exist in the current market paradigm. New processes and IT systems are needed for the facilitation of these functionalities. The Northern Demonstrator of the OneNet project took an approach to develop an open and modular architecture which aims at facilitating an efficient and transparent market framework for flexibility markets as illustrated in Figure 5.9.

The basis of architecture came from the assignment of roles and responsibilities for the new functionalities which are built to satisfy selected Business and System Use Cases. Different roles include both regulated and competitive roles. In the architecture, these roles have their responsibilities, and their seamless cooperation ensures the efficiency of the framework. The OneNet platform is designed to work seamlessly with other components and system roles in the Northern demonstrator. It consists of two main components – flexibility register (FR) and TSO-DSO coordination platform (T&D-CP) which have interfaces for market stakeholders such as market operators and system operators, data administrators and OneNet middleware ecosystem, while enabling the interconnection with other modules (e.g. the optimization module as a market clearing engine).

The optimization module is interconnected within the T&D CP coordination module, from which it receives the inputs required and to which it posts back the generated market results. This interface is managed through an API, connecting between the platform hosted by Cybernetica and the optimization module hosted by VITO, as highlighted in Figure 5.10.

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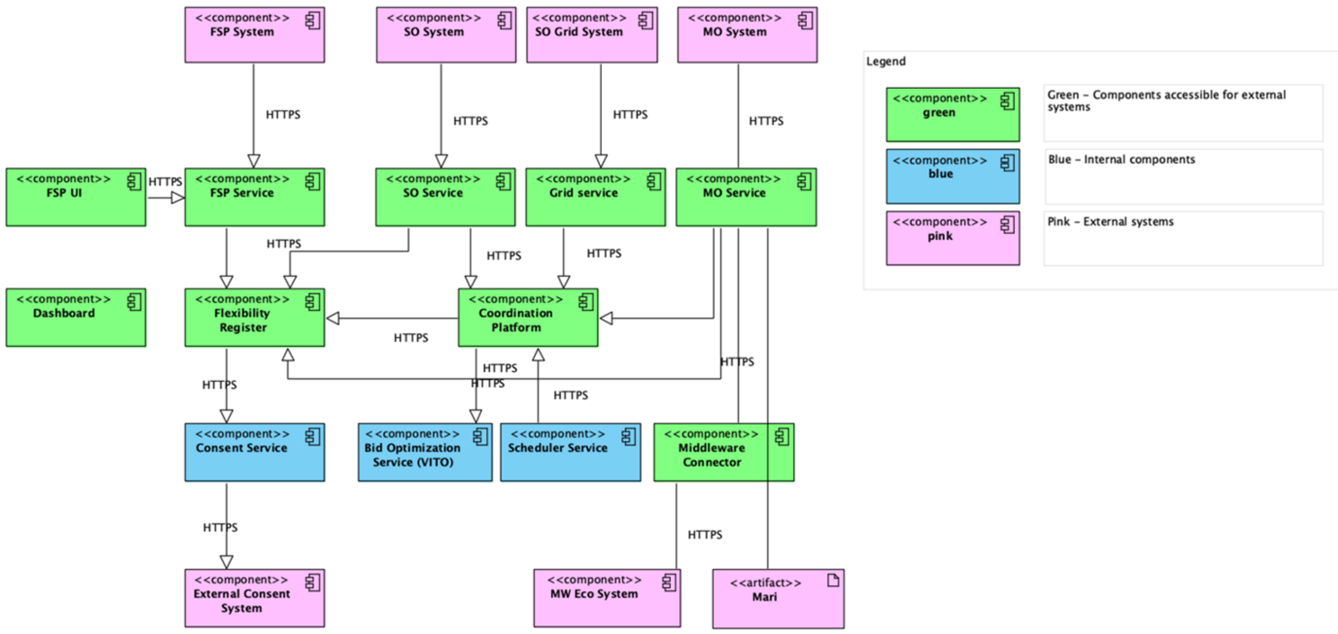

Figure 5.9: High level architecture of the OneNet platform in the Northern demonstrator

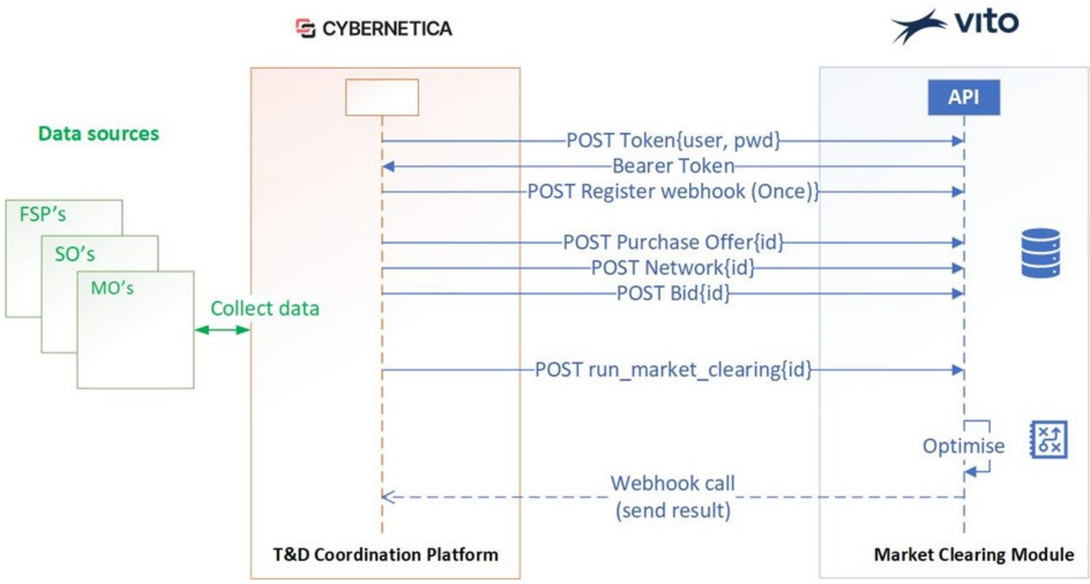

Figure 5.10: API Integration between the Market Clearing (Optimization) Module and the T&D-CP

5.1.5 Data models

The following data dictionary / business object definitions have been considered according to the CIM IEC62325 European Style Market Profile which has been deployed down to API used for Flexibility Service Provider interfaces.

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ResourceQualification_TimeSeries	mRID	EIC code of the flexibility resource
RegisteredResource	description	Flexibility resource description
	Name	ResourceName
ResourceCapacity	defaultCapacity	Capacity Value
	CapacityType	Nominal Power or Nominal Capacity
Process	process.processType	Type of the document
CoordinateSyste	mRID	The type of coordination system (GPS, etc.)
Domain	AreaID	Resource Area
MktPSRType	psrType:Type_String	A05: Load A04: Generation B25: storage
Location	Name	Street Address and Country
PositionPoint	xPosition	Coordinate System
	xPosition	Coordinate System
	xPosition	Coordinate System
Constraint Duration	Duration	Maximum Duration
	Duration	Recovery Time
TimePeriod	Time	time
	Time	Temporal Availability: Upregulation
	Time	Temporal Availability: Downregulation

Owner_MarketParticipant	Name	Name of the resource owner
	streetAddress	Postal Address of the resource owner
	phone1	Telephone Number of the resource owner
	electronicAddress	email address of the resource owner
	mRID	EIC Code
MarketEvaluationPoint	mRID	Connection Point Identifier of the System Operator
	connectionCategory	Metering Structure

Figure 5.11: CIM based data exchange for DER flexibility

The following key assumptions have been made for our demonstration configuration:

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- Each flexibility resource enrolled in a DER Flexibility program has a dedicated EIC code (same approach as for larger grid scale flexibilities). This EIC code has been defined arbitrarily for the purpose of the demo.
- Flexibility resource descriptions are defined per type of residential DER (i.e. water heater, heat pump, EV chargers etc.). Associated names define associated DER manufacturers (for the purpose of standardising flexibility templates per manufacturer).
- Default resource capacities are defined by DER types. The D4G platform includes a library of DER types with associated flexibility capacity per type of DER.
- The default coordinate system used is GPS.
- The following Area ID have been considered for the purpose of the demonstration: DSO Grid Node A corresponding to Roinville DER Group and TSO Bidding Zone Area A corresponding to Estonian DER Groups. We have assumed Area IDs are not unique per resource to properly account for separate TSO and DSO-E supporting needs.
- MktPSRtype is A05 Load for home submetered flexible DERs (including EV smart charging) and A06 for home PV.
- Location corresponds to the DER owner market participant home address and Position Point are the associated GPS coordinates. We have assumed Prosumers are owners of their home energy data and have provided their consent using D4G platform to manage their home energy data (which has been a condition for them to access the platform). We have also assumed for the purpose of the demonstration that D4G has obtained consent to share Prosumer private data with TSO, DSO and market operators for the purpose of the auto trading test.
- Constraint durations have been defined per residential DER type.
- Time Period: the following assumptions have been made for the ex-ante/ex-post flexibility event performance monitoring (implicitly assuming each flexible DER is considered as a Significant Grid User as soon they auto trade their flexibility into the market).

  a/ 5s data granularity for the Active Power monitoring of flexible resources engaged in aFFR programs

  b/ 1min data granularity for the Active Power monitoring of flexible resources engaged in mFRR and Congestion Management programs.

  c/ 15min data granularity for Energy imbalance measurements.

- The market evaluation point corresponds to the DER submetering/accounting point (and so expanding beyond the metering point).

This has resulted in using the following market exchange messages particularly:

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- A/ For Flexibility Bidding

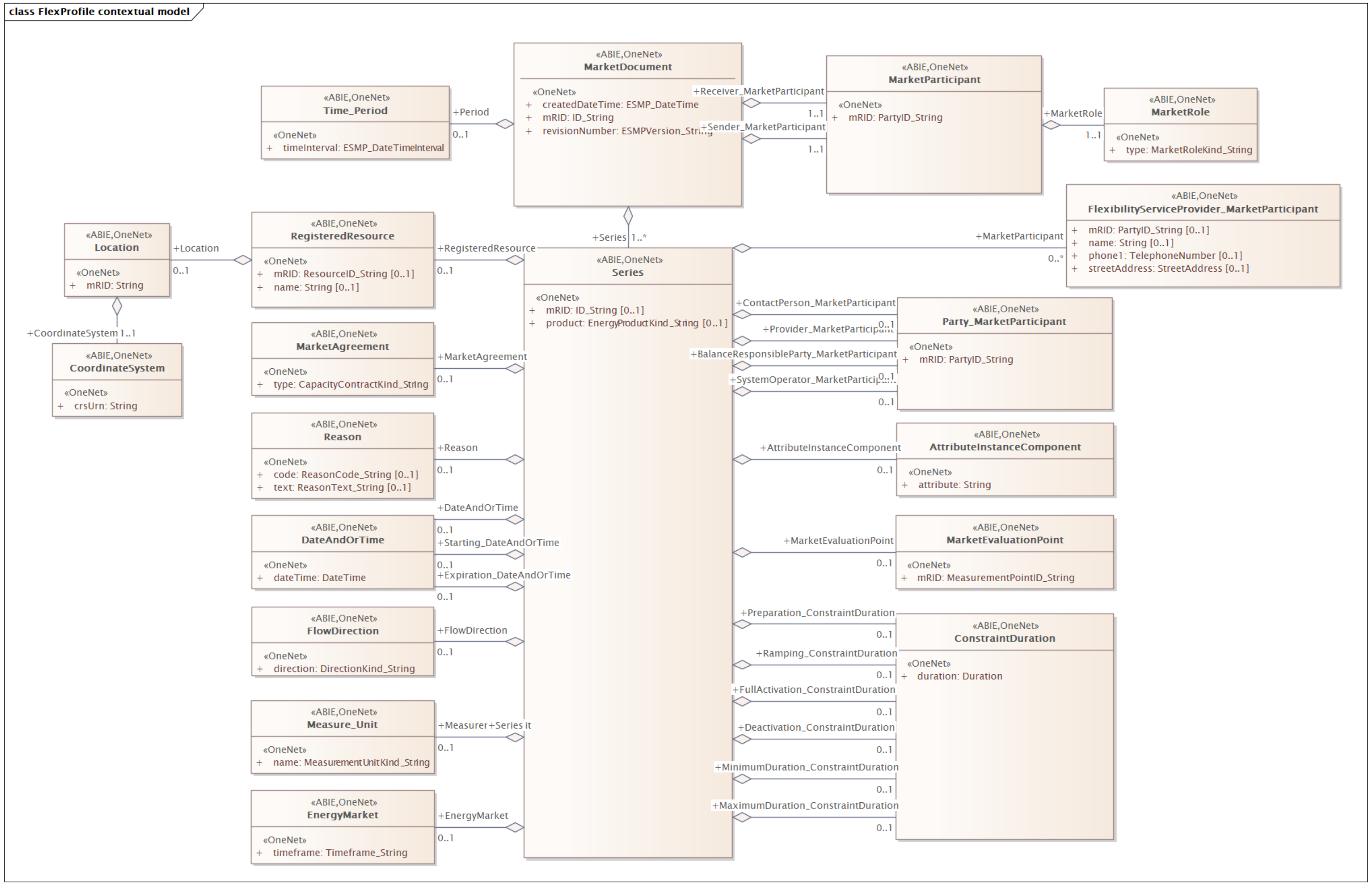

Figure 5.12: Data exchanges across market participants for flexibility bidding

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- B/ For Flexibility Activation

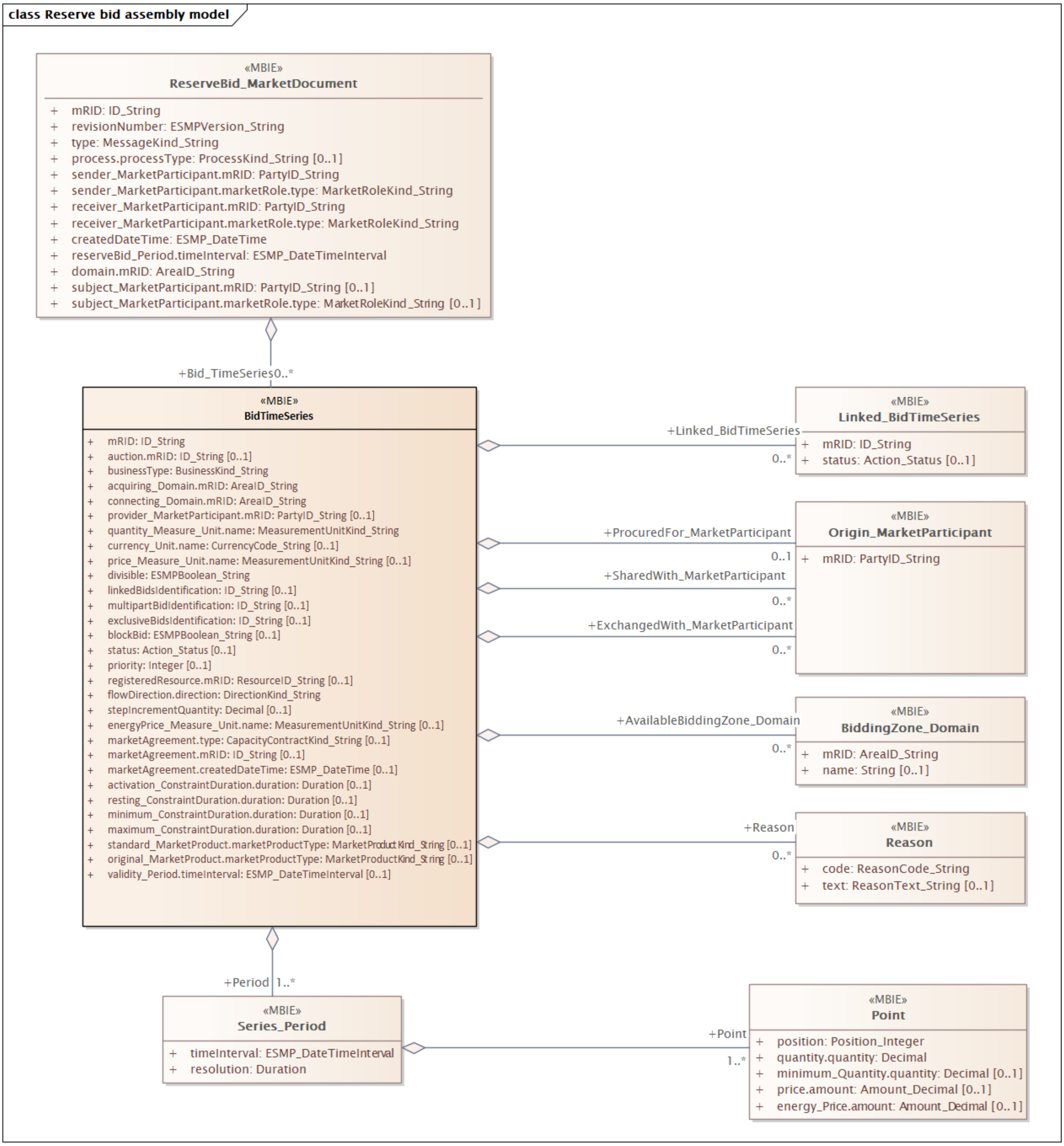

Figure 5.13: Data exchange for flexibility activations

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5.1.6 Interfaces

Table 5.5: Interfaces for MO activities

MARKET OPERATOR	SERVICE_CODE	API DATA MODEL	DATA CONTENT TYPE
Elering (SO acting as MO)	MO-T2-CLEARED-BID	urn:iec62325.351:tc57wg16:451-7:moldocument:7:2	application/xml
Fingrid (SO acting as MO)	MO-T2-CLEARED-BID	urn:iec62325.351:tc57wg16:451-7:activationdocument:6:3	application/xml
LATVIA-MO	MO-T2-CLEARED-BID	um:iec62325.351:tc57wg16:451-x:flexbid:1:0	application/xml
OneNet Middleware	MO-T2-CLEARED-BID	um:iec62325.351:tc57wg16:451-x:flexbid:1:0	application/xml
LITHUANIA-MO	MO-T2-CLEARED-BID	um:iec62325.351:tc57wg16:451-x:flexbid:1:0	application/xml
Nord Pool	MO-T2-CLEARED-BID	Proprietary model agreed between Nord Pool and NOCL	application/json
Piclo	MO-T2-CLEARED-BID	PicloFlex "Create Bid Decisions" API	application/json
Piclo	MO-T2-ACTIVATE-BID	PicloFlex "Create a Dispatch Instruction" API	application/json
Nord Pool	MO-T1-BID	Proprietary model agreed between Nord Pool and NOCL	application/json
Piclo	MO-T1-BID	Proprietary model agreed between Piclo and NOCL	application/json
All others	MO-T1-BID	um:iec62325.351:tc57wg16:451-x:flexbid:1:0	application/xml
OneNet Middleware	MO-T1-BID	um:iec62325.351:tc57wg16:451-x:flexbid:1:0	application/xml

Table 5.6: Other Interfaces

STAKEHOLDER	SERVICE_CODE	API DATA MODEL	DATA CONTENT TYPE
For All SOs	SO-T1-GRID	um:iec62325.351:tc57wg16:451-x:gridprofile:1:0	application/xml
For All SOs	SO-T1-GRID	NOCL proprietary	application/json
For All FSPs	All FSP services	NOCL proprietary	application/json

5.2 Country specific implementation

5.2.1 Finland

5.2.1.1 Context and objectives

The main goal of the Finnish demonstration was to test the market-based and coordinated flexibility procurement developed by the Northern Demonstration Cluster with relevant network situations for the Finnish

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environment to learn how the congestions can be solved using flexibility and how the combination of flexibility from DSO and TSO networks interacts. The developed platform solution with the optimization algorithm provided a novel tool to investigate the different flexibility use cases.

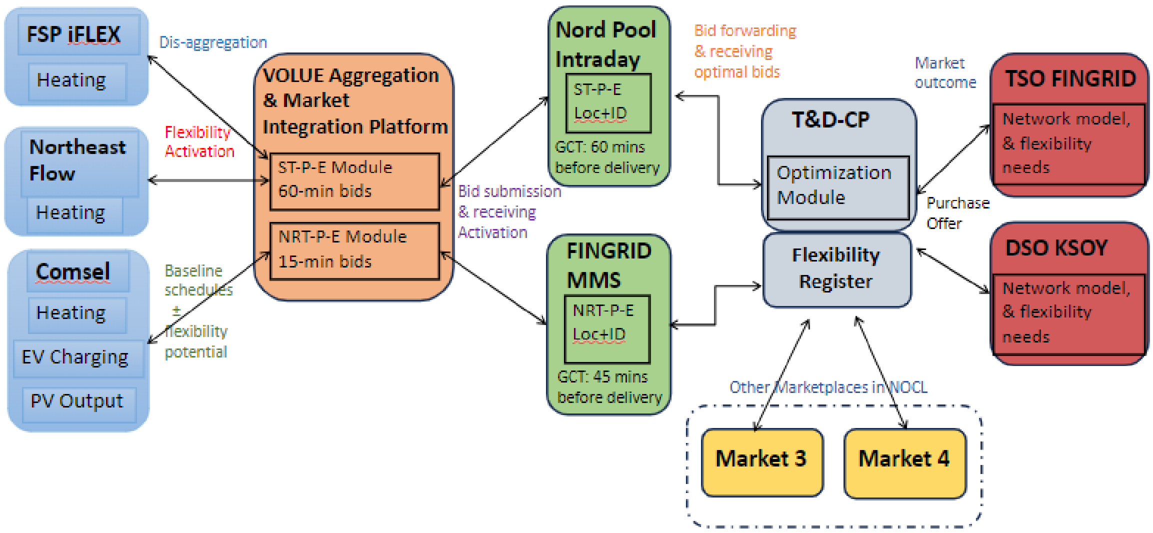

Figure 5.14: Technical implementation of the Finnish demo

The starting point for the design of the Northern demonstrator was the actual flexibility needs of the system operators. Based on these needs both the standard products (defined in chapter 5.1.2) and the used network scenarios were designed. In the Finnish demonstration the network data required by the process was created by a load flow calculation software (PSS/E). The aim with the scenarios was to create network situations that reflect the realistic needs that would trigger the need for market-based congestion management actions in the Finnish network environment. The network model included an interconnected TSO and DSO network. Testing the overall process in the Finnish demonstration was accompanied by flexibility activations from real resources (described in chapter 4.2.1 and 4.2.2).

The technical implementation included integrating market platforms, namely Nord Pool's intraday platform and Fingrid's market management system to the TSO-DSO coordination platform and Flexibility Register. To provide flexibility to these market platforms, Volue's Aggregation platform was integrated to them as shown in Figure 5.14.

5.2.1.2 Technical implementation

Volue's Aggregation & Market Integration Platform

Volue's aggregation platform has been developed and used in different National and International European R&D projects namely INTERRFACE, iFLEX, TIoCPS, and RESONANCE, to name a few. The platform is developed to perform market integration of (distributed) resources, to enable resource owners and FSPs to provide different

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services to energy system as well as to gain more benefits from their investment. Since the capacity of the resources does not usually fulfil the market entry requirements, the platform aggregates them in a way the aggregated service can be offered to the market. To maximize the benefit of the resource owners, the platform optimizes the offering value and price against the product requirement. Since the offered service is provided by different resource owners, allocation of the cleared volume / service to the resources are also done by the platform.

According to the above descriptions, the platform has different functionalities which are described below:

- Interface with FSPs: The aggregation platform uses the interface to mainly receive information about available services from different connected FSPs, send service activation signal and receive acknowledgment (activation feedback).
- Aggregation and market integration: The platform aggregates service potential offered by different resources or FSPs and prepares the optimum offer for the market. The offer includes price and volume. This functionality is continuously being developed since same flexibility can provide services to different energy and flexibility markets simultaneously, which can be translated to a need for an advanced optimal bidding model in a multi-market environment.
- Interface with market: The platform uses the interface to submit the prepared bids to the market. The target market is Nord pool Intraday and the Finnish national mFRR market. The interface is also used to receive activation signal from the markets including the service that has been purchased or cleared in the market.
- Service and profit allocation: The platform also calculates the allocation of the sold services between the connected resources.

In Finnish demonstration scenarios, Volue's aggregation and market integration platform integrated various real FSPs and real resources to marketplaces. The aggregated flexibility potential from individual resources or FSPs reaches a several tens of kWs. Contrarily, the power flows in the grid scenarios were of the order of MWs. Therefore, to match the grid-level needs, the flexibility from FSPs is scaled inside aggregation platform before bidding to markets.

Fingrid's market management system (MMS)

To implement the standardised NRT-P-E product in the Finnish demonstrator, the market management system (MMS) operated by Fingrid, was integrated to the OneNet platform. The used instance of Fingrid MMS was operated in a separated environment and the existing functionalities developed earlier for the 15-minute MARI compatible mFRR product was used. The NRT-P-E product was designed based on the definitions of the standard European MARI product, which showed how the product can be used for both balancing and congestion management. Today, the mFRR product is the main tool for market-based TSO congestion management in Finland.

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Fingrid MMS is a technical platform for managing information exchange regarding reserve trading between balancing service providers and Fingrid or in the context of congestion management between flexibility service providers and Fingrid.

Today automatic communication between FSPs and Fingrid MMS takes place over the ENTSO-E's Energy Communication Platform (ECP) and it was decided to make use also in the Finnish demonstrator thus avoiding any development on that side. On the contrary, the integration between Fingrid MMS and TSO-DSO Coordination Platform needed development work as locational bids received from FSPs are submitted by Fingrid MMS to T&D CP and respectively T&D CP sends optimization results back to Fingrid MMS to further pass them on to related FSPs. Integrations were implemented using APIs communicating through HTTP requests and provided by both T&D CP and Fingrid MMS.

All the data flows to and from Fingrid MMS uses CIM compliant data structures. The most important ones are Reserve Bid Document and Activation Document. The information exchange related to Fingrid MMS in the Finnish demonstration is depicted in the Figure 5.15Figure 5.15. First FSPs submit and edit their bids until gate closure time. Then 25 minutes before the quarter-hour in question Fingrid MMS sends all bids addressed to that period to T&D CP. Every bid sent to T&D CP must have a reference to a resource group known by Flexibility Register. Original bids submitted by FSPs to be used for congestion management must have a locational tag which is then converted into a resource group using cross-reference information maintained in Fingrid MMS.

After the optimization T&D CP returns selected bids as activation orders back to Fingrid MMS. 15 minutes before the start of a delivery period Fingrid MMS sends activation orders to related FSPs following the acceptance of activation order sent by FSP. All the communication between FSP and Fingrid MMS follows the market rules and data exchange practices set by Fingrid in the role of Market Operator.

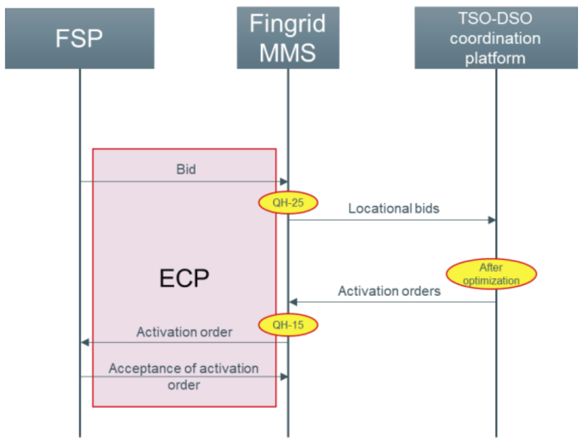

Figure 5.15: Information exchange to connect Fingrid MMS to T&D-CP and communicate with an FSP

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5.2.1.3 Demonstration scenarios and results

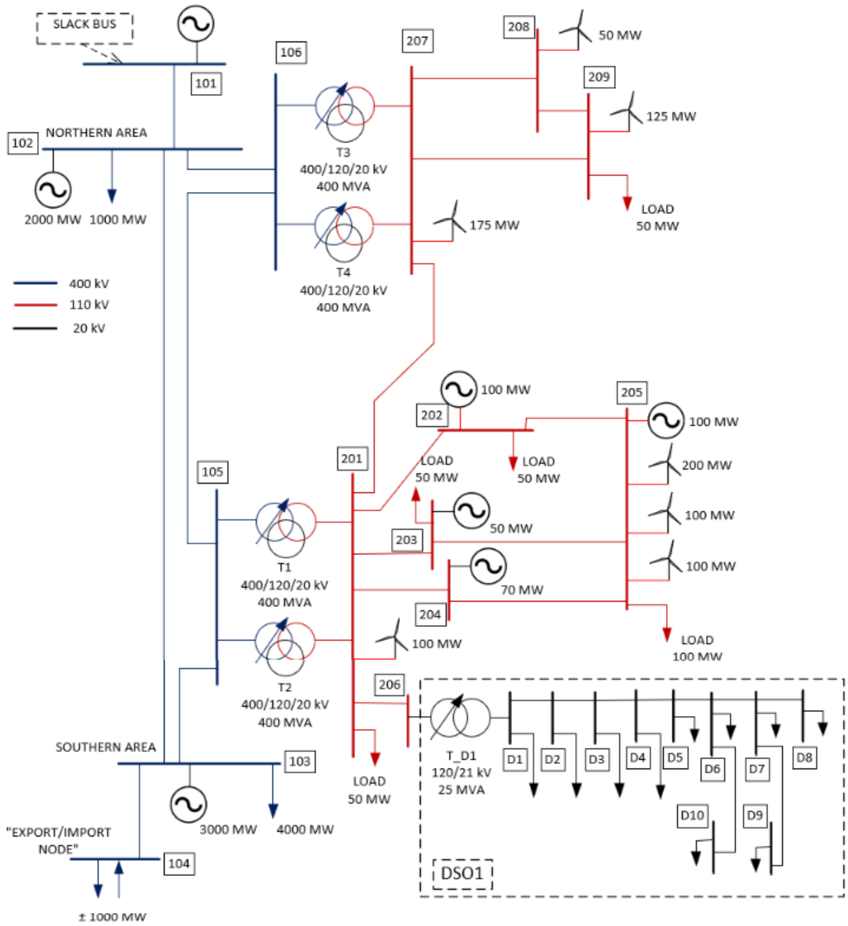

Figure 5.16: Representation of the base grid model used in the Finnish demonstration scenarios.

The Finnish demonstration scenarios were based on the same base grid model presented in Figure 5.16. The model represents a grid where on the 400 kV voltage level there are Northern and Southern areas between which there is a transmission connection. The two areas are also connected via another 400 kV line between two substations. Third connection between the areas is formed on the 110 kV level. To the 110 kV substation node 206 there is a radial 20 kV DSO network connected. The Figure 5.16 also depicts the generation and load assets on the 400 kV and 110 kV networks. As one can also note from the figure, both 110 kV networks are surplus areas, meaning that the generation assets exceed the consumption in the areas, especially in times when the wind turbines are in full production.

The presented base grid model was amended according to the designed scenarios by running a load flow calculation to determine the flows in the different components of the grid. This data was then exported and translated into the data format used by the OneNet platform. In addition to the flows, also the sensitivity matrix (PTDF matrix) was exported from the simulation tool. The sensitivity matrix is used by the optimisation to determine how a change to the power infeed or withdraw from any of the nodes affects the rest of the system.

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The demonstration scenarios are summarised in the Table 5.7.

Table 5.7: List and summary of scenarios in the Finnish demonstration.

Scenario	Product	Congested network	Activated bid volume up/down (MW)	Result of optimization	Total cost of procurement (€)
1	ST-P-E	TSO	3 / 3	All congestions resolved	200
2	ST-P-E	DSO	0,15 / 0	All congestions resolved	75,6
3	NRT-P-E	TSO	149 / 155	Congestions partially solved (insufficiency of bids)	24 740
4	NRT-P-E	TSO and DSO	61 / 75	All congestions resolved	10 029
5	NRT-P-E	TSO	168 / 180	All congestions resolved	25 590

ST-P-E Product

Procurement of ST-P-E product was demonstrated using Nord Pool marketplace. Nord Pool facilitates flexibility trading by utilizing the Intraday platform. This is achieved by enhancing the intraday market orders with a flexibility asset ID which refers to the asset information in the Flexibility Register. This information, apart from the locational data, indicates details on contracted FSP, connected network and type of asset etc. The orders can then be activated to fulfil any flexibility need of the TSOs or DSOs. Flexibility asset owners or service providers can offer the same flexibility volume on the intraday market with the same order which will help them to commercialize the service more as they have a broader possibility to trade the flexibility. The gate closure time for receiving bids is two hours before the physical delivery.

For ST-P-E framework, two real flexibility resources located in Finland are piloted. The resources include heating demand of a residential building (from iFLEX Project) and a data center owned by Northeast Flow described in chapter 4.2.1 and 4.2.2. The ST-P-E procurement is demonstrated separately for each of the two resources.

Figure 5.17 illustrates the data flow sequence followed in demonstrating the proof-of-concept of the flexibility market solution. Fully automated machine to machine interfaces were implemented such that the flexibility information flows across country-demo partners' IT platforms, i.e. starting from purchase offer by relevant SO through the delivered flexibility verification, thus covering the whole value chain.

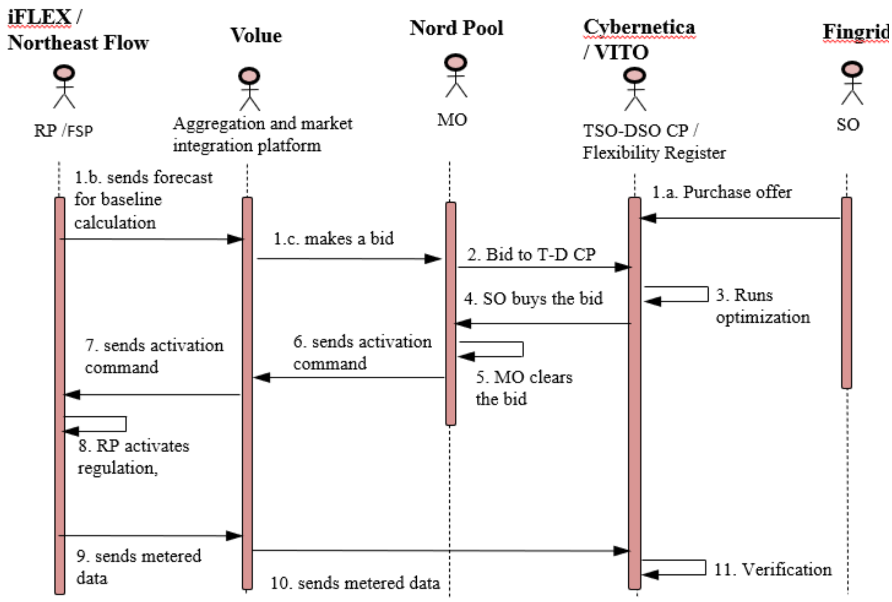

Figure 5.17: Process flow diagram

Scenario 1: TSO Grid congestion

In the scenario depicted in *Figure* 5.18, scaled flexibility from iFLEX building resources is utilized to resolve a power congestion of 3 MW in the line connecting nodes 201 and 206 of the Finnish TSO network. The node 206 also represents a DSO network. The iFLEX building is in the KSOY (DSO) network behind node 8 along with simulated resources as an aggregated asset. Furthermore, a simulated iFLEX building (digital twin) is located at node 10 of the KSOY distribution network and other virtual resources are located at nodes 206 and 209 of the Fingrid network.

The complete flexibility procurement process is explained as follows for clarity and applies for all the Finnish NRT-P-E demonstration cases.

The market-driven flexibility uptake process is initiated when SO identifies or forecasts a possible power imbalance or power congestion issue in the network in any following point of time. In this scenario, TSO forecasts network state and recognizes a congestion of 3 MW in the line connecting nodes 201 and 206 for the time stamp 14:00 – 15:00 (Finnish Time). Accordingly, SO specifies a purchase offer to the OneNet coordination platform. This purchase offer is a data set with the necessary information to initiate the procurement process. It comprises the desired market product to be procured, delivery hour or timestamp, congestion (if any), imbalance position of the network (marking if balancing needs to be included) and cost cap of the market session to mitigate the issue. Note that flexibility is needed several hours after registration of the purchase offer, therefore the market product ST-P-E is chosen by SO, being the most suitable under given conditions. After passing this info to the coordination platform, the trading phase is initiated.

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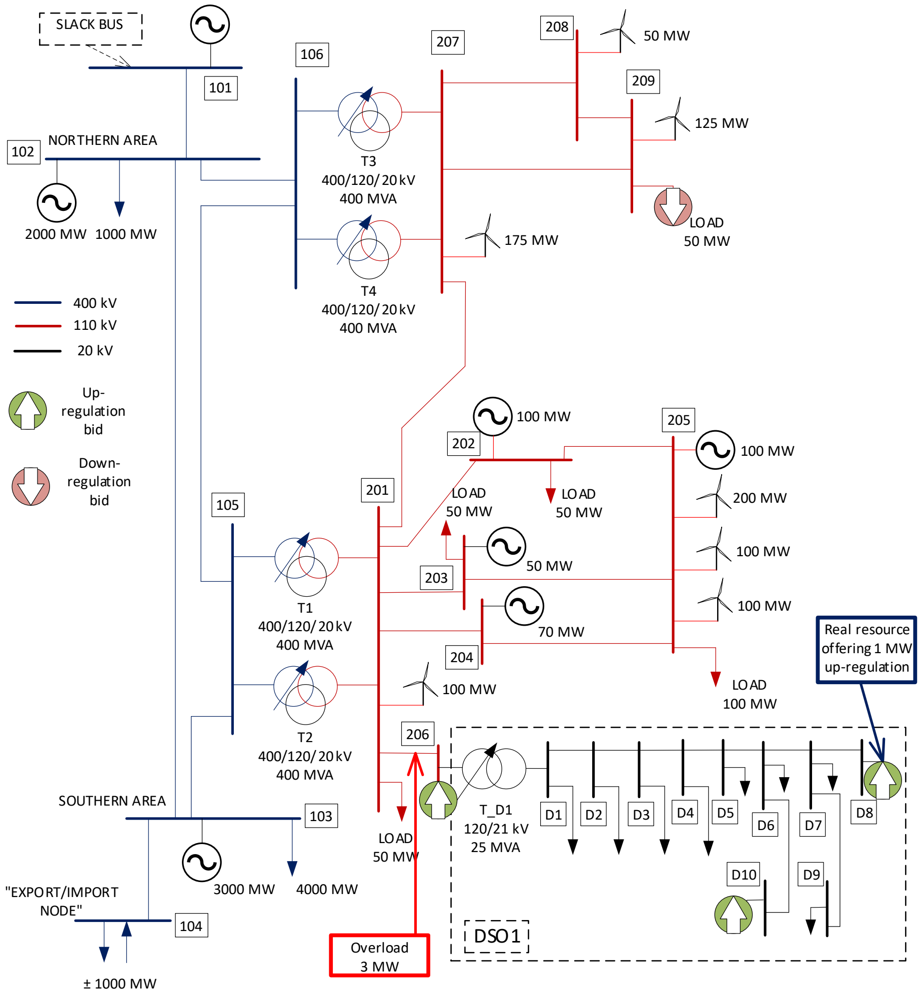

Figure 5.18: Network scenario for ST-P-E procurement via flexibility from iFLEX resources

Volue's Aggregation and market integration platform receives baseline consumption and flexibility potentials of the flexible resources after regular intervals, for the following time slots via the iFLEX interface. It is important to mention here that the forecasted flexibility is yet to be harnessed by sacrificing thermal comfort levels, i.e. slightly altering the indoor temperature from the preferred set point in the pilot building. It is supported by preheating or pre-cooling the well-insulated building envelope depending on the electricity, district heat tariffs and self-consumption of solar power production. Such a building thermal dynamics result in a significant reduction of energy procurement costs. The market interface module optimizes the flexibility potential in terms of price to form bids that does not lead to limiting market liquidity.

The flexibility bids submitted to the marketplace are illustrated in Figure 5.19 which represents an instance of Nord Pool UI. It is to be noted that these bids have a locational / metering ID associated with them along with other attributes. Also note that the negative price for the asset located at node 209 indicates the buy order. In other words, the flexibility provider is willing to pay to provide down-regulation. This is to comply with the purchase offer stating that imbalance position remains the same before and after the power congestion is

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optimally removed. Further, for simplicity, the bids are assumed to be fully divisible, i.e. can be cleared between any energy quantity ranging from 0 to the offered maximum volume and does not involve any minimum bid volume requirement. However, other bid types such as indivisible or partially divisible bids are also supported by the coordination platform.

Figure 5.19: Submitted bids to Nord Pool Intraday for ST-P-E procurement

As part of automation, Nord Pool forwards all the bids with locational tags to TSO-DSO coordination platform which fetches necessary information from the FR to perform mandatory checks before proceeding to actual bid optimization. The objective of optimization is to match purchase offer with flexibility bids at minimum costs, and avoiding further issues in the neighboring grids involved, enabling value stacking. The cleared bid volumes are listed in Table 5.8. In NOCL, pay-as-bid pricing is followed. Based on the optimization results, the coordination platform proposes MO to clear bid quantities against the purchase offer. The MO, i.e. Nord Pool clears the bids, or volume of bids, provided the bids still exist, which was the case in this demonstration run. The uncleared volume of partially cleared bids remains at the marketplace till expiry time or acceptance by a participant, whichever is earlier. If, for some reason, bids would have become unavailable during optimization due to matching or contracting by other parties, the whole optimization routine must be performed again considering the available bids and the SO might need to update the purchase offer and network state.

Table 5.8: Optimization results of scenario 1.

System ID	Node ID	Direction	Price offered (€/MWh)	Quantity offered (kW)	Quantity cleared (kW)
KSOY	D10	Upward	700	500	500
FINGRID	206	Upward	900	2000	1500
KSOY	D8	Upward	600	1000	1000
FINGRID	209	Downward	-700	5000	3000

After bid clearing, MO, i.e. Nord Pool sends an activation command to the ‘aggregator and market integration platform, i.e. step no. 6 in Figure 5.17, which calculates the amount of flexibility needed to be activated by flexibility resources. The market interface platform reflects the activation signal to respective FSP who prepares to activate flexibility at the desired time stamp.

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During the delivery period, the flexibility is activated from piloted resources including the real residential building. Flexibility activation would impart 3 MW power imbalance in the network, which is not acceptable according to the purchase offer, hence 3 MW of generation at node 209 is downregulated to restore the power balance of the network. The process and results of ex-post flexibility verification and financial settlement could not be performed for ST-P-E framework, as the needed development work was accomplished after the ST-P-E demo sessions. However, the said process was executed for NRT-P-E product procurement and corresponding results are documented in following sub-sections.

Scenario 2: DSO grid congestion

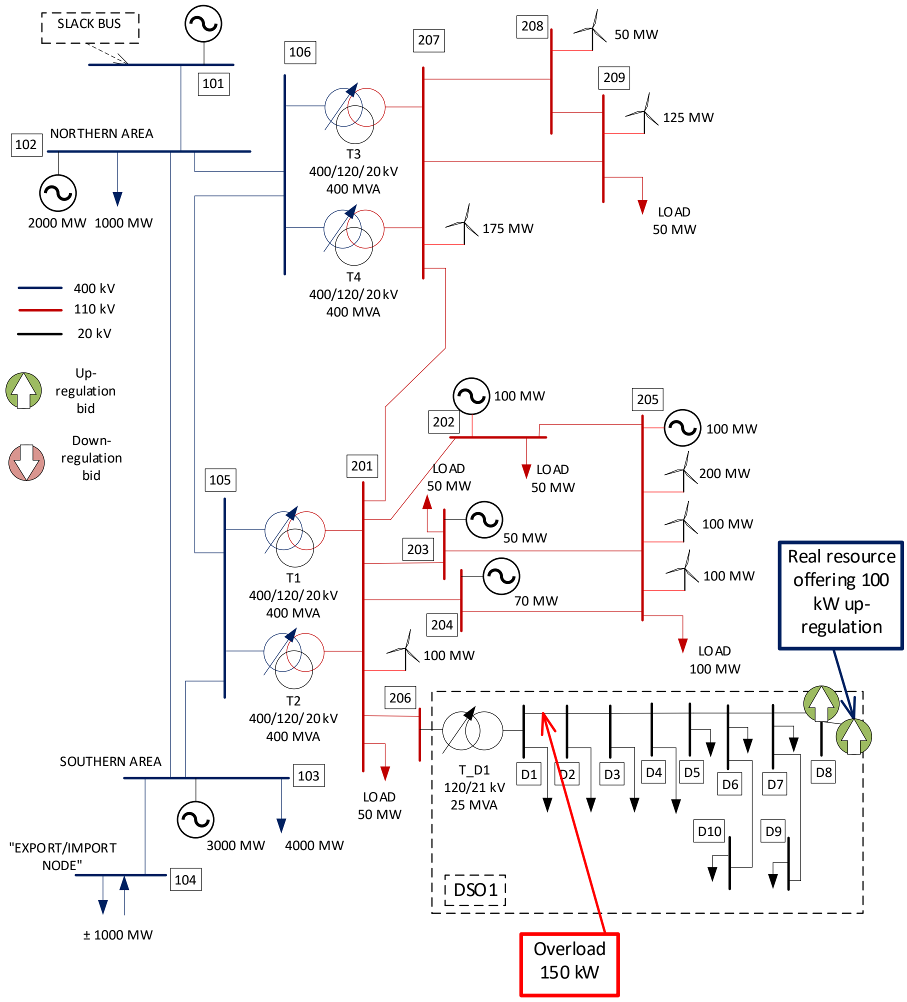

Figure 5.20: Network scenario for ST-P-E procurement via flexibility from Northeast Flow resources

In this scenario, the DSO grid is congested at the primary feeder connecting nodes D1 and D2, as depicted in Figure 5.20. The flexibility need is 150 kW upwards. The piloted flexibility resources include a real data center and simulated loads located at node D8 of the distribution grid. The purchase offer by DSO specifies the need for the following hour: 09–03–2024, 13:00–14:00 UTC, while power imbalance can mutate in the range of –1 to

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1 MW. Two flexibility bids each with an up-regulation volume of 100 kW were submitted to the Nord Pool Intraday platform.

The same market clearing process is followed as explained in the preceding sub-section. The optimization resulted in clearing of one bid in full and one bid partially totaling 150 kW flexibility volume to completely resolve the congestion. In addition, the activation of flexibility bids will cause 150 kW of power imbalance in the network which is in the permissible range. Offered and cleared bids are listed in the Table 5.9 while Nord Pool Intraday platform view is shown in Figure 5.21.

Table 5.9: Optimization results of scenario 2.

System ID	Node ID	Direction	Price offered (€/MWh)	Quantity offered (kW)	Quantity cleared (kW)
KSOY	D8	Upward	504	100	100
KSOY	D8	Upward	504	100	50

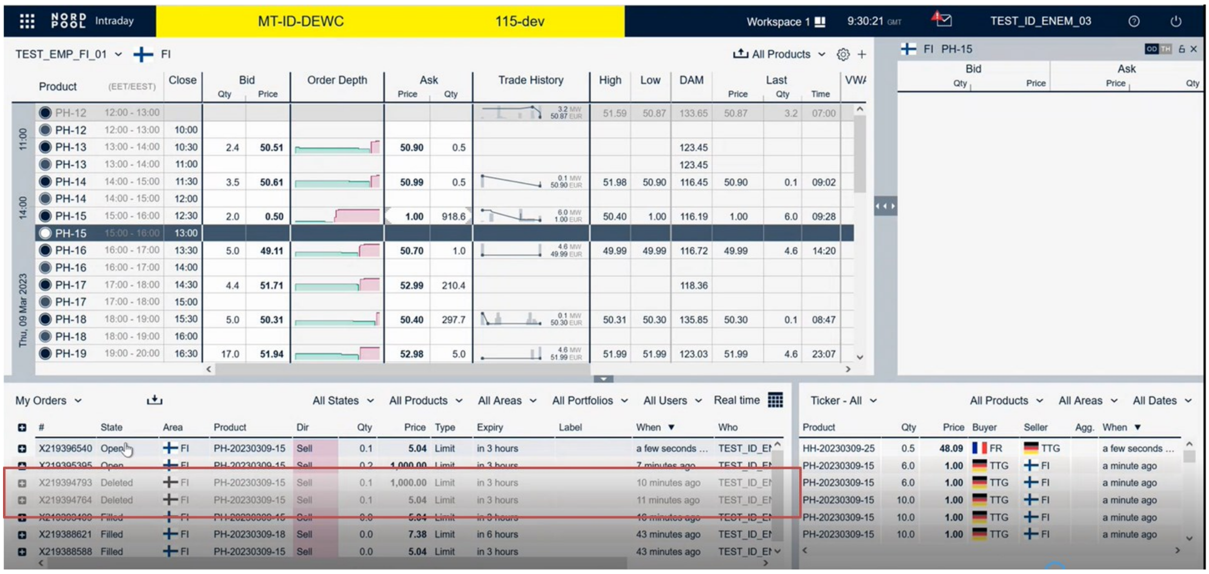

Figure 5.21: Market clearing for ST-P-E product in Nord Pool Intraday platform

Table 5.10: Definition of Intraday platform fields

Product	Displays the selected product types for the selected market area. If 'Product Delivery/Close Times' has been selected in the column group filter, the delivery/gate closure time is displayed in the market information.
DAM	Price of the corresponding product in the Day-Ahead auction Market.
Bid/Ask	Bid and Ask columns will at all times show the best bid (buy) and ask (sell) price for the applicable instrument per bidding zone.

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Order Depth	The Order Depth column provides a graphical overview of the current order stack for each product. The Y-axis indicates the volume of an order relative to the other orders in the order depth. The X-axis indicates the spread of the order stack. Green represents bid and red represents ask. Hovering over the Order Depth indicator displays the Order Depth with up to ten orders.
Trade History	The trade history column provides a graphical overview of the trade history for each specific product.
High/Low	Displays the highest and lowest price for each product.
Last	These columns show the quantity, price information and time for the last trade of a product.

NRT-P-E Product

In NRT-P-E product demonstrations, Fingrid MMS was employed with some modifications to support general purpose flexibility product attributes as well as automation with key NOCL stakeholders. The NRT-P-E product procurement is demonstrated for three different network scenarios separately. A diverse portfolio of real flexibility resources was utilised as part of the pilot. The resources are offered and controlled by Comsel as detailed in sub-section 4.2.2. The resources of the same type are aggregated into a group in the FR, and thus used on the marketplace. For instance, three real resource groups comprising heating, EVs and PVs are formed. The metering points for each of the resource groups are then defined accordingly in the FR.

Scenario 3: Main grid fault

In this scenario, Fingrid's network suffered from a fault in a 400 kV circuit (represented by blue lines) as illustrated in Figure 5.22. As a result of this fault, the parallel circuit is overloaded by 150.6 MW and imparting a power imbalance of 40 MW in the network. Therefore, the given scenario considers both congestion management and power balance management problems. It translates into a flexibility need in the up-regulation direction. To resolve such issues, available up and down-regulation bids are distributed at different nodes, as displayed in Figure 5.22. To simplify further, up-regulation is sought from FSP Comsel whereas down-regulation is provided by virtual resources.

The purchase offer submitted by SO specifies the flexibility need for the time stamp 17-01-2024 T12:15 – T12:30 UTC. The cost cap is set to a very high value implying the removal of congestion has a very high priority for the SO. Additionally, purchase offer states the power balance to be in the range 0–35 MW during the delivery period. A total of 8 indivisible bids are submitted to Fingrid MMS, i.e.one for each of the nodes marked thereof, a few time slots before the delivery period. The optimization model is highly efficient such that it took only

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0.0468 s to solve the market clearing problem considering grid qualification. The congestion is partially resolved which is highly attributed to indivisibility of bids. Such a bid type leaves very little freedom for the solver especially when power balance is hardly constrained, which is the case in the current scenario.

The submitted bids as well as cleared bids are listed together in Table 5.11. Note that cleared bids at nodes 103 and 104 correspond to real heating and EV resources of Comsel. The offered quantities of the real resources are scaled up to match the TSO network need. The optimization algorithm also checks the MARI compliance for the set of un-cleared bids. In this case, the bids at node 203 and 207 qualified for MARI requirements which could be forwarded to MARI platform. The total MARI check time is 0.125 s.

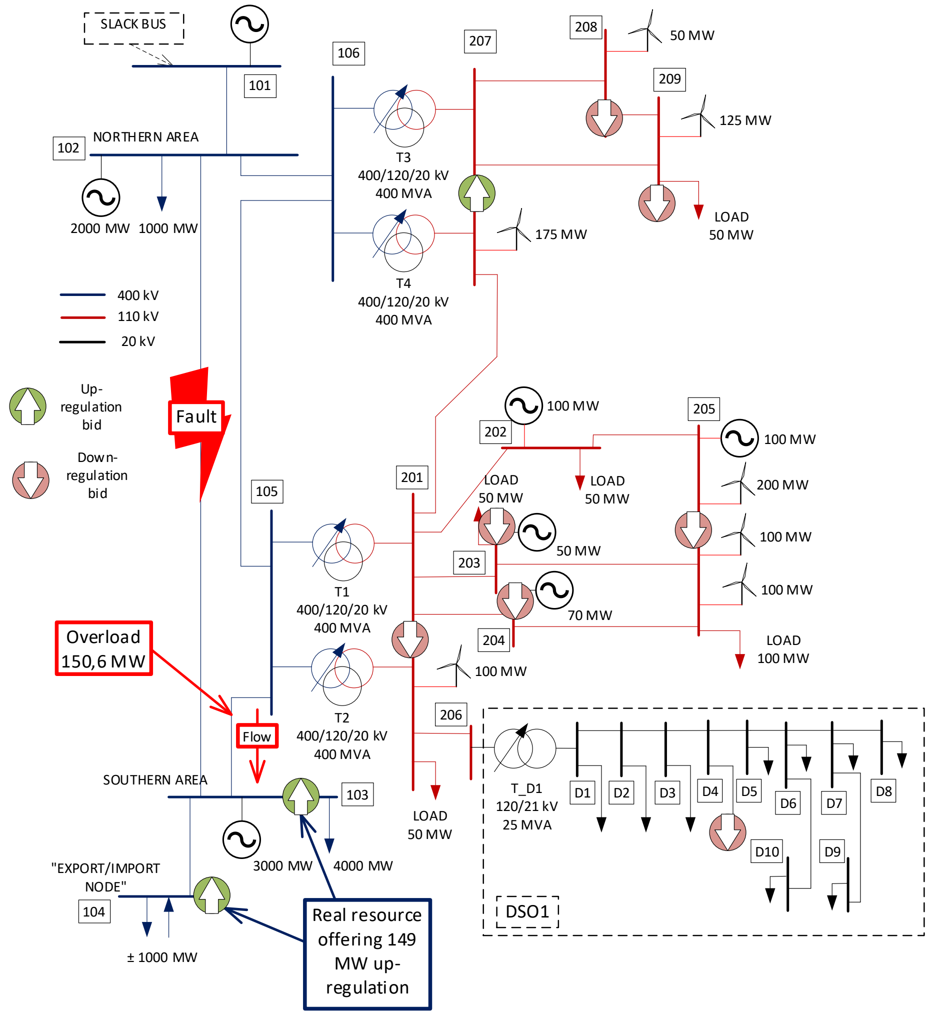

Figure 5.22: Network scenario for the scenario 3.

Fingrid MMS receives the list of optimal bids through developed API. Upon receipt of results, Fingrid MMS clears the recommended bids. Sending activation to the market integration platform is also automated which takes place just 15 minutes before the delivery period. Figure 5.23 shows the cleared bids (marked in green) in Fingrid MMS when bids have been received from T&D CP. A bit later bid activation requests concerning real

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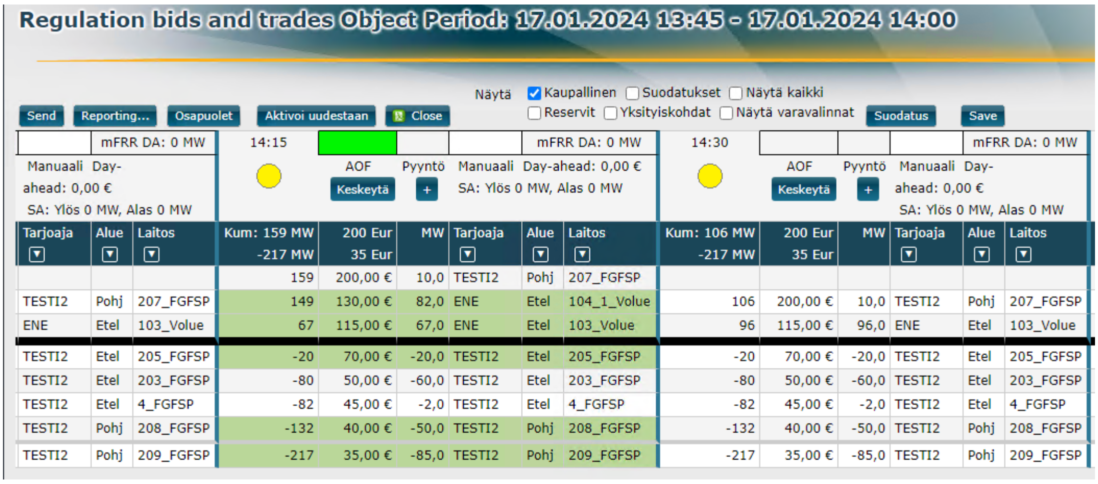
Comsel resources are sent by Fingrid MMS in the form of a CIM document and received by the market integration platform.

Table 5.11: Offered and cleared bids in scenario 3.

System ID	Node ID	Direction	Price offered (€/MWh)	Quantity offered (MW)	Quantity cleared (MW)
FINGRID	207	Upward	200	10	-
FINGRID	104	Upward	130	82	82
FINGRID	103	Upward	115	67	67
FINGRID	209	Downward	35	85	85
FINGRID	208	Downward	40	50	50
KSOY	D4	Downward	45	2	-
FINGRID	203	Downward	50	60	-
FINGRID	205	Downward	70	20	20



Tarjoaja	Alue	Laitos	Kum: 159 MW -217 MW	200 Eur 35 Eur	MW	Tarjoaja	Alue	Laitos	Kum: 106 MW -217 MW	200 Eur 35 Eur	MW	Tarjoaja	Alue	Laitos
			159	200,00 €	10,0	TESTI2	Pohj	207_FGFSP						
TESTI2	Pohj	207_FGFSP	149	130,00 €	82,0	ENE	Etel	104_1_Volue	106	200,00 €	10,0	TESTI2	Pohj	207_FGFSP
ENE	Etel	103_Volue	67	115,00 €	67,0	ENE	Etel	103_Volue	96	115,00 €	96,0	ENE	Etel	103_Volue
TESTI2	Etel	205_FGFSP	-20	70,00 €	-20,0	TESTI2	Etel	205_FGFSP	-20	70,00 €	-20,0	TESTI2	Etel	205_FGFSP
TESTI2	Etel	203_FGFSP	-80	50,00 €	-60,0	TESTI2	Etel	203_FGFSP	-80	50,00 €	-60,0	TESTI2	Etel	203_FGFSP
TESTI2	Etel	4_FGFSP	-82	45,00 €	-2,0	TESTI2	Etel	4_FGFSP	-82	45,00 €	-2,0	TESTI2	Etel	4_FGFSP
TESTI2	Pohj	208_FGFSP	-132	40,00 €	-50,0	TESTI2	Pohj	208_FGFSP	-132	40,00 €	-50,0	TESTI2	Pohj	208_FGFSP
TESTI2	Pohj	209_FGFSP	-217	35,00 €	-85,0	TESTI2	Pohj	209_FGFSP	-217	35,00 €	-85,0	TESTI2	Pohj	209_FGFSP

Figure 5.23: Bid list on the screen of Fingrid MMS

Acknowledging the received activation signal is automated in Volue's market integration platform. The activation signal is sent to FSP Comsel who allocates flexibility activations to the portfolio of resources for the desired delivery period. Figure 5.24 illustrates a particular instance of Comsel UI when flexibility activations per aggregated resource type are scheduled just before the delivery period. Note that the capacities in the figure are scaled to MW level.

The settlement results are presented in Table 5.12. It is to be noted that the virtual bids are included in the settlement to give a figure for the total costs of the congestion management actions. For the bids using the real resources (Res_Comsel_chargers and Res_Comsel_heating) the baseline calculation model of the OneNet platform was used. In the case of Res_Comsel_heating the delivered flexibility deviated from the activated amount quite considerably, and thus the penalty of the non-delivery exceeded the price paid for the trade.

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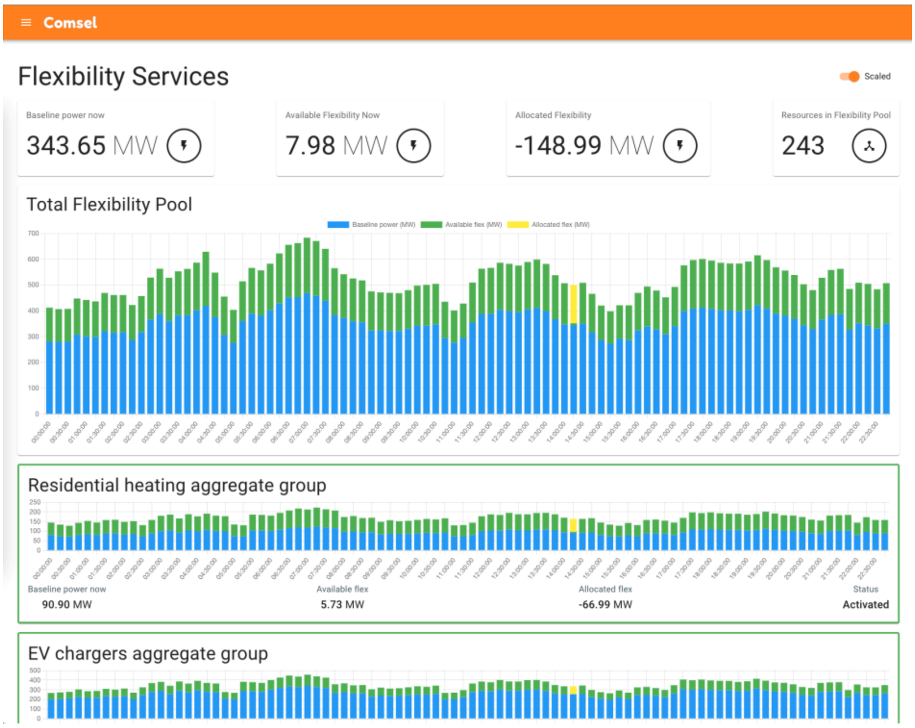

Figure 5.24: Screen of Comsel's user interface showing the forecasted behavior of their resources.

Table 5.12: Settlement results of scenario 3.

Resource group	Bid Price	Activated Amount (MW)	Measure-ment (MW)	Baseline/ Schedule (MW)	Delivered Flexibility (MW)	Remune-ration
MP_205	70,00 €	20	0	20	20	1 400,00 €
MP_208	40,00 €	50	0	50	50	2 000,00 €
MP_209	35,00 €	85	0	85	85	2 975,00 €
Res_Comsel_ chargers	115,00 €	67	392,5	462,48	69,98	7 705,00 €
Res_Comsel_ heating	130,00 €	82	57,32	84,17	26,85	-3 679,83 €
Total		**304**			**251,83**	**10 400,17 €**

Scenario 4: TSO-DSO Congestion Scenario

In the scenario 4, there is a planned outage in the TSO's 400 kV transmission line connecting the nodes 102 and 106. During the planned outage, a permanent fault occurs in the 400 kV transmission line connecting the nodes 106 and 105 and causes congestion in the 110 kV transmission line connecting the nodes 207 and 201. In this scenario, the permanent admissible loading of the 110 kV line connecting the nodes 207 and 201 is 250 MW and the temporary (transitory) admissible loading is 312.5 MW (1.25 times the permanent admissible loading). In the scenario, the permanent admissible loading of the 110 kV line is exceeded but the temporary admissible

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loading is not. The temporary admissible transmission loading is used as an enabler of a post-fault activation of flexible resources (down-regulation). Since the activation is done post-fault (as a curative action), the approach minimizes the need to restrict the active power input into the transmission grid during a planned outage while still complying with the operational security limits. The used approach is presented more in detail in [7]. In the scenario 4, there was no need to restrict the active power input into the transmission grid in advance (as a preventive action) in the nodes 207, 208 and 209 since the loading of the 110 kV line between nodes 207 and 201 would remain within the temporary admissible transmission loading of the 110 kV line in a case of a permanent fault during a planned outage. In this scenario, the temporary admissible loading of the transmission line is used as an enabler of post-fault activation of flexible resources to return the loading of the 110 kV line below the permanent admissible transmission loading within 15 minutes (using the NRT-P-E product).

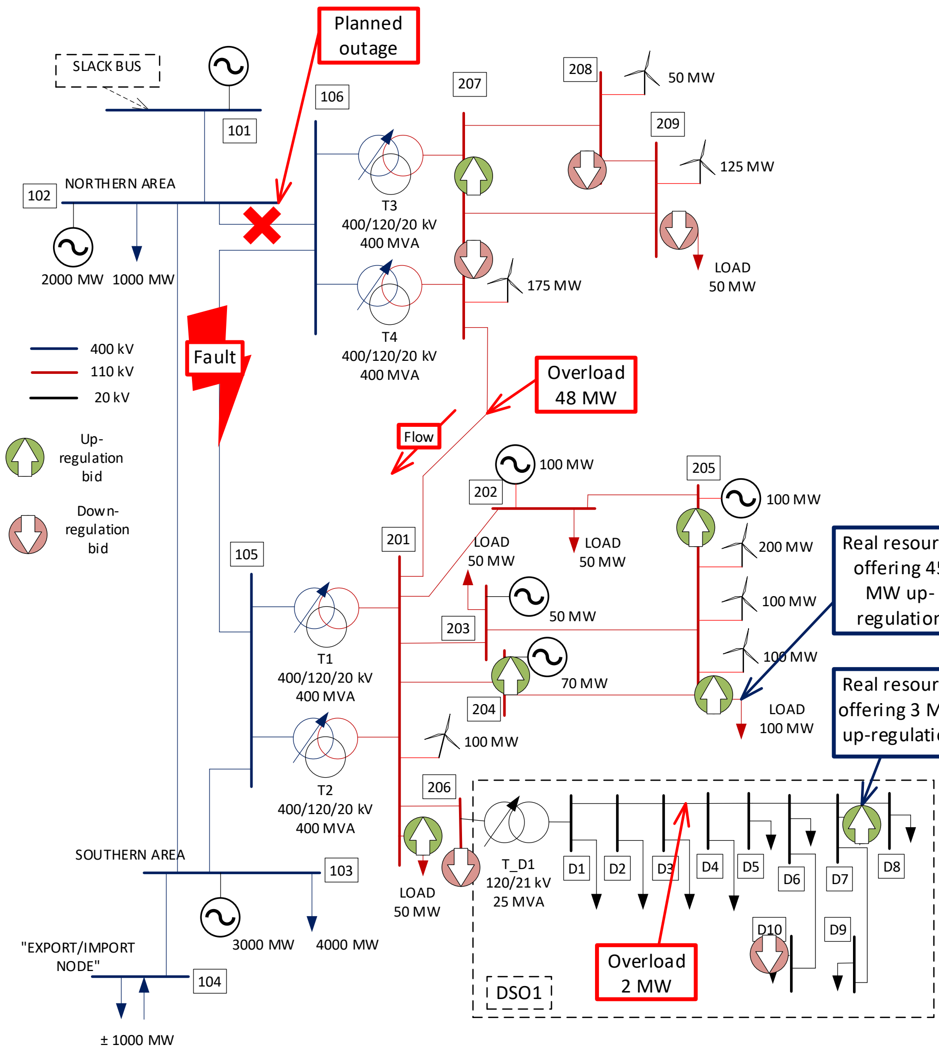

Figure 5.25: Network scenario for scenario 4.

This scenario is peculiar in a sense that a fault at 400 kV level triggers congestion in both the transmission and an adjacent distribution grid. This scenario serves as a comparison benchmark for evaluating the

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performance of joint market clearing over SO-specific fragmented market models. The fault clearing at 400 kV line causes overloading in 110 kV circuit by 48 MW. Simultaneously, an overloading occurs in the 10 kV KSOY feeder by 2 MW, which needs to be solved during the same optimisation run. It implies that the market will be cleared jointly for both SOs, and the corresponding flexibility procurement costs will be split between them according to individual bids' contribution to each network congestion resolution. The onset of the fault also introduces a power imbalance of 5 MW. Moreover, flexibility assets are available in both the transmission and distribution grids. A purchase offer is specified at the coordination platform accordingly. Further, the purchase offer defines that power balance be bounded by -15–15 MW after the congestion removal.

The market clearing process in Fingrid MMS is the same as detailed in Scenario # 3. Contrarily, in this scenario, Comsel resource groups, i.e. heating, EV charging and PV generation, are distributed at FG Node 205 and KSOY Node 7 as marked in Figure 5.25. The available as well as cleared bids are listed in Table 5.13. Like previous scenario, all bids are indivisible. The coordination platform identifies the 5 most economical bids out of the 10 available bids to completely resolve the congestion, however slightly aggravating the power balance to 9 MW. The procurement costs a total of 10029 €. The total optimization time is 0.0781 s. Lastly, among uncleared bids, the bids located at FG Node 209 and 206 complies with MARI format requirements and will not cause any congestion if activated individually. This process is also fast and took 0.1093 s.

Table 5.13: Offered and cleared bids in scenario 4.

System ID	Node ID	Direction	Price offered (€/MWh)	Quantity offered (MW)	Quantity cleared (MW)
FINGRID	207	Upward	200	10	-
FINGRID	201	Upward	195	10	10
FINGRID	204	Upward	180	15	-
KSOY	D7	Upward	100	3	3
FINGRID	205	Upward	98	48	48
FINGRID	207	Upward	35	45	45
KSOY	D10	Downward	25	2	-
FINGRID	208	Downward	50	30	30
FINGRID	206	Downward	60	15	-
FINGRID	209	Downward	70	30	-

As part of the NOCL BUC KPI (KPI_N04) calculation, and to compare the performance of joint market clearing model, the Finnish demo evaluated the impact of fragmented market clearing on the neighbouring SO. The results are summarized in Table 5.14. It can be seen when market is cleared for FINGRID alone, the congestion at KSOY remains, whereas resolving congestion in KSOY without coordination with the transmission grid worsens the FINGRID network congestion.

Table 5.14. Comparison of the performance of joint and fragmented market clearing model in scenario 4.

Congested network	Initial congestion (MW)	Congestion after Joint market clearing	Congestion when Market clearing for FINGRID only (MW)	Congestion when Market clearing for KSOY only (MW)
FINGRID	47.8	0	0	49.955
KSOY	1.976	0	1.976	0

Fingrid MMS clears the bids as recommended by the coordination platform, followed by sending bid activations for real resources to market integration platform. The onset of this event leaves only 15 mins to the delivery period. An instance of UI of market integration platform acknowledging the activations received from Fingrid MMS is illustrated in Figure 5.26. The activation is communicated using ECP channel. The same activation is then forwarded to Comsel within the prescribed 15 min time window.

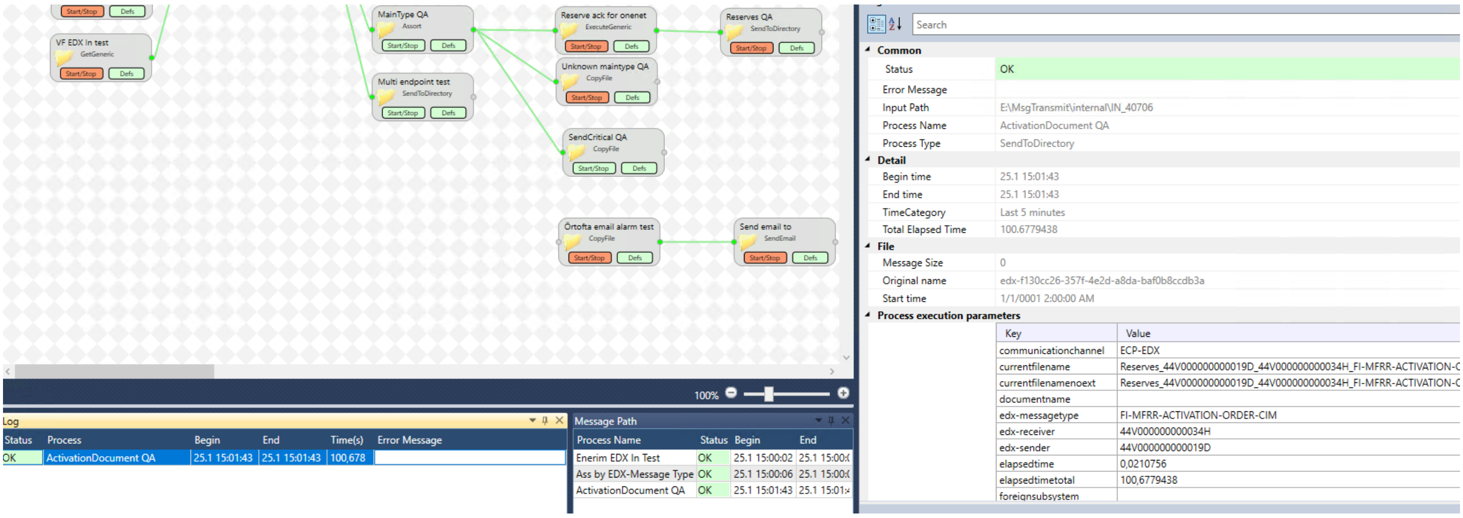

Figure 5.26: Screen of Volue's market integration platform.

Upon receipt of the activation signal, Comsel schedules the flexibility activations for each resource group accordingly. Figure 5.27 illustrates the baselines and flexibility potentials of the piloted loads that are computed by the FSP Comsel just a few minutes before the delivery period and accordingly used for bidding. Additionally, ex-post metering data and the un-utilized potential are also depicted next to them. The available potential is the flexibility not offered to market. It is visible in Figure 5.27 that 13.71 kW of EV charging load and 3 kW of heating load is up regulated based on the activation signal. However, this activated flexibility is with reference to the baselines defined by the FSP itself. The actual delivered flexibility will be computed using the baselines established by the flexibility register and the financial settlement be carried out subsequently. Please also note that in Figure 5.27, the down potential of loads corresponds to up-regulation. The settlement results of the scenario are presented in Table 5.15.

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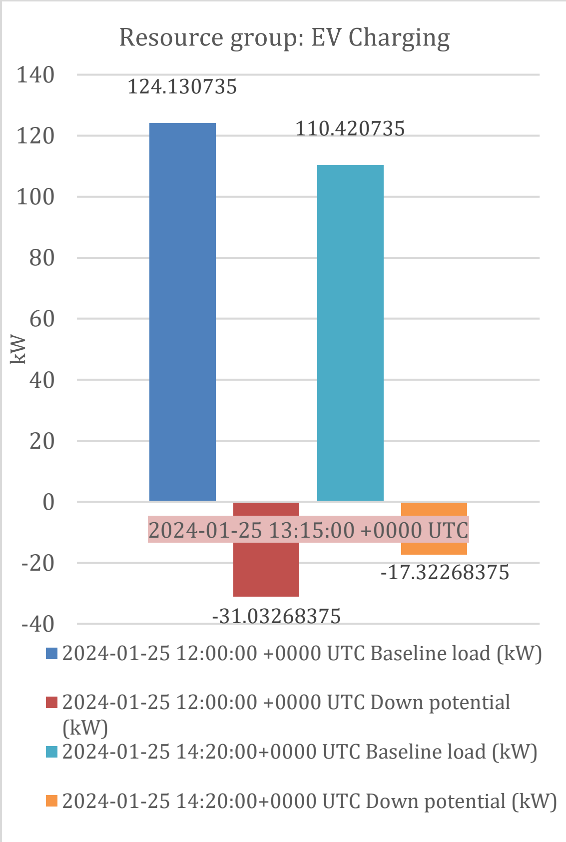

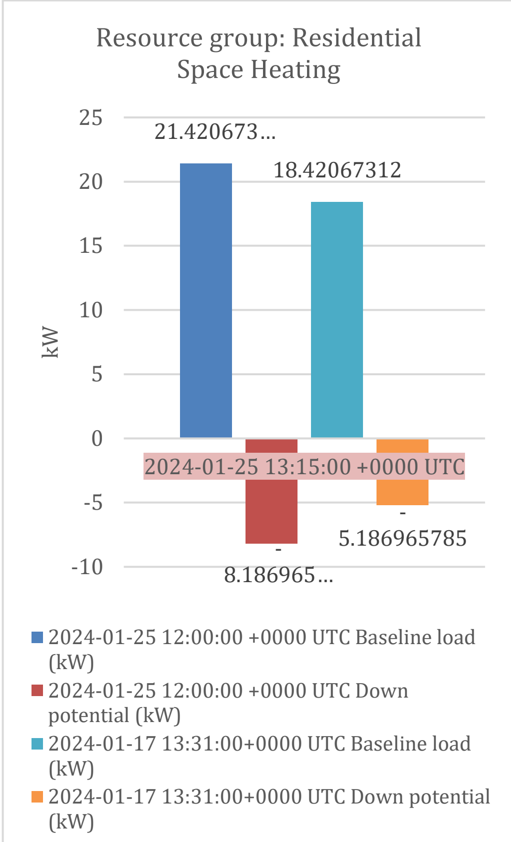

(a) *(b)*

Figure 5.27: Baselines before and after activating flexibility

Table 5.15: Settlement results of scenario 4.

Asset	Bid Price	Activated Amount (MW)	Measurement (MW)	Baseline / Schedule (MW)	Delivered Flexibility (MW)	Remuneration
MP_201	195,00 €	10	0	10	10	1 950,00 €
MP_207_2	35,00 €	45	45	0	45	1 575,00 €
MP_208	50,00 €	30	50	0	50	1 500,00 €
Res_Comsel_chargers_2	98,00 €	48	386,47	667,04	280,57	4 704,00 €
Res_Comsel_heating_2	100,00 €	3	18,4207	20,74	2,32	300,00 €
	Total	**136**			**388**	**10 029,00 €**

Scenario 5: TSO-DSO flexibility for main grid fault

In the scenario 5, the TSO has connected wind power plants with flexible connection agreements in the southern 110 kV network in the nodes 201 and 205. The flexible connection agreement obligates the customer to offer down-regulation on the NRT-P-E market. The scenario 5 is based on a flexible connection concept used in [8], and presented in Figure 5.28. The proposed concept utilizes a short-term (temporary) rating of power

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system components and operational flexibility of market-based resources. In a case of congestion, the short-term rating of power system components provides technical flexibility and enables market-based activation of flexible resources via the NRT-P-E market to maintain system security.

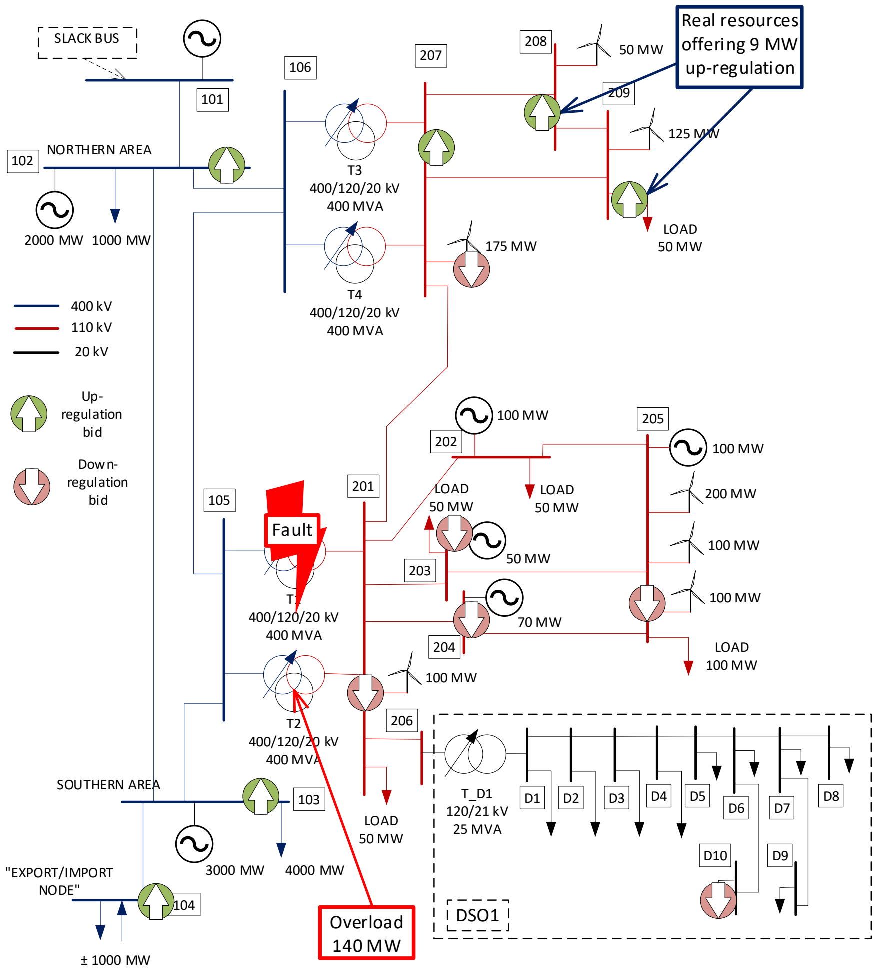

Figure 5.28: Network scenario for the scenario 5.

A fault on a transformer (connected between nodes 105-201) causes congestion on the parallel transformer and NRT-P-E bids from the market are used to solve it. Additional NRT-P-E bids are required from other parts of the network, including the DSO network. A fault clearing in the main grid causes 140 MW congestion in the parallel transformer bay. The TSO specifies a purchase offer to procure NRT-P-E product for the time stamp 02-02-2024, 11:00 – 11:15 UTC. For this case, the power balance is allowed to vary between -10 MW and 25 MW. Like previous Finnish NRT-P-E scenarios, 13 indivisible flexibility bids listed in Table 5.16 are considered. Further, up-regulation at nodes 208 and 209 is offered by FSP Comsel resources whereas remaining flexibility is provided by virtual resources distributed in the network.

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Table 5.16: Offered and cleared bids in scenario 5.

System ID	Node ID	Direction	Price offered (€/MWh)	Quantity offered (MW)	Quantity cleared (MW)
FINGRID	102	Upward	90	65	65
FINGRID	103	Upward	100	30	30
FINGRID	104	Upward	200	25	25
FINGRID	207	Upward	110	40	40
FINGRID	208	Upward	55	8	8
FINGRID	209	Upward	67	1	-
FINGRID	209	Upward	300	40	-
FINGRID	201	Downward	44	70	70
FINGRID	203	Downward	34	55	55
FINGRID	204	Downward	50	15	15
FINGRID	205	Downward	30	40	40
FINGRID	207	Downward	30	25	-
KSOY	D10	Downward	25	2	-

The market clearing algorithm cleared 9 bids and resolved all congestions. It also reported a new power imbalance position of -7 MW. The imbalance results from activating un-equal volume of up- and down-regulation flexibility. Please note that only one bid of Comsel is cleared by the coordination platform. Fingrid MMS cleared all bids as recommended by the coordination platform. The activation was sent to Market integration platform who then acknowledges and forwards the activation to the FSP Comsel. An instance of UI is depicted in Figure 5.29.

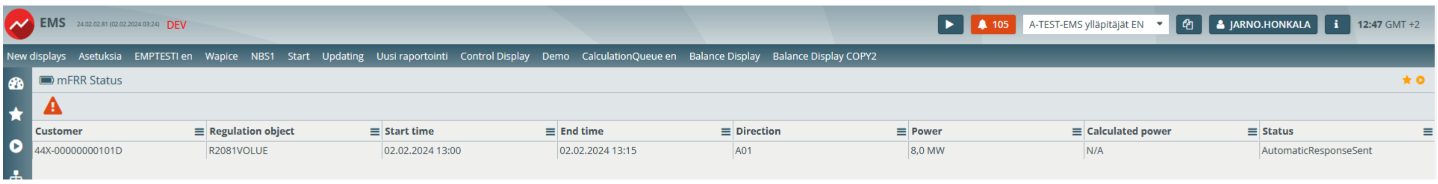

Figure 5.29: Volue's platform sending activations to FSP

Upon receipt of activation, Comsel schedules flexibility activation for the desired time slot. Figure 5.30 demonstrates the EX-post metering data for the resource group corresponding to the cleared bid.

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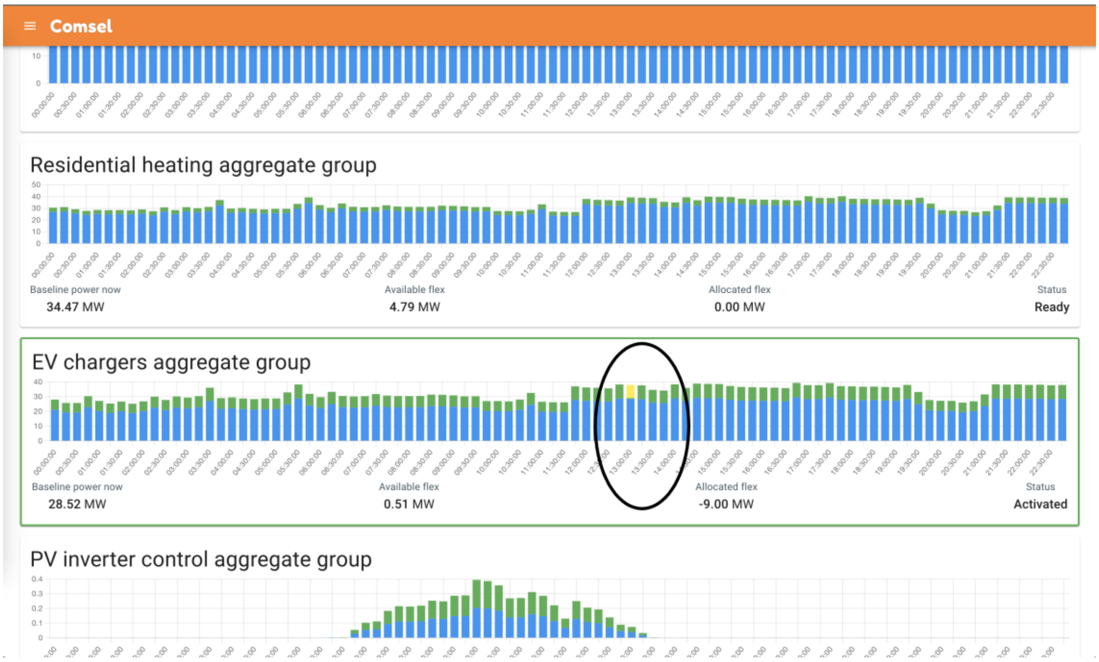

Figure 5.30: FSP UI for scheduling and sending flexibility activations at end-user level

The settlement results of the scenario 5 are presented in Table 5.17.

Table 5.17: Settlement results of scenario 5.

Asset	Bid Price (€)	Activated Amount (MW)	Measurement (MW)	Baseline / Schedule (MW)	Delivered Flexibility (MW)	Remuneration (€)
MP_102	90,00	65	0	65	65	5 850,00
MP_103	100,00	30	0	30	30	3 000,00
MP_104	200,00	25	0	25	25	5 000,00
MP_201	44,00	70	70	0	70	3 080,00
MP_203	34,00	55	55	0	55	1 870,00
MP_204	50,00	15	15	0	15	750,00
MP_205	30,00	40	40	0	40	1 200,00
MP_207_2	110,00	40	40	0	40	4 400,00
Res_Comsel _chargers_3	55,00	8	32,5	30,9	1,6	440,00
Total		**348**			**341,6**	**25 590,00**

5.2.1.4 Conclusions of the Finnish demonstration

The Finnish demonstration successfully demonstrated the end-to-end process of the Northern Demonstrator. This showcased the functioning of the proposed market design and the BUC. The proposed market design and system architecture is comprised of several components, which need to interact efficiently

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for the whole process to work. This was achieved by well-planned process description and working data exchange using commonly designed and agreed interfaces.

The demonstration was made for simulated network situations. Still the workability and scalability was demonstrated by using existing market platforms and real resources. These resources were connected to the process by providing metering data to the aggregation platform which generated the bids based on the forecasted available flexibility. The resource owners or their service providers made estimations about the flexibility potential of their resources, which was found to be a crucial factor for the process.

It was found that the optimization model could find solutions for the congestion cases in the different scenarios. The model provided interesting results since in a complex meshed network, the end-result was not always evident. In this kind of networks, a functionality like the demonstrated optimization model is valuable to find the most cost-effective solutions and avoid creating new congestions while removing existing ones. In real-world, such topologies must be considered when managing congestions in HV grids, which are operated as meshed networks in Finland, as opposed to MV and LV networks which typically are operated as radial networks. In a radial system, the effect of flexibility activations directly affects the flows, losses considered. It is still noteworthy that in operational use such an optimization model, would require up-to-date grid data combined with real-time topology information from all the associated networks, which would be a challenge in the near future. The optimization functionality was also designed to manage congestion while giving a desired range how the imbalance of the system is affected. This functionality both enabled the co-optimization between these needs, but also affected greatly the optimization result. In addition to this, the fact that the Finnish MMS was not developed during the project to handle divisible bids, affected the result by narrowing the options the optimization functionality had in combining different bids.

5.2.2 Estonia

5.2.2.1 Context and objectives

The objective of Estonian demonstrator is to increase liquidity and transparency in the flexibility market, thereby enabling more RES connections while avoiding congestions in the grid. This could be achieved through a common marketplace consisting of harmonised set of flexibility products, processes and tools, both on national and regional level.

Estonian main DSO is already faced with the urgency to manage grid congestions based on the example of neighbouring Hiiumaa island, which is connected to transmission grid through Leisi substation in Saaremaa. Due to the congestions, there is no longer possible for micro-producers to join the grid. The maximum voltages in Hiiumaa's 35 kV power grid have risen to 37.7 kV (see Figure 5.32). The voltage regulators of the 35/10 kV transformers are set to the lowest voltage level, there is no additional regulation capability. It is not possible to

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ensure that voltages remain within the permitted limits. Therefore, it is necessary to reconstruct the electricity network or provide flexibility services. On the voltage side, the critical limit is when consumption exceeds production by 2 MW or less.

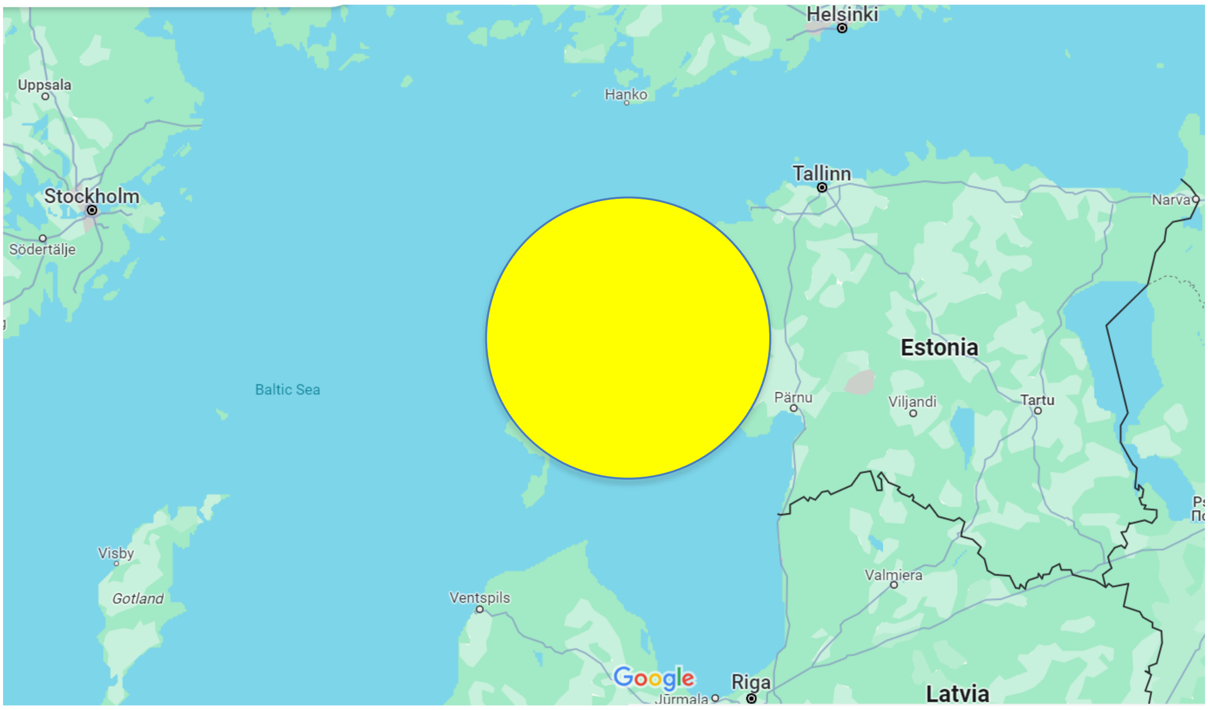

Figure 5.31: Estonian demonstrator – Saaremaa island

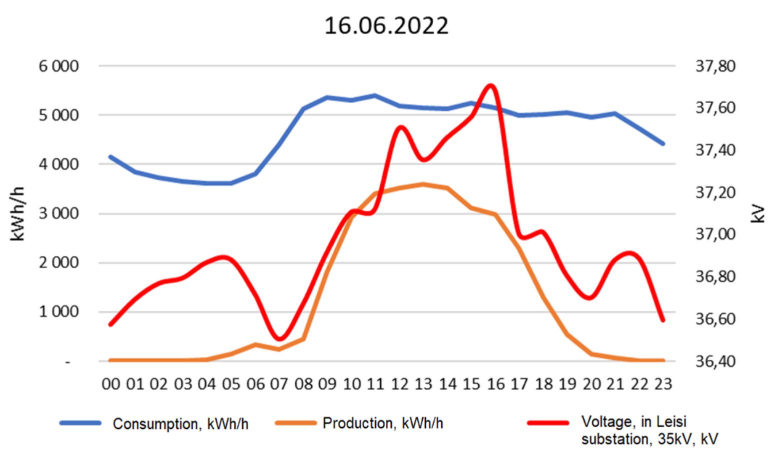

Figure 5.32: Example of critical voltage levels in Hiiumaa island

The expectations of Estonian TSO (Elering) and DSO (Elektrilevi) vis-à-vis the solutions provided in the OneNet project:

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- Registering flexibility resources and prequalification results → Flexibility Register enables that, including separate "product prequalification" and "grid prequalification". Common register of both TSO and DSO facilitates the participation of FSPs.
- Collecting of flexibility bids → Direct interaction with the FSPs regarding bid collection is the task of MOs. All MOs forward the bids to the central clearing/optimisation algorithm using CIM compliant message structure. FSPs are encouraged to use this same structure.
- Collecting grid information → Grid information is needed for optimization and grid qualification. It includes topology, line limits, base flows and PTDFs. TSO and DSO can submit grid information to TSO-DSO Coordination Platform and thereby use common data structure.
- Optimising the bids → Central optimisation algorithm enables value-stacking, i.e. optimising the bids from all MOs per product across different needs (balancing, congestion management) and different flexibility buyers (TSO, DSO). The algorithm is based on least total cost and aims at minimising the total amount of congestions as much as possible with available bids.
- Activating cleared bids → Information about cleared bids is sent from the optimization algorithm back to the concerned MOs. It is the task of the MO to forward the activation request to the FSP, which has the responsibility to activate the resource.
- Collecting metering data → While measurements from both main meters and sub-meters are needed for verification and financial settlement, these data can be provided from the national data hub as well as directly by the FSPs to the Flexibility Register.
- Verifying the activated flexibilities → Verification is performed by the Flexibility Register based on metering data and baselines. FSP can calculate the baseline itself and send it to Flexibility Register or Flexibility Register calculates the baseline itself.
- Settling financially → Financial flexibility settlement is primarily the task of buying SO and imbalance settlement is the task of TSO. However, Flexibility Register can easily calculate the cost of activated flexibilities and provide this information as input to other parties.

Regarding balancing, the need is to integrate distributed resources, including demand side, in practice (regulation already allows), at the same time avoiding creation of congestions in the distribution grid. Optimisation algorithm enables to take into account the imbalance position when optimising for the congestion management.

Regarding congestion management, adding new RES generation in some areas would cause congestions in certain hours in both distribution and transmission grids creating voltage issues, especially if taking future bookings into account.

NRT-P-E product proposed by Northern cluster to solve simultaneously balancing and congestion management issues is almost one-to-one based on mFRR, it can be applied to aFRR also. As such it is familiar at

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least to TSOs already on one side. On the other side, it enables to bring synergies and value-stacking. Therefore, NRT-P-E was of the primary interest in Estonian demonstrator.

As part of that also LT-P-C product was put into scope for ensuring long-term readiness. However, it is essentially the same from demonstration perspective – registration and prequalification of resources, submission of (capacity) bids and optimising them would happen exactly in the same way as in case of NRT-P-E product.

5.2.2.2 Technical implementation

Figure 5.33 summarises the main actors and objects involved in Estonian demonstrator. Strong focus was on actual residential resources to provide the flexibility. Different types of real assets like heat pumps were made available by Digital4Grids, while Futugrid brought in a bulk of simulated water boilers. R8 Energy provided flexibility from commercial buildings.

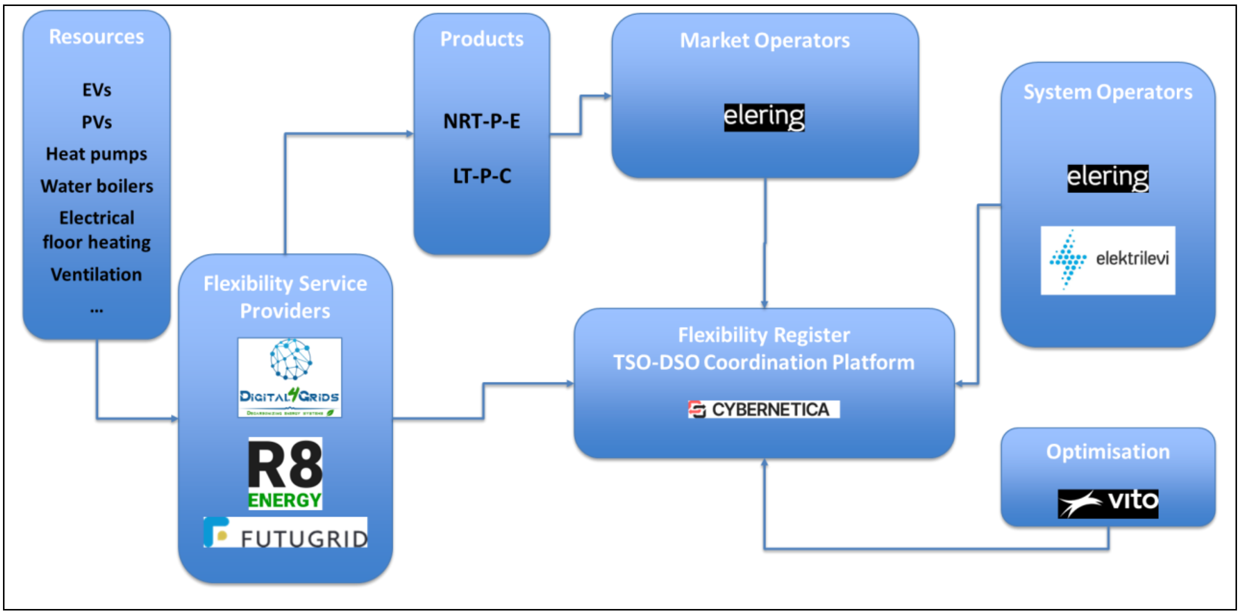

Figure 5.33: Interrelations of actors and objects of Estonian demonstrator

The most interesting product to demonstrate was NRT-P-E product which can be consumed by both TSO and DSO for congestion management, but also for the balancing. Elering as TSO plays the role of Market Operator for this product. Capacity product (ST-P-C / LT-P-C) was also analysed, but it did not require dedicated demonstration being technically very similar to NRT-P-E product.

Elering's Balance Management System and FSPs' internal systems were integrated with Flexibility Register and TSO-DSO Coordination Platform, which were developed by Cybernetica for the project. Elektrilevi and Elering as system operators provided grid information on ad-hoc basis – there are no permanent existing IT solutions available yet. Vito development the optimisation service connected to T&D CP.

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5.2.2.3 Demonstration scenarios

Two scenarios linked to network congestions in Saaremaa island were investigated:

1) "Summer" scenario with lots of grid connected solar and wind in combination with some line outages
2) "Winter" scenario with peak demand in combination with even further line outages

While in normal conditions grid congestions are not expected in Estonia, two extreme hours based on year 2023 were picked where the risk of either generation- or consumption-side congestions might occur. Beside considering the actual consumption and generation amounts and grid characteristics of these hours, the new grid capacity bookings potentially implemented in coming years must be added. Only against this starting point the congestions resulting from even further grid connections can be evaluated.

Figure 5.34 outlines the geographical location and some main characteristics of the demonstrated scenarios. Though some of the flexibilities are simulated and some are located elsewhere in real life, all of them were linked to the specific demonstration area as shown on the map.

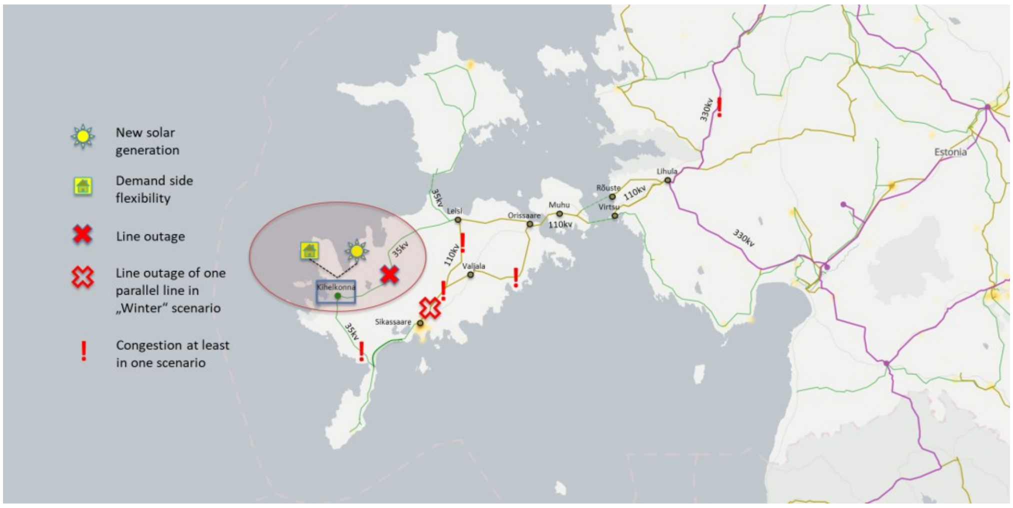

Figure 5.34: Geographical location of Estonian demonstrator's scenarios [9]

Figure 5.35 illustrates the nearby area and grid characteristics of Kihelkonna substation where the flexible resources are either virtually or in real life connected to in Estonian demonstrator. The substation itself and its two connecting 35 kV lines are part of distribution grid. Both 35 kV lines are connected to transmission grid. If one of the 35 kV lines would be disconnected because of a planned or unplanned event, the other line could still provide demand load to Kihelkonna area or transport RES generated power from that area. It should be noted that the numbers used hereby are not exact and are meant only for the purpose of this demonstration.

When taking future booked connection capacities into account it is already impossible to install new solar and wind facilities in many locations in Saaremaa. Even as small installations as 10-100 kW would require grid enhancements, both in distribution and transmission grids. This means that just very few flexible heat pumps (or other devices) could additionally consume the production of a 20 kW PV installation in peak hours. In this case, PV plant owner would be obliged to compensate this additional consumption (i.e. to receive lower price compared to market price) in order to make someone to consume the extra generation. The alternative would be non-firm grid connection agreement.

Using flexibilities should be also considered in case of both planned (maintenance) and unplanned (storm damages) outages. The goal is to minimise the unserved energy and optimise costs – cost of flexibility vs. cost of compensation of unserved energy. Possible consequences to be solved: (a) disconnection of one line will overload the other line connecting the consumers and generators with dual connection (meshed solution); (b) even if the other line is not overloaded it is necessary to ensure n-1 situation.

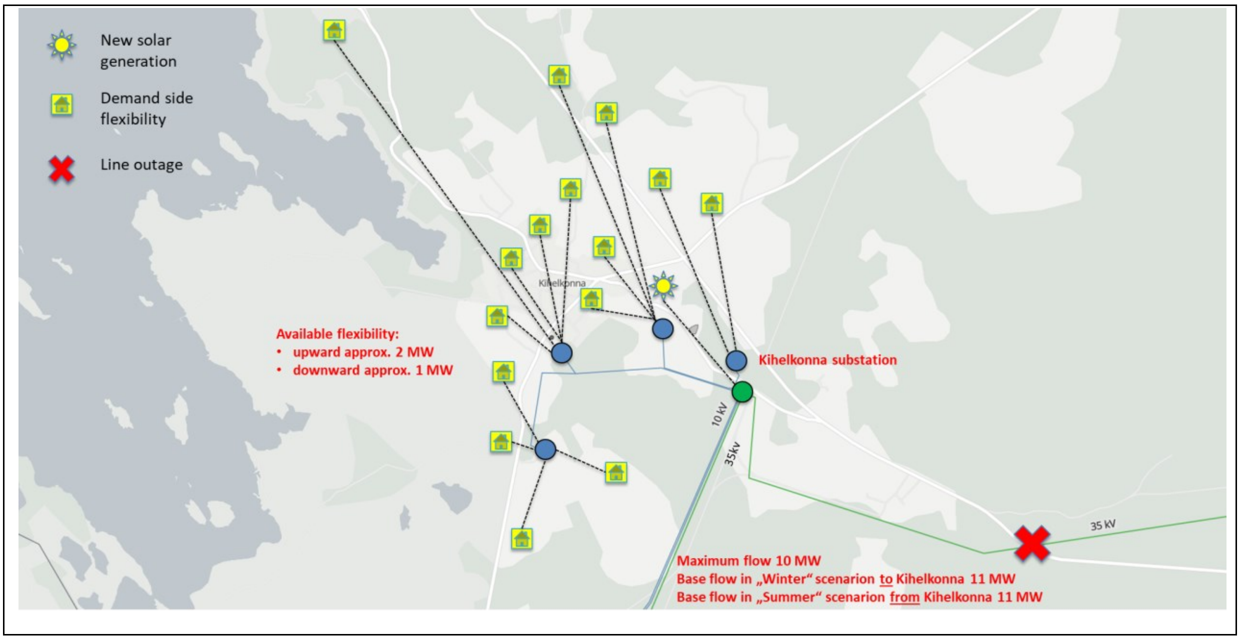

Figure 5.35: The area and characteristics of Kihelkonna substation in Estonian demonstrator [9]

The starting point for defining "Winter" and "Summer" scenarios were the actual peak hours in 2023:

- Consumption peak in winter – 23.01.2023 at 11-12EET, total Estonian consumption – 1380 MWh (and total generation – 872 MWh) – Figure 5.36;
- RES generation peak in summer – 3.07.2023 at 13-14EET, total Estonian generation – 810 MWh, incl. solar 366 MWh and wind 306 MWh (and total consumption – 946 MWh) – Figure 5.37;

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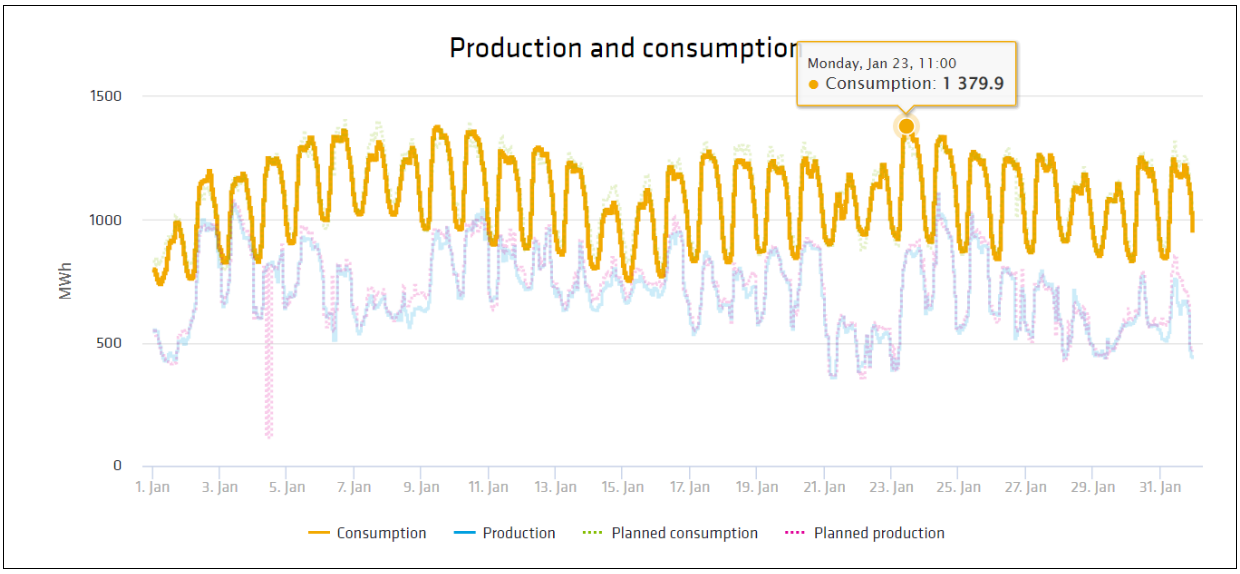

Figure 5.36: Total hourly electricity consumption and generation in Estonia in January 2023 [10]

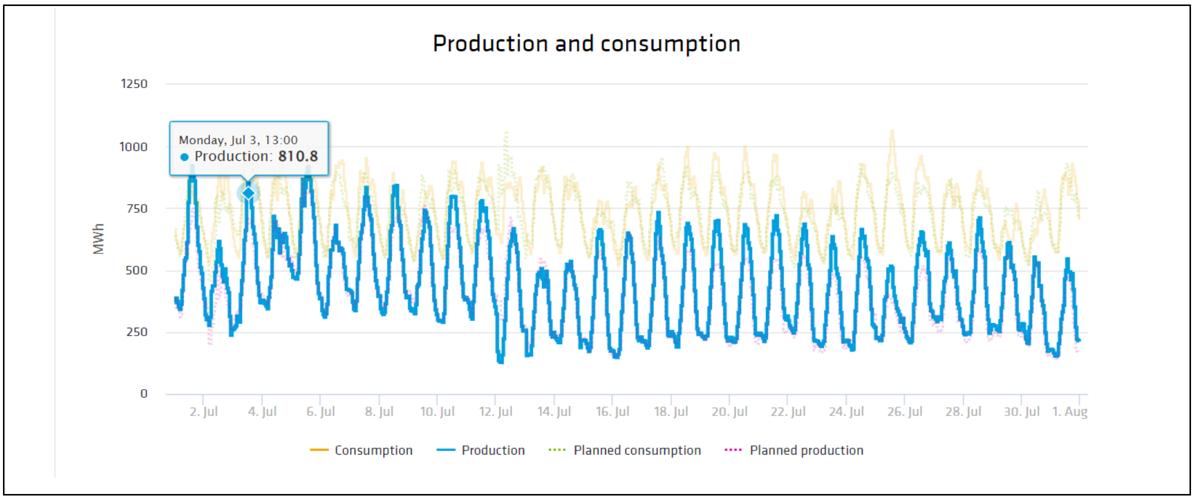

Figure 5.37: Total hourly electricity consumption and generation in Estonia in July 2023 [10]

For these two extreme hours the data about all transmission lines in Saaremaa and relevant distribution lines was collected, and then complemented with additional demand and generation emerging in five years from now. In case of demand the normal growth was projected. In case of generation, all currently known new connection applications were considered. Table 5.18 summarises the line capacities and base flows for both scenarios. It should be noted that some simplifications in grid topology were made. Also, maximum line capacities of some key lines were divided by two, in order to reflect the N-1 situation.

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Table 5.18: Grid capacities and base flows in "Winter" and "Summer" scenarios

	Line name	Winter consumption peak		Summer RES generation peak	
		Capacity at 0°, MW	Base flow, MW	Capacity at +25°, MW	Base flow, MW
TSO lines	Kullamaa_Lihula	143	30	143	-145
	Lihula_Rouste	136	30	136	-50
	Lihula_Virtsu	150	30	82	-40
	Rouste_Virtsu	60	8	60	0
	Virtsu_Orissaare	89	35	42	-25
	Rouste_Leisi	71	20	71	-35
	Orissaare_L177HP *	**30**	30	**16**	-20
	L177HP_Sikassaare *	**30**	32	**16**	-20
	L177HP_Valjala *	**30**	-2	**16**	0
	Leisi_L175HP *	**30**	5	**21**	-25
	L175HP_Valjala *	**30**	5	**21**	-5
	L175HP_Sikassaare *	OUTAGE		**21**	-20
DSO lines	*Sikassaare_Kihelkonna*	10	11	10	-11
	Leisi_Kihelkonna	OUTAGE		OUTAGE	

* Maximum actual capacity divided by two to reflect the N-1 situation.

5.2.2.4 Demonstration results

FSP perspective

The D4G platform is acting as a Flexibility Service provider platform through the demonstration and is interacting with both Flexibility Register (for flexibility registration, near real-time nomination as well as ex post DER measurements exchanges) as well as with Elering's (MO) Balance Management System (for flexibility bidding and activation) as per Figure 5.38.

The proposed D4G platform is composed of 2 applications interacting with each other through Cloud-to-Cloud communication as follows:

1. First, front-end application providing prosumers with real-time analytics on their energy, power flexibility and carbon footprint performance based on measurements provided by smart meters, dedicated measurement devices and IoT sensors installed on flexible resources throughout the house environment – covering necessary user consent management on sharing her/his private data. This application was demonstrated based on a portfolio with 14 homes being real-time metered and incorporating real-time APIs to auto trade near real-time flexibility with System Operators.

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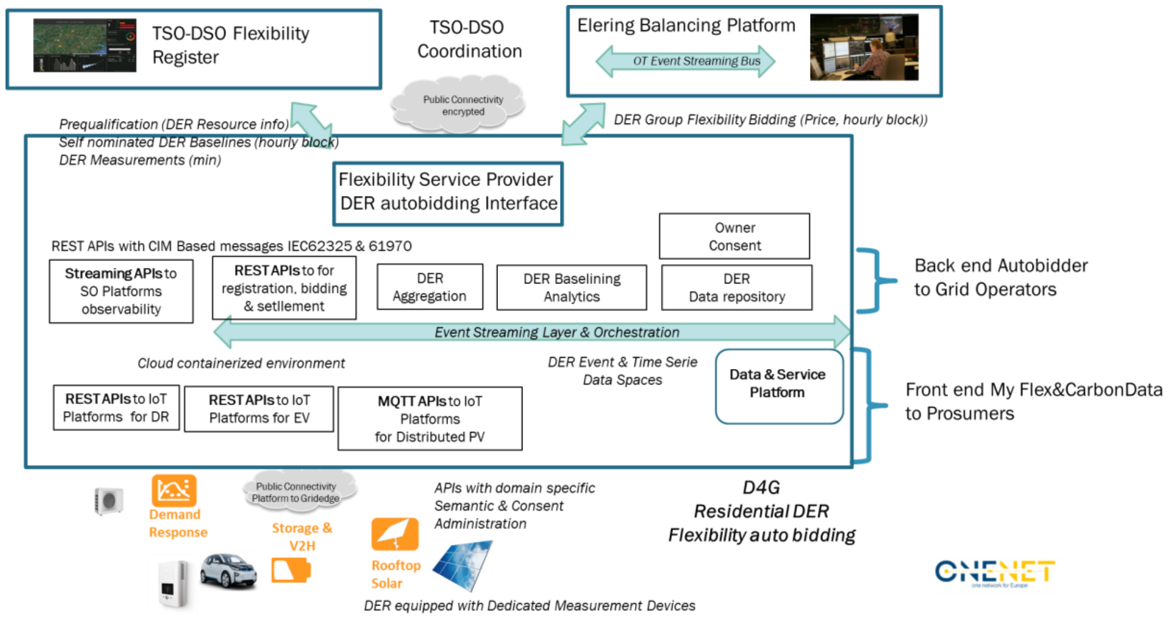

Figure 5.38: FSP platform of D4G

2. Second, back-end application enabling intraday automated baseline nomination, DER flexibility calculations and real-time activation as well as ex-ante/ex-post event performance monitoring to TSO and DSOs considering various DER groups distributed at different grid nodes of their electricity system. This application is able to manage necessary spatial and time-based aggregation / disaggregation of flexibility transaction data related for mFRR, aFRR and congestion markets spread at different nodes of the TSO-DSO electrical system. The event performance monitoring can be offered down to real-time second level response for fastest flexibility products. For the purpose of the demonstration, the application has been tested on the basis of the data published by real homes using submetering and DER control units through real-time metered and aggregated data of DER Group referred as Roinville and Estonia (both associated to a local DSO node).

The demonstration interacts with 14 real homes located in France and Estonia, particularly focusing on residential prosumers equipped with different DERs behind the utility meter for which the only use of smart metering data exchanges neither allow accurate flexibility baselines and calculation nor any automated controls and so representing significant obstacles to residential flexibility participation. Figure 5.39 provides indications of typical residential environment configurations connected through the demonstration.

My Flex Power Dashboard in Figure 5.40 highlights the typical real-time data granularity used in homes to compute associated flexibility analytics through complementary submetering / dedicated measurement devices used at DER level.

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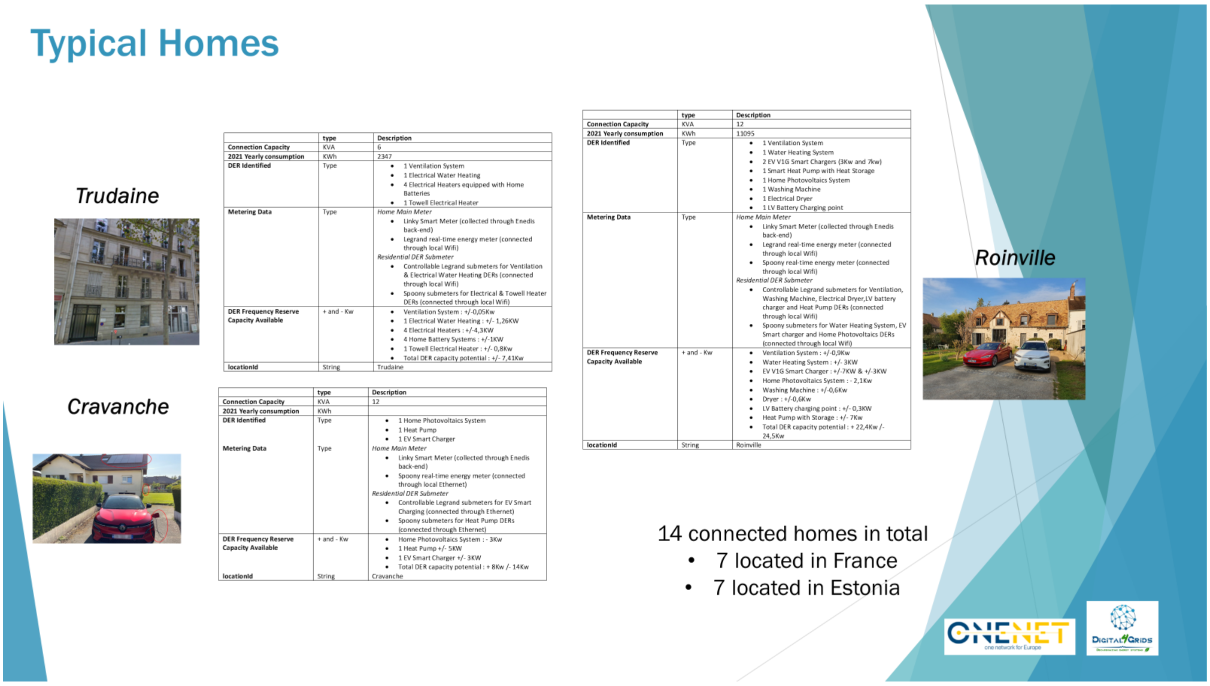

Figure 5.39: Typical residential environment configurations

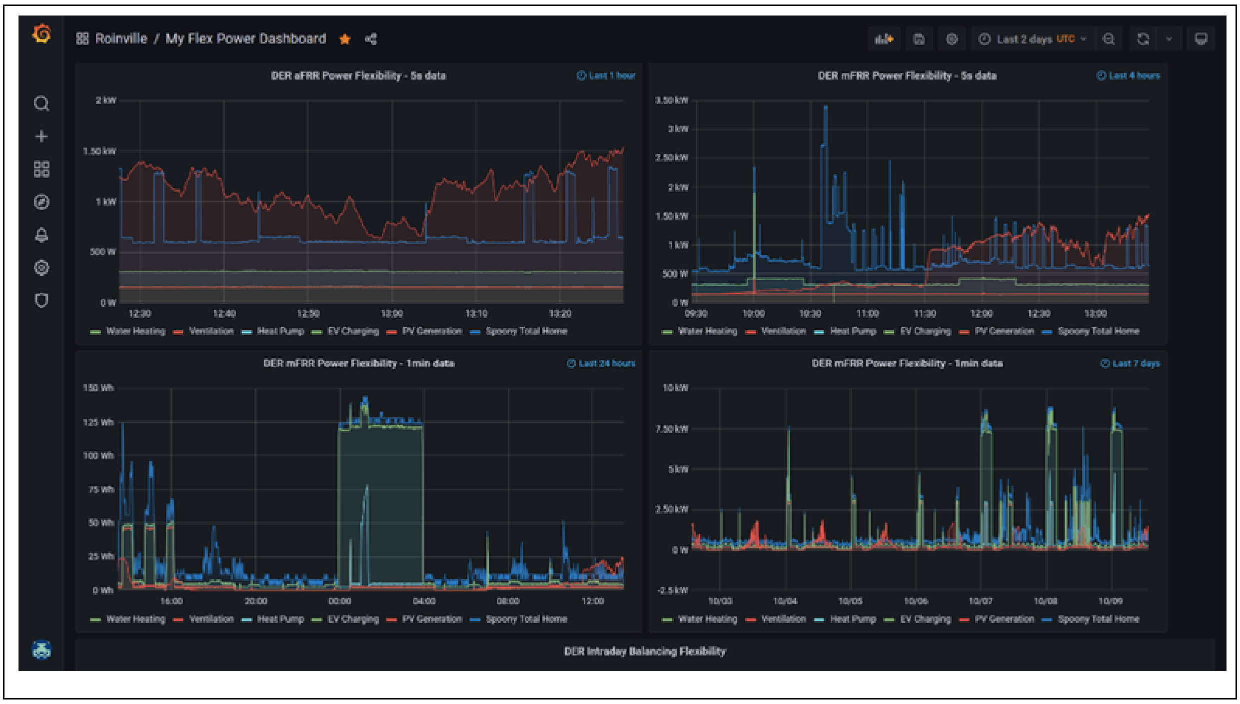

Figure 5.40: My Flex Power Dashboard

My Flex Forecast Dashboard in Figure 5.41 allows to calculate DER baselines near real-time over different daily time horizons (day ahead/hour ahead/15min) incorporating different options for statistical and/or machine learning algorithms. These forecasts are used as a basis to calculate associated DER flexibilities and aggregate into DER group transactions.

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Figure 5.41: My Flex Forecast Dashboard

The D4G platform has been natively designed leveraging CIM ontology and semantic and so enabling data exchanges derived from IEC62325 European Style Market Profile for market interfaces as well as IEC62746-4 standards for exchanges with DER control units (which has not been used in this demonstration given the specificities of associated DERs). All APIs are enabling real-time intraday data exchanges as required for the near real-time nomination of DER baselines and intraday flexibility bidding and activation of DER using dedicated measurement/submetering devices.

Each sub metered DER can share its relevant flexibility data through D4G platform directly per DER and through groups of DERs covering typically the following use cases:

- the allocation of sub metered DER per FSP portfolio. The platform allows prosumers to opt for different FSP per DERs as well as define different price sensitivities for these resources. As part of this process, prosumers have to provide their consent to participate in different DER flexibility programs which indirectly cascade in corresponding authorisation to share DER private data with FSPs and/or SOs. The platform assumes a given sub metered resource can only be allocated into a single FSP for a given market time unit and so allows to stack revenue opportunities through different days from different mFRR, aFRR and congestion management flexibility products (assuming market rules allow it);
- for certain DER to act as an auto trading platform virtually aggregating flexibility resources on prosumer's behalf in selected markets and so automating near real-time baseline calculation and flexibility bidding into markets (mFRR, aFRR, congestion management). We have assumed in the OneNet demonstration that all DERs have been allocated to two aggregation groups directly trading into the NRT-P-E market;

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- for citizen energy communities to be able to aggregate in real-time community renewables with their citizen flexible DER loads and so maximise the use of their community renewables through community self-consumption while nominating the associated balance to an FSP. This functionality has not been directly tested in OneNet.

We have assumed the allocation of sub metered flexibility resources per DER group is fixed for the period of the demonstration and configured as follows.

- all sub metered flexibility resources have been allocated to one out of two different DER groups – referred as Roinville and Estonia– directly participating into the NRT-P-E market using mFRR intraday products;
- the demonstration focused on DER near real-time baseline nomination, bidding, activation and ex-post settlement considering all flexibility available at t-25 (i.e.25 minutes ahead of each delivery period). The platform has set up necessary analytics to monitor baseline accuracy and associated event performance down to every event and DER.

My Flex Transaction Dashboard in Figure 5.42 has been designed per DER group to be able to monitor flexibility transaction from bidding to settlements.

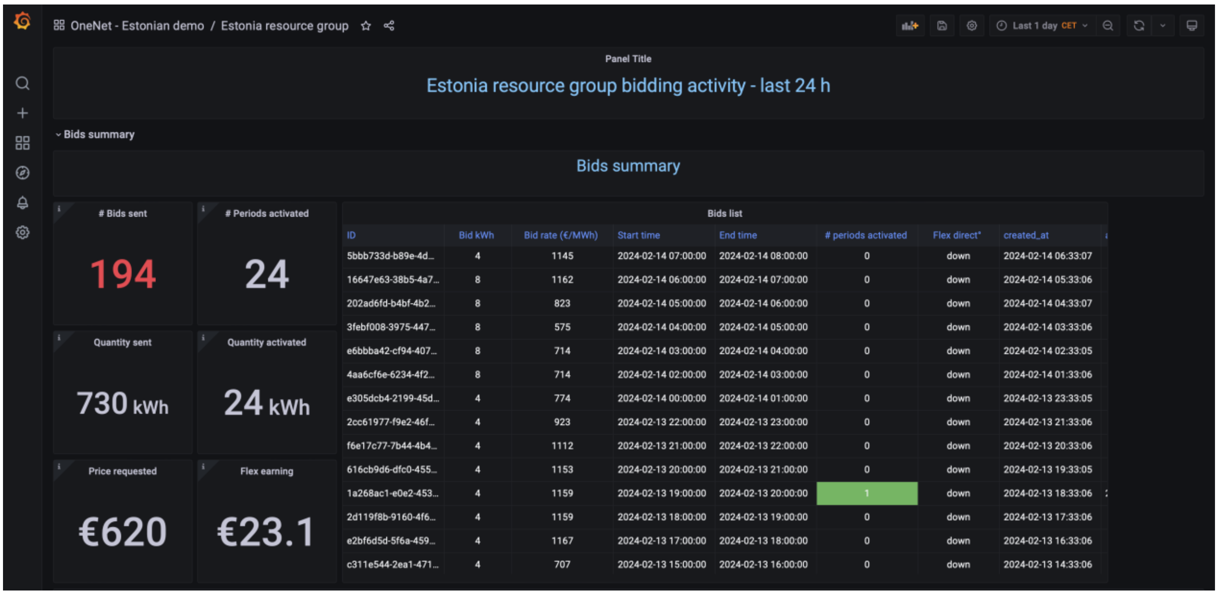

Figure 5.42: My Flex Transaction Dashboard

The D4G platform also allows to identify flexibility events down to prosumers through their My Energy Data Dashboard leveraging their Dedicated Measurement Device information (Figure 5.43).

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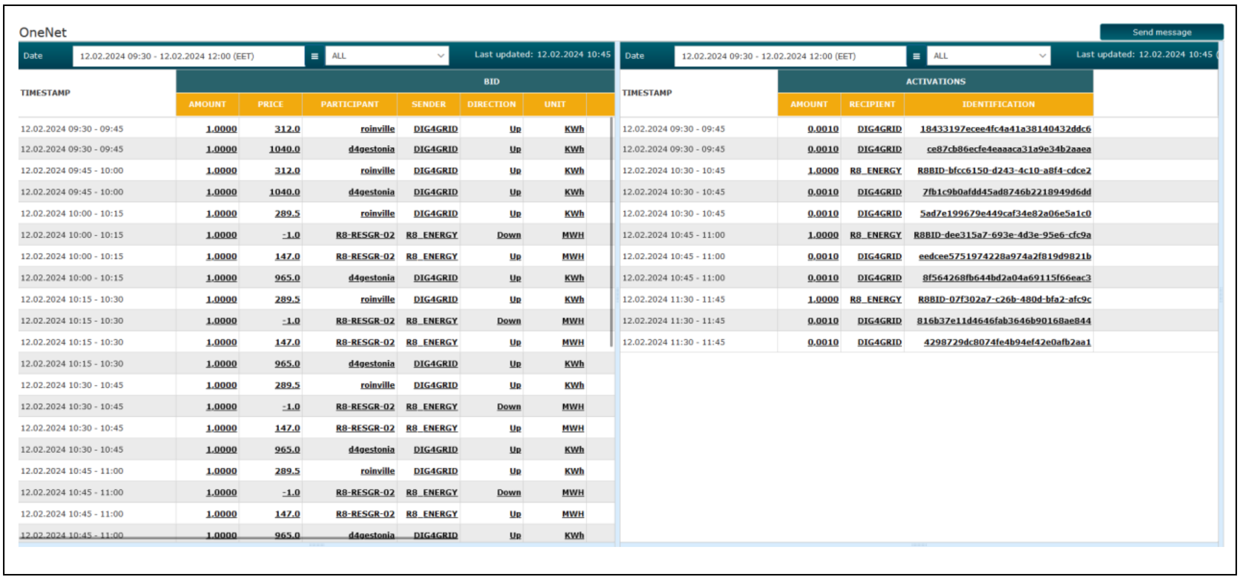
Figure 5.43: My Energy Data Dashboard

__MO perspective__

In the demonstrator the MO role was assumed by Elering, Estonian TSO (as it is the practice today on the balancing market). Main tasks of the MO were to collect bids from three participating FSPs, forward the bids to T&D CP for optimisation, receive optimal set of bids from T&D CP, and send activation orders to FSPs. Figure 5.44 depicts the screenshot with submitted bids and sent activation orders from Elering's Balance Management System – the same system as used currently for mFRR market.


OneNet

Date: 12.02.2024 09:30 - 12.02.2024 12:00 (EET) | ALL | Last updated: 12.02.2024 10:45

TIMESTAMP	BID					
	AMOUNT	PRICE	PARTICIPANT	SENDER	DIRECTION	UNIT
12.02.2024 09:30 - 09:45	1,0000	312.0	roinville	DIG4GRID	Up	KWh
12.02.2024 09:30 - 09:45	1,0000	1040.0	d4gestonia	DIG4GRID	Up	KWh
12.02.2024 09:45 - 10:00	1,0000	312.0	roinville	DIG4GRID	Up	KWh
12.02.2024 09:45 - 10:00	1,0000	1040.0	d4gestonia	DIG4GRID	Up	KWh
12.02.2024 10:00 - 10:15	1,0000	289.5	roinville	DIG4GRID	Up	KWh
12.02.2024 10:00 - 10:15	1,0000	-1.0	R8-RESGR-02	R8_ENERGY	Down	MWH
12.02.2024 10:00 - 10:15	1,0000	147.0	R8-RESGR-02	R8_ENERGY	Up	MWH
12.02.2024 10:00 - 10:15	1,0000	965.0	d4gestonia	DIG4GRID	Up	KWh
12.02.2024 10:15 - 10:30	1,0000	289.5	roinville	DIG4GRID	Up	KWh
12.02.2024 10:15 - 10:30	1,0000	-1.0	R8-RESGR-02	R8_ENERGY	Down	MWH
12.02.2024 10:15 - 10:30	1,0000	147.0	R8-RESGR-02	R8_ENERGY	Up	MWH
12.02.2024 10:15 - 10:30	1,0000	965.0	d4gestonia	DIG4GRID	Up	KWh
12.02.2024 10:30 - 10:45	1,0000	289.5	roinville	DIG4GRID	Up	KWh
12.02.2024 10:30 - 10:45	1,0000	-1.0	R8-RESGR-02	R8_ENERGY	Down	MWH
12.02.2024 10:30 - 10:45	1,0000	147.0	R8-RESGR-02	R8_ENERGY	Up	MWH
12.02.2024 10:30 - 10:45	1,0000	965.0	d4gestonia	DIG4GRID	Up	KWh
12.02.2024 10:45 - 11:00	1,0000	289.5	roinville	DIG4GRID	Up	KWh
12.02.2024 10:45 - 11:00	1,0000	-1.0	R8-RESGR-02	R8_ENERGY	Down	MWH
12.02.2024 10:45 - 11:00	1,0000	147.0	R8-RESGR-02	R8_ENERGY	Up	MWH
12.02.2024 10:45 - 11:00	1,0000	965.0	d4gestonia	DIG4GRID	Up	KWh

Send message

Date: 12.02.2024 09:30 - 12.02.2024 12:00 (EET) | ALL | Last updated: 12.02.2024 10:45

TIMESTAMP	ACTIVATIONS		
	AMOUNT	RECIPIENT	IDENTIFICATION
12.02.2024 09:30 - 09:45	0,0010	DIG4GRID	18433197ecee4fc4a41a38140432ddc6
12.02.2024 09:30 - 09:45	0,0010	DIG4GRID	ce87cb86ecfe4eaaaca31a9e34b2aaea
12.02.2024 10:30 - 10:45	1,0000	R8_ENERGY	R8BID-bfcc6150-d243-4c10-a8f4-cdce2
12.02.2024 10:30 - 10:45	0,0010	DIG4GRID	7fb1c9b0afdd45ad8746b2218949d6dd
12.02.2024 10:30 - 10:45	0,0010	DIG4GRID	5ad7e199679e449caf34e82a06e5a1c0
12.02.2024 10:45 - 11:00	1,0000	R8_ENERGY	R8BID-dee315a7-693e-4d3e-95e6-cfc9a
12.02.2024 10:45 - 11:00	0,0010	DIG4GRID	eedcee5751974228a974a2f819d9821b
12.02.2024 10:45 - 11:00	0,0010	DIG4GRID	8f564268fb644bd2a04a69115f66eac3
12.02.2024 11:30 - 11:45	1,0000	R8_ENERGY	R8BID-07f302a7-c26b-480d-bfa2-afc9c
12.02.2024 11:30 - 11:45	0,0010	DIG4GRID	816b37e11d4646fab3646b90168ae844
12.02.2024 11:30 - 11:45	0,0010	DIG4GRID	4298729dc8074fe4b94ef42e0afb2aa1

Figure 5.44: Screenshot of Elering's Balance Management System with submitted bids from FSPs (left side) and activation orders to FSPs (right side)

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For the OneNet demonstrator, only minor upgrades were needed to apply the system to congestion management. Bid and activation messages were configured compliant to standards (CIM). For processing incoming messages (bids from FSPs, selected bids for activation from T&D CP) gates for receiving the messages and transformations for storing the messages were created. For forwarding the outgoing messages (bids to T&D CP, activation orders to FSPs) the messages were configured towards the respective endpoints.

SO perspective

SO role was assumed by Elering (TSO) and Elektrilevi (main DSO in Estonia) in the project. While the main task of SO is the purchaser task in flexibility market, technically most challenging was to compile the needed grid data in the needed structure. Such data is required for both grid qualification and bid optimisation. Access to source data was not always straightforward because it was time-consuming for SOs to provide the necessary data and the way how to interpret the data took quite some further effort. Next, PTDFs have not been used before and were calculated for the first time (for TSO lines only) – this presumed setting up methodology and script for automated calculation. Finally, for calculating the congestions, also the "booked" network capacities must be considered. This is especially the case on generation side, whereby large amounts of RES providers are in the process to sign network connection agreements in coming years.

TSO-DSO coordination platform perspective

Bid optimisation functionality of the T&D CP was demonstrated over a period of several days. This included regular 15-minutes bids from three FSPs forwarded by MO to T&D CP as well as two sets ("summer" and "winter" scenarios) of grid data (topology, line capacities, base flows over the lines, PTDFs) from both TSO and DSO as input data to the optimisation algorithm. Figure 5.45 summarises some of the optimisation algorithm output data (cleared bids, total cost, updated grid data) as contained in the respective message.


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"response": {
 "requestId": 950772561,
 "clearedBids": [
  {
   "id": "R8BID-82eb50ea-f45a-4482-91ca-9bf84",
   "systemId": "Elering2",
   "requestSense": "Upward",
   "bidType": "FullyDivisible",
   "dispatch": 1000,
   "price": 0.149
  },
  /.../
 ],
```


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```
    "totalCost": 295,
    "totalCostComponents": null,
    "updatedFlowsOverLines": [
     {
       "lineId": "Sikassaare_Kihelkonna",
       "systemId": "Elering2",
       "fromNode": "Sikassaare",
       "toNode": "Kihelkonna",
       "flow": 9000,
       "overflow": 0
     },
     /.../
     ],
    "updatedFlowsOverInterfaceLines": [],
    "newImbalance": 2000,
    "optimizationStatus": "ALL CONGESTION RESOLVED",
    "timestamp": {
     "start": "2024-02-07T19:45:00Z",
     "end": "2024-02-07T20:00:00Z"
    },
    "optimizationTime": 0.04687643051147461,
```

Figure 5.45: Example of optimisation algorithm output data structure

The user interface for SOs enables summary reports per delivery period and detailed overview of all the bids, including if they were selected for activation. According to the screenshot of a summary report in Figure 5.46 seven bids with upward capacity of 4,002 MW and downward capacity of 1 MW from two FSPs were received for the given delivery period and three bids were selected in the node called Kihelkonna for activation as the result of optimisation.

Figure 5.47 depicts a snapshot of slightly simplified network topology of the demonstration area, including the key nodes of TSO and DSO, based on one specific market run of “Summer” scenario. It includes flows over lines before market run and after bid optimisation. Flows are negative, meaning that during summertime flows are from island towards mainland, which will be more and more common in coming years when additional RES generation will emerge.

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Delivery time: 2024-02-13T08:30:00Z - 2024-02-13T08:45:00Z
Product code: NRT-P-E
Domain: EE

Bids:	7
Activated bids:	3
Total quantity coming in:	4.002 MW
Total quantity going out:	1 MW
Total activation order quantity coming in:	2.002 MW
Total activation order quantity going out:	0 MW
FSPs:	2

SO - Node pairs

SO ID	Node	Total quantity in (MW)	Total quantity out (MW)	Activation order quantity in (MW)	Activation order quantity out (MW)
Elering2	Kihelkonna	4.002	1	2.002	0

Figure 5.46: Screenshot of SO user interface with summary report of submitted and selected bids

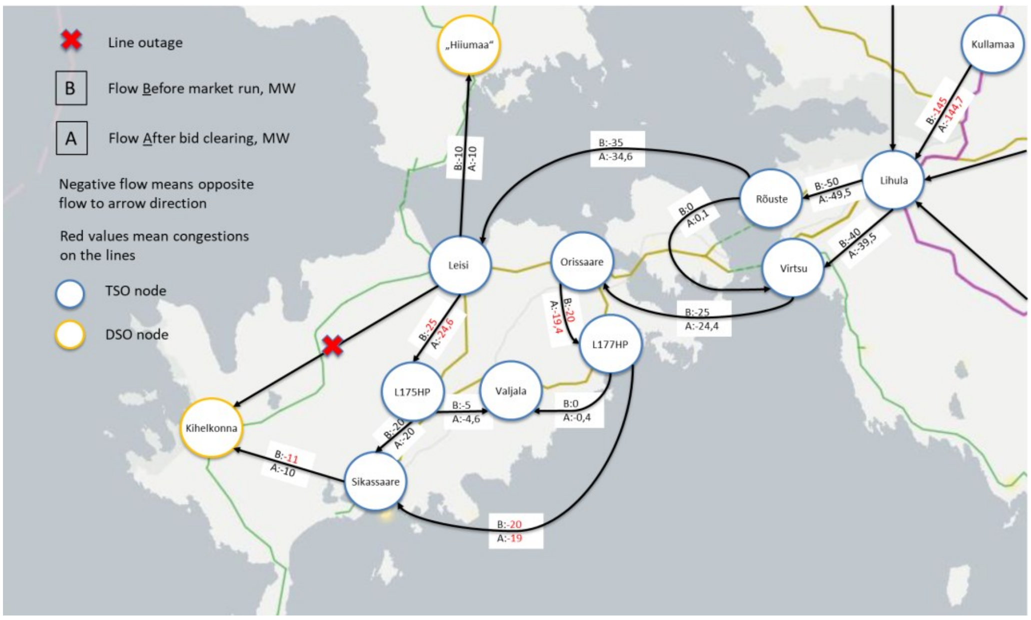

Figure 5.47: Grid topology with flows before and after flexibility market run

In this example 1 MW of downward flexibility (i.e. consumption increase) was available in DSO owned Kihelkonna node. This helped to solve the congestion between Kihelkonna and TSO grid (Sikassaare node), while the other connection between Kihelkonna and TSO grid (Leisi node) was assumed not to be available. The same flexibility contributed to decreasing congestions in TSO grid, though sometimes to a lesser extent because of the PTDF values. As such, with the optimisation process it was confirmed that simultaneous congestions in both TSO and DSO grids can be solved with same resources at the same time. Table 5.19 summarises these synergies for the very same example described in this paragraph in terms of total number of congestions and total sum of

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overflows in both grids. 1 MW of DSO connected flexibility contributed to removal of 1 MW congestion in DSO grid and 2,3 MW in TSO grid.

Table 5.19: Synergies of common bid optimisation

	Number of congestions		Cleared bids, kW	Sum of overflows, kW	
	initial	after optimisation		initial	after optimisation
In TSO network	4	4	0	14 000	11 735
In DSO network	1	0	1 000	1 000	0

Flexibility register perspective

Flexibility register enables an API and graphical user interface for FSPs for several processes and data exchanges – registration of FSP, registration of resources (Figure 5.48), building resource groups, prequalification, access to flexibility needs and calls for tender, submission of metering data and baselines, calculation of baselines, receiving verification results.

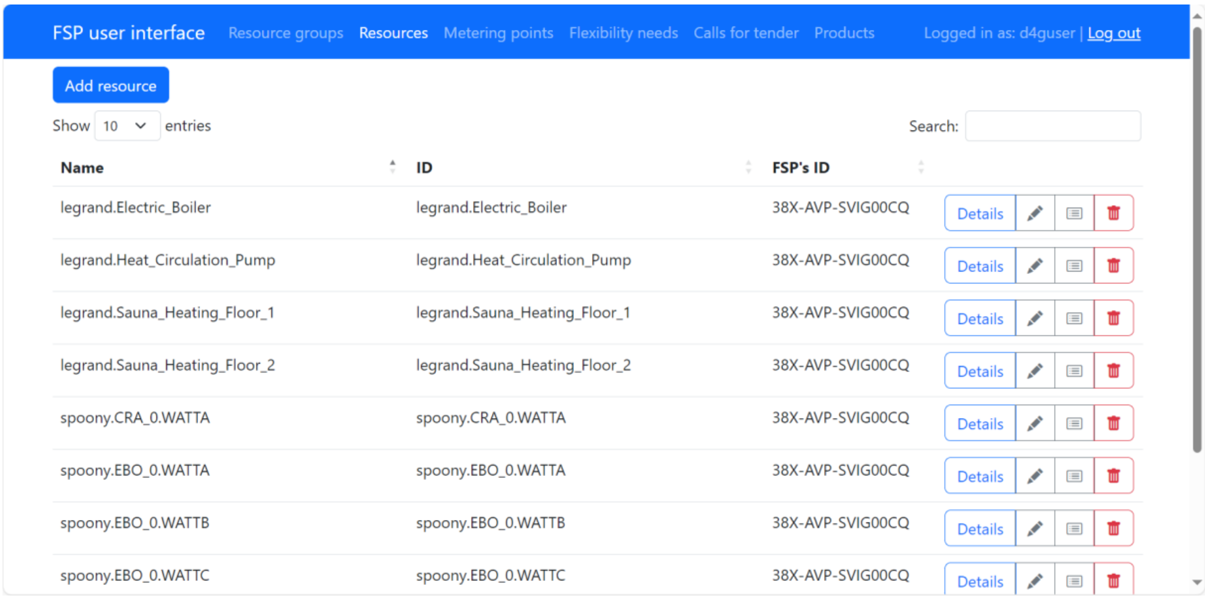

Figure 5.48: Screenshot of FSP user interface with list of available resources

Regarding verification of activated flexibilities, the submission of sub-meter data was facilitated by flexibility register and largely used by one FSP. The same FSP also provided the baselines calculated by themselves. For comparison, flexibility register also calculated the baselines based on the received metering data. This all enabled to check the accuracy of both kinds of baselines (during the periods of no activation) and to verify to what extent the cleared bids were actually activated. Some results are reported in Table 5.20. As it can be seen, the accuracies of both baseline and schedule are quite similar. It should be noted that the main goal of the

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demonstrator was not to maximise the availability of flexibilities nor actually activate everything available, but rather to test the solution, including data flows, data formats, tools and methods.

Table 5.20: Analysis of baselining accuracy

Delivery time	Adjusted baseline, kWh	Measurement, kWh	FSP schedule, kWh	Inaccuracy of baseline	Inaccuracy of FSP schedule
09.02.2024 02:00	2,255563737	0,85295	2,22313	-164,44%	-160,64%
09.02.2024 02:15	1,662755193	0,52255	1,6444	-218,20%	-214,69%
09.02.2024 02:30	1,658307213	0,34994	1,35306	-373,88%	-286,65%
09.02.2024 02:45	1,023436381	0,56419	0,76751	-81,40%	-36,04%
09.02.2024 03:00	1,042724638	0,68263	0,90586	-52,75%	-32,70%
09.02.2024 03:15	1,156167127	0,43134	1,25078	-168,04%	-189,98%
09.02.2024 03:30	1,147288092	0,74815	1,10223	-53,35%	-47,33%
09.02.2024 03:45	0,788000297	0,15004	0,80074	-425,19%	-433,68%
09.02.2024 04:00	0,573363286	0,75764	0,69516	24,32%	8,25%
09.02.2024 04:15	0,504711636	0,63856	0,50927	20,96%	20,25%

Table 5.21 reports an example of financial settlement. Deviation means relative difference of ordered flexibility (i.e. cleared bids) and delivered flexibility. Remuneration indicates the payment to FSP if it would have been delivered exactly what was requested. In this example, it was never the case, and a theoretical penalty was assigned. As agreed among Northern demo partners, penalty is calculated as double of the price offered by the FSP and multiplied with the deviation. Potentially, the penalty could be adjusted with the remuneration to FSP.

Table 5.21: Example of financial settlement

Delivery Start	Bid #	Bid Price EUR/MW	Ordered flexibility, kW	Delivered flexibility, kW	Deviation	Remuneration for ordered flexibility, EUR	Penalty, EUR
09.02.2024 09:45	1	868,8	1	-0,012	112%	0,87	1,95
09.02.2024 09:45	2	260,64	1	-2,09	309%	0,26	1,61
09.02.2024 10:15	3	886,4	1	3,09	209%	0,89	3,71
09.02.2024 10:15	4	265,92	1	-0,056	156%	0,27	0,83
09.02.2024 10:45	5	886,4	1	2,08	108%	0,89	1,91
09.02.2024 10:45	6	265,92	1	-1,09	209%	0,27	1,11
09.02.2024 12:15	7	1149,6	1	3,57	257%	1,15	5,91
09.02.2024 12:15	8	344,88	1	-1,25	225%	0,34	1,55
09.02.2024 12:30	9	1149,6	1	2,11	111%	1,15	2,55
09.02.2024 12:30	10	344,88	1	-0,02	120%	0,34	0,83
09.02.2024 12:45	11	1149,6	1	2,9	190%	1,15	4,37
09.02.2024 12:45	12	344,88	1	0,021	79%	0,34	0,54
09.02.2024 15:15	13	1550	1	2,65	165%	1,55	5,12
09.02.2024 15:15	14	465	1	-1	200%	0,47	1,86

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09.02.2024 15:45	15	1550	1	3,83	283%	1,55	8,77
09.02.2024 15:45	16	465	1	-0,96	196%	0,47	1,82
9.02.2024 AVERAGE		**746,72**	**1**	**0,823**	**183%**	**0,75**	**2,78**

To be clear, the focus hereby was not to minimise the deviation, but to test the end-to-end integration and automation feasibility on different types of DERs while only limited time was spent on mobilising the community as such due to time limitation. Automated controls have therefore been tested on limited device activations to minimise end user disturbances. The deviation calculated combines both errors on baselines.

5.2.3 Latvia

5.2.3.1 Context and objectives

The demonstration project aligns with and supports the broader goals of Latvian TSO and DSO to facilitate nation-wide policies related to grid flexibility and energy markets. The demonstration project also illustrates efforts to increase public awareness about the benefits of common energy market structure across Europe as well as provide campaigns to inform the public about the benefits of a flexible network infrastructure, emphasizing how it contributes to lower network infrastructure investment costs.

This comes at a time when the Latvian system operators are preparing for the perfect storm given the coincidence of rapid increase in DER capacity, extreme weather events, desynchronization from the Russian electricity network and geopolitical situation that converge to an immense pressure on the national grid.

For the TSO, it was a great opportunity to model the future congestion scenarios and examine system use cases considering reserved generation capacity from customer connection requests and the required flexibility capacity to remove future congestions. Equally important was to demonstrate NRT-P-E product and study how the DSO customers could assist the TSO in reducing congestion on TSO's network or providing balancing services. Sadales Tīkls meanwhile focused on the LT-P-C/E demonstration scenarios for congestion management at 110kV primary substations.

The OneNet project is the first instance where the Latvian TSO and DSO is considering a single network since historically there hadn't been such need.

5.2.3.2 Technical implementation

In Latvian Demo, network topology was manually pre-processed to simplify the network by reducing the number of nodes. This was required since the topology data source contains information about every single pole and the line section in between. This, however, would create intrinsically large network to be solve by the optimization algorithm. While TSO considered line losses derived from line impedance and distances, line losses were ignored in the DSO's demonstration as congestion occurs in primary substations and actual line flows from each feeder are not known. In the Demo, the lines only had a mathematical meaning to provide a connection to the congested node.

The technical communication between the OneNet modules has been simulated using a Postman collection, which sends API requests to the systems and collect the respective responses. Network topology, customer flexibility and metering data needed for such requests were extracted from the corresponding system operator databases based on real topology and smart meter data.

During OneNet project, Latvian system operators had an opportunity to evaluate the congestion risk in the network and establish the business potential for flexibility services. For Sadales Tikls, this was an opportunity defined methodology for designing an optimal investment strategy, which allows Sadales Tikls to compare traditional investment in network upgrade against the provision of flexibility services (e.g. in a form of LT-P-C/E product). The main steps are shown in Figure 5.49.

Sadales Tikls completed flexibility assessment for all customers in the relevant congested areas to learn about customer resources and available capacities derived from smart meter data analysis. This allowed to derive customers with flexible loads and generation that were used to form the basis for FSPs. Finally, Sadales Tikls used a forecasting tool for day-ahead primary substation load forecasts. Since no congestion is observed on the primary substations today, the load values were inflated to generate the required congestion periods.

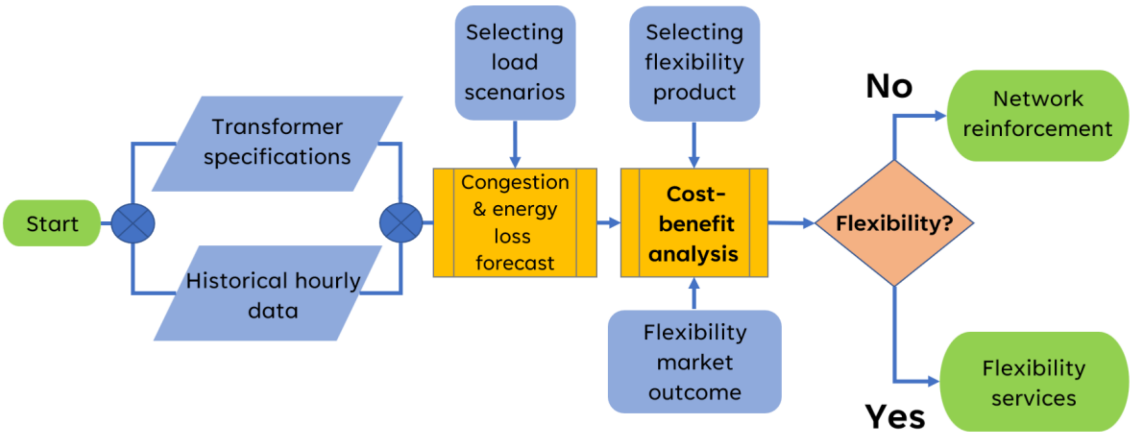

Figure 5.49: Sadales Tikls optimal capital investment strategy through a flexibility services approach (Rauzins, Lusis, Lidaka, 2023)

5.2.3.3 DSO demonstration scenarios

LT-P-C/E is purely focused on congestion management in the DSO network, primarily considering the 110kV substations as the congested area. While technically the primary substations fall under the TSO jurisdiction, operational decisions and requirements are determined by the DSO. Five grids (five primary substations) were selected due to the peak load which is approaching or have already exceeded the smallest transformer nominal capacity. As Sadales Tikls requires to maintain N+1 transformers for the planned or unplanned outage periods, there is a need to install an additional transformer resulting in large capital investment. Thus, a lot of effort in

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this project was also put on developing a cost-benefit analysis methodology for flexibility services as a deferral of investment costs.

All five networks are based on real Sadales Tikls topology data. However, the cases are simplified according to NRT-P-E and LT-P-C/E product needs as well as to provide the required level of anonymity. Each node represents either a:

- Medium voltage (MV) customer or generator (10/20kV),
- Low voltage (LV) customer or prosumer (0.4kV),
- Secondary transformer (MV/LV).

Table 5.22 Table 5.22: Summary of five grids for Sadales Tikls Demoshows the summary of Sadales Tikls congested grids. In total, Sadales Tikls Demo cover 142 nodes, 137 lines, and 85 virtual flexibility assets with the total flexibility capacity of 26.61MW.

Table 5.22: Summary of five grids for Sadales Tikls Demo

Network ID	# of nodes	# of lines	# of flexibility resources	Flex quantity Available (MW)	Max congestion (MW)
A/st.8	55	54	32	7.817	1.045
A/st.11	19	18	13	6.137	0.669
A/st.16	28	27	19	6.833	2.090
A/st.19	30	29	16	5.152	1.338
A/st.40	10	9	5	0.7	0.233
Total	**142**	**137**	**85**	**26.61**	**5.375**

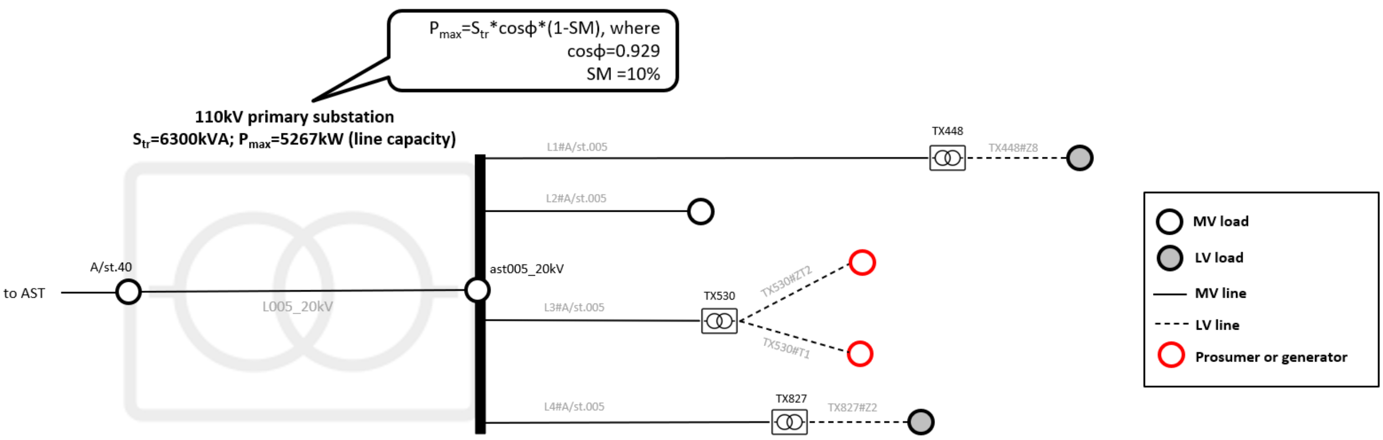

Figure 5.50: Illustration of Sadales Tikls A/st.40 grid. Substation transformer represented as a line L005_20kV

The flexibility procurement and purchase results are explicitly presented for the network A/st.40, while for other networks only the overall results are shown. Figure 5.50 is representation of Sadales Tikls grid A/st.40. The visual example emphasizes that congestion in Sadales Tikls scenarios always occurs at the primary substation

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level. Following the OneNet principles of network connectivity, the congested transformer inside the primary substation must be represented as a line. Therefore, line L005_20kV denotes the primary substation transformer, and the capacity of L005_20kV is the transformer accepted capacity threshold. Typically, each primary substations have more than 10 feeders. In the Demo, only the feeders with flexibility resources were added to the topology model.

Sadales Tikls distinguished between customers with demand side flexibility and prosumers with demand and generation and call them prosumers. The presented network A/st.40 consists of five potential flexibility resources: three loads and two prosumers.

The OneNet project also allowed Sadales Tikls to study an acceptable congestion threshold level. The initial plan was to use the transformer nominal capacity (kVA). However, that would require an ideal active power forecast which is not possible. It was decided to include a 10% forecast safety margin (SM) to determine the final threshold that would trigger a need for flexibility services.

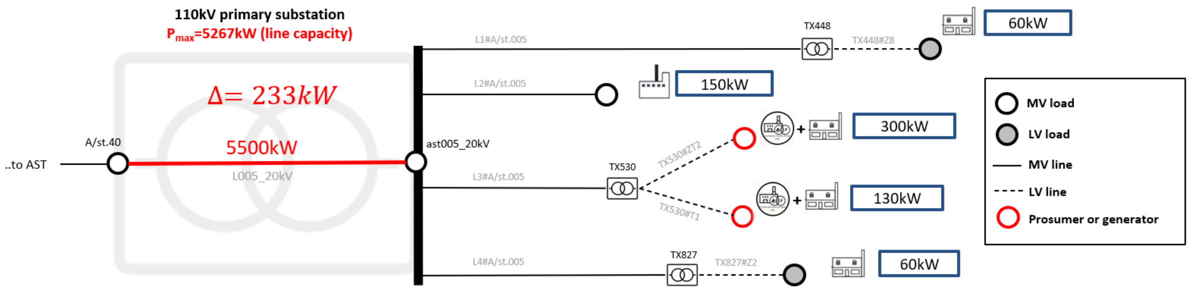

Figure 5.51: Illustration of Sadales Tikls A/st.40 grid under congestion at the primary substation.

In addition, non-linear and non-additive nature of reactive power makes it very difficult to predict exact substation loading. Sadales Tikls accounted for reactive power flow in the network considering the minimum permitted power factor of 0.929. Power factor rarely drops below this value. Otherwise, TSO would penalize DSO in the same way as the DSO would apply financial penalty to its commercial and industrial customers. As a result, the threshold of a 6300kVA transformer was set to 5267kW (Figure 5.51). Any hourly forecast value for the next 12 months above this threshold would require congestion management and trigger procurement of LT-P-C/E product. The scenario in figure below shows a congestion based on forecasted values. For the given example, the maximum load forecast over the next 12 months is 5500kW with load exceeding the transformer maximum load threshold by 233kW. As a result, it is needed to procure at least 233kW of flexibility. Sadales Tikls forecasting process also provides info on the expected number of congestion events and duration of each event.

5.2.3.4 DSO demonstration results

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Each FSP needs to register itself and its assets in Piclo Flex FR using API requests through TSO and DSO coordination platform (T&D CP) or via a web user interface provided by Piclo Flex. For the demonstration of LT-P-C/E product, Piclo Flex serves as a Flexibility Register and Market Operator (MO).

All 85 flexibility assets were created as a single FSP (single FSP account used). It is possible to create and submit individual bids for each flexibility asset when a competition is open on Piclo Flex. Figure 5.52 shows the details of one the flexibility assets after registration. *Ex.Active* Power denotes its maximum UPWARD flexibility of 60kW that can be provided using LT-P-C/E product. The Figure on the right-hand side demonstrates a generation asset with an option to increase power output by up to 300kW that would also help to reduce congestion at the substation. Please note that all flexibility assets for LT-P-C/E product are considered as indivisible and the system operator (SO) either must purchase full amount or none.

Figure 5.52: Demand Side Response asset (on left) and renewable asset (on right) with upward regulation capability.

In the figures below assets are set as Ineligible/Disqualified simply because SO has not published any Flexibility Call for Tender (FCT) and there is no active competition yet.

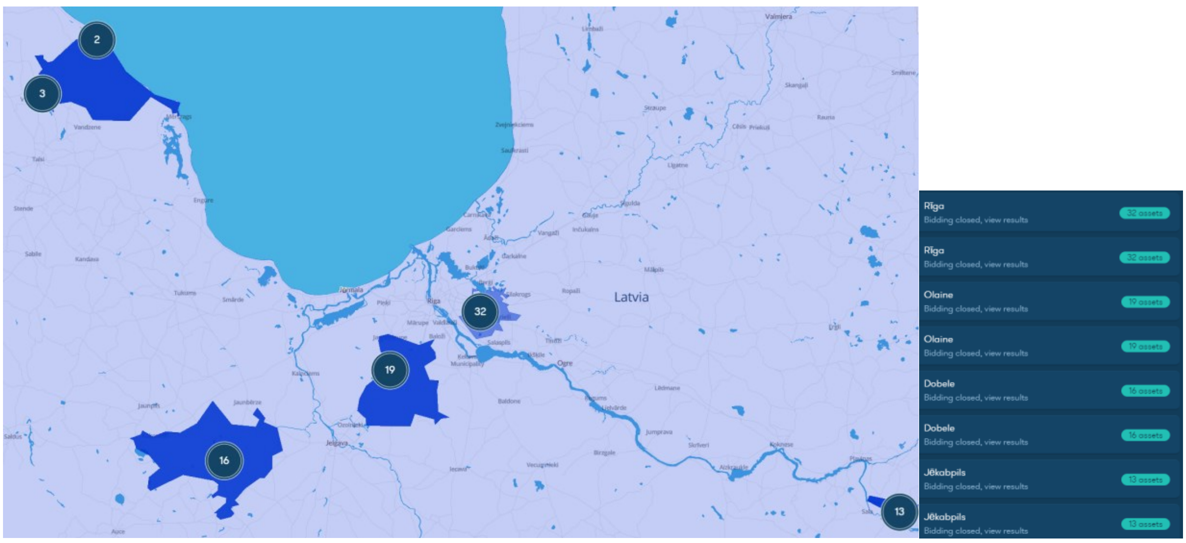

Figure 5.53: Live competition events after successful implementation of FCT in Piclo Flex.

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It's not critical whether flexibility assets are registered before or after FCT is published. However, FSPs shall not miss the Qualification Open and Qualification Close dates that are specified by the system operator. The qualification period cannot overlap with bid submission period. The trigger for Flexibility Call for Tender (FCT) from Sadales Tikls's perspective is the expectation of congestion at the primary substation. When the assets are correctly set up, competition is automatically launched on the Piclo Flex portal. Figure 5.53 shows the live events for all five grid areas. Piclo Flex provides a user-friendly interface to summarize the open competition results (Figure 5.53). From the competition dashboard, it can be easily seen what the flexibility requirements are, and when can the flexibility activation may be requested by SO.

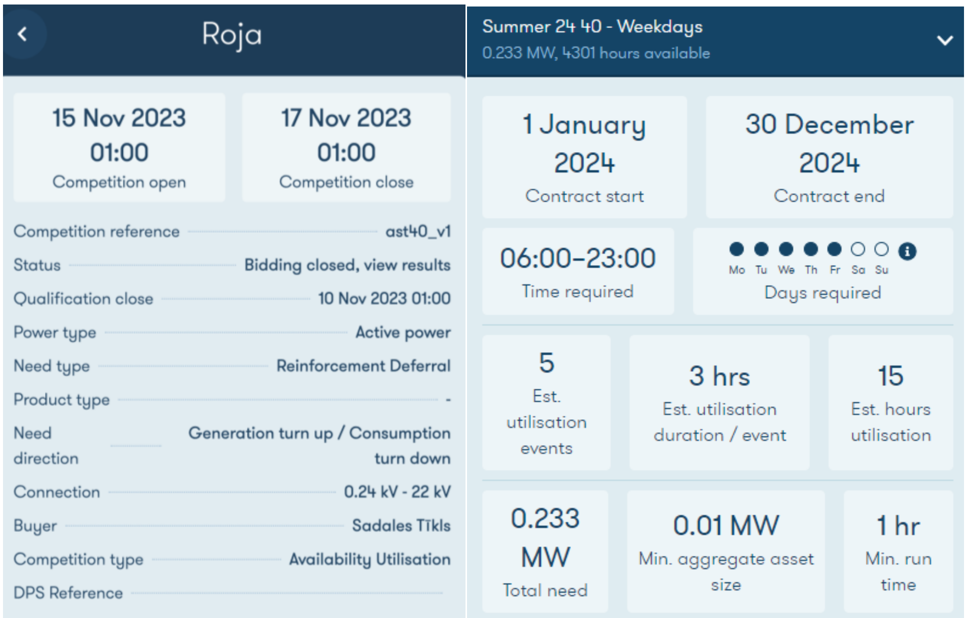

Figure 5.54: List of main attributes for Roja FCT.

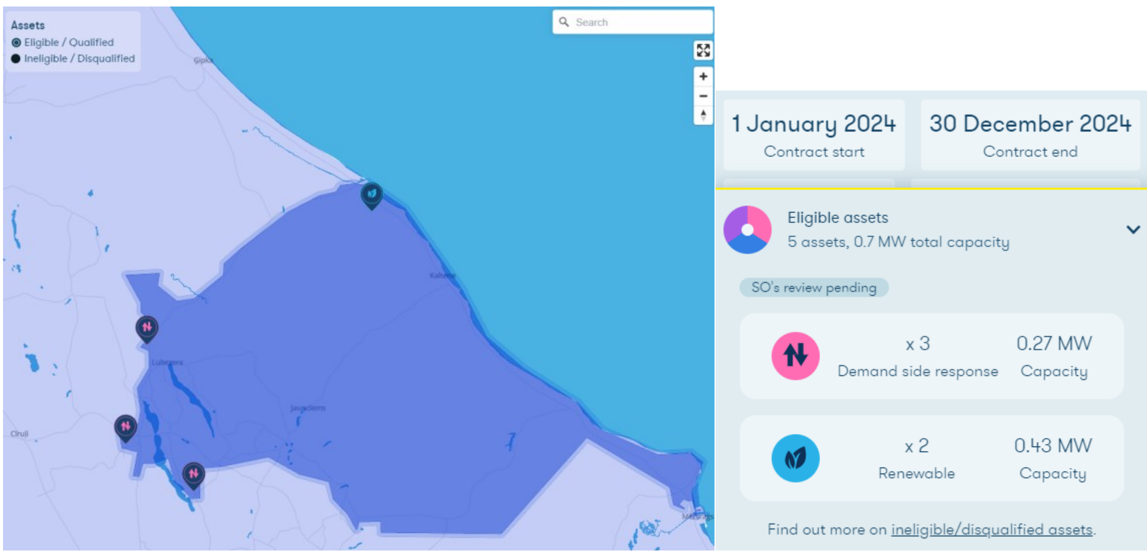

Figure 5.55: Congested substation area A/st.40 and qualifying flexibility assets.

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Prior SO publishes FCT, FSPs must complete the qualification of flexibility assets. This has to be done only once per competition area. If competition is repeated, then qualification process doesn't have to be repeated for the previously qualified assets. In Figure 5.55Figure 5.54, the FSP can see the qualifying assets for grid A/st.40. The geotagging of the congested area on the map allows FSPs to faster evaluate if the FSP has resources in the given geographical area to qualify for the competition. Typically, Sadales Tikls customers wouldn't know to which substation they are connected, especially since this is depending on the network configuration.

There are five flexibility assets with the total flexibility capacity of 0.7MW. Icons are different for Demand Response Side and Renewable flexibility assets. As per FCT, the required capacity is 233kW (0.233MW) to alleviate the congestion. Since the total FSP flexibility capacity is 0.7MW, Piclo Flex flexibility register allows to select which assets will be used as part of FSP's bidding strategy. If any of the assets is disabled, FSPs total flexibility capacity will be updated automatically. In this example, we disabled the largest biomass CHP 'Ražotne A' with 0.3MW UPWARD capacity as both biomass CHPs cannot me changed to condensing mode simultaneously. The FSP can still participate with four assets and the total of 0.4MW capacity (Figure 5.56). This still exceeds the FCT requirement of 0.233MW.

Figure 5.56: FSP asset control window.

In Piclo Flex, FSP can provide a quantity up to the FCT required amount. This means that FSP has to internally decide on how to optimize the use of its assets for the best bidding strategy in each competition. Since in Sadales Tikls Demo there is only one FSP with 85 virtual assets, the provided capacity by FSP always has to match the FCT requirements in order to alleviate congestion. Otherwise, bidding outcome will not be able to return complete congestion resolution, and Sadales Tikls will have to proceed with network upgrade.

When the competition ends, SO can choose the bids to be cleared. In Figure 5.57, we can see a system operator's view with all the submit bids. From Ballot ID, it can be understood that the same FSP has submitted all bids. By accepting the remaining three bids, the SO can collect the required flexibility capacity for Roja A/st.40 competition. To preserve fairness of the evaluation process, the information on the bidders is revealed after the competition results have been evaluated and accepted.

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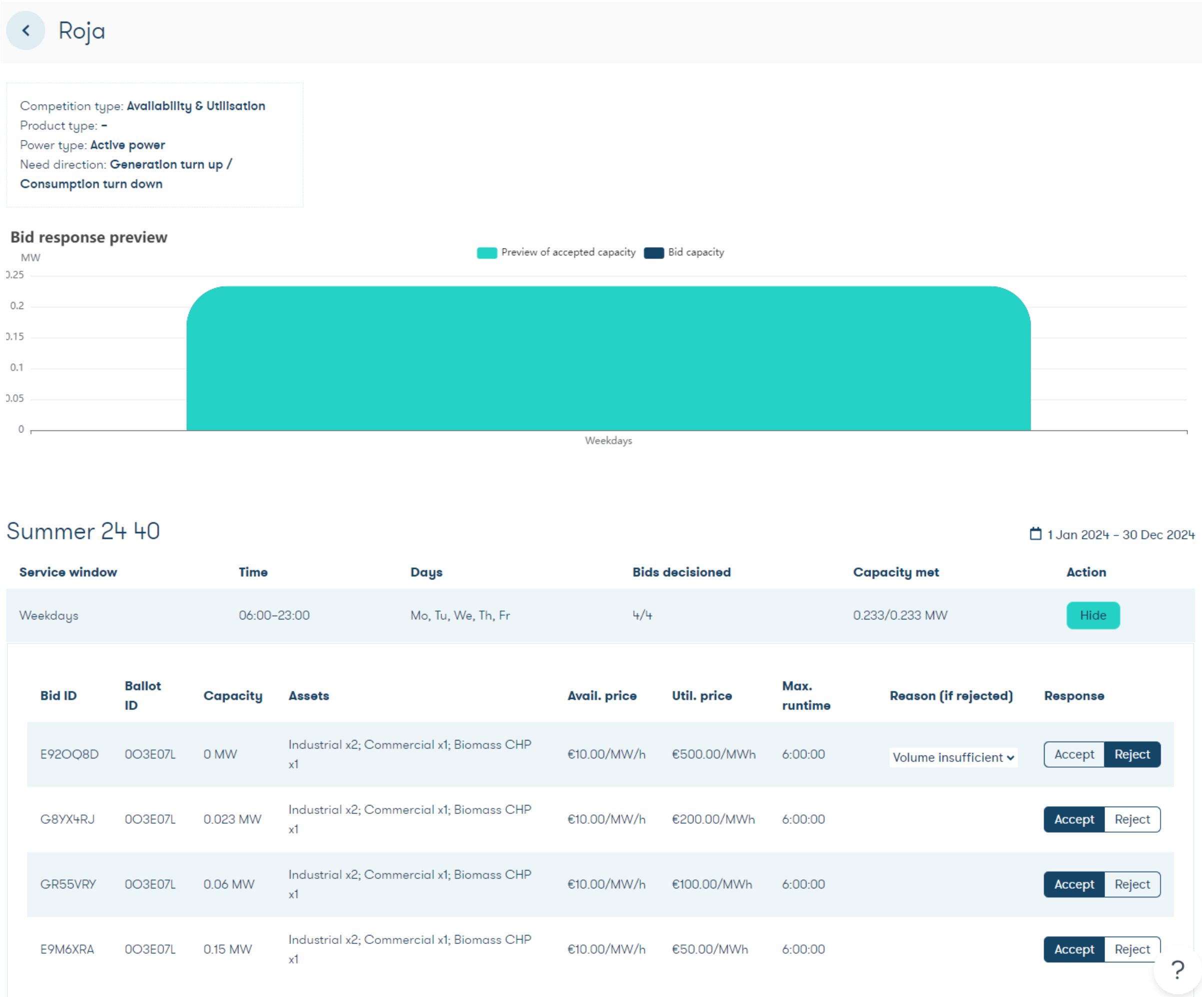

Figure 5.57: Bidding results for A/st.40.

After the bids are confirmed, both SO and FSP have a respective record about their contractual obligations, stored in Piclo Flex. Currently, Piclo Flex marketplace doesn't provide node-specific bid data to the SO, but for the demonstration purposes as SO has created the bids and knows this information – it is possible to submit the bid information to the T&D CP module. As a result, the cleared bids are provided to the DSO.

From the conversations with potential FSPs in Latvia, it seems that their expectation of payments for flexibility activation is between 300-500EUR/MWh. As the total sum (Total Cost Cap) that Sadales Tikls can pay to FSPs is relatively low compared to already existing markets like the UK, Total Cost Cap has to be wisely set. In order to keep flexibility markets economically viable to Sadales Tikls, meaning that flexibility costs shall not exceed the lifetime network upgrade costs, and to not lose the interest from FSPs to participate, Sadales Tikls introduced only activation price when launching the first flexibility competition. Without reservation price, the complexity of the market would be reduced and FSPs could demonstrate their true marginals costs of flexibility. However, to test the full functionality of LT-P-C/E product, Sadales Tikls fixed the reservation price at 10EUR/MWh.

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OneNet flexibility product parameters were defined based on the flexibility assessment methodology as well as using the available literature and uses cases on the subject concept. Highly influenced by other use cases, it was decided that FSPs should be reimbursed both for the reserved capacity (C) for the duration of contract and for the activated energy (E). Sadales Tikls applied flexibility service cost-benefit analysis methodology including sensitivity analysis for future load increase and customer expectations on the activation price (Rauzins, Luis, Lidaka, 2023). Figure 5.58 shows the sensitivity analysis results for all five grids with load increase between 1-10MW and expected activation price between 100-500EUR/MWh. While there is a positive business case for all five primary substations with 1MW load increase, higher load increase in three out of five cases will result in network reinforcement. Substation #3 case was calculated disregarding N+1 requirement to show that with both substations' transformers operational under normal grid conditions, there is no congestion risk.

Substation Serial No.	Price EUR/MW	Consumer flexibility market Load, MW				
		1	3	5	7	10
1#	100	734.22	596.64	390.76	186.52	-34.59
	300	605.55	423.00	225.53	30.29	-187.02
	500	544.93	362.75	154.42	-5.67	-339.45
2#	100	310.29	13.76	-418.24	-1600.99	-4321.95
	300	255.40	-37.61	-1327.05	-4875.31	-13038.18
	500	235.15	-86.79	-2235.86	-8149.62	-21754.41
3#	100	1321.80	895.21	873.60	723.26	275.25
	300	896.83	891.95	827.13	583.73	119.81
	500	896.83	888.69	780.67	510.24	63.86
4#	100	296.55	23.60	-233.32	-985.77	-3203.87
	300	198.36	-35.49	-773.48	-3030.83	-9685.12
	500	158.47	-83.65	-1313.63	-5075.88	-16166.36
5#	100	367.64	-76.49	-1607.87	-3551.09	-6466.03
	300	300.07	-264.13	-4858.29	-10687.94	-19432.75
	500	292.05	-451.78	-8108.70	-17824.79	-32399.48

Substation Serial No.	Price EUR/MW	Consumer flexibility market Load, MW				
		1	3	5	7	10
1#	100	20	20	15	8	0
	300	20	15	8	3	0
	500	15	10	6	0	0
2#	100	9	2	0	0	0
	300	8	0	0	0	0
	500	7	0	0	0	0
3#	100	40	20	20	20	9
	300	20	20	20	15	5
	500	20	20	20	15	3
4#	100	10	2	0	0	0
	300	7	0	0	0	0
	500	6	0	0	0	0
5#	100	20	0	0	0	0
	300	15	0	0	0	0
	500	15	0	0	0	0

Figure 5.58: Sensitivity analysis for Flexibility assessment showing NPV (on left) and the optimum flexibility contract duration (on right).

After the required capacity have been reserved, rolling day-ahead congestion forecast period would start to determine when activation is needed. The grid topology doesn't change during the contract period, but only the bids that were cleared during the reservation phase will participate in the activation phase.

5.2.3.5 TSO demonstration scenario

In the Baltic States, which include Estonia, Latvia and Lithuania, the following years will greatly change situation in the power system. Change is related to the power systems of the Baltic States which, up till now, have been part of the Integrated Power System/Unified Power System (IPS/UPS) jointly with Russia and Belarus, also referred to as 'BRELL' (Belarus, Russia, Republic of Estonia, Republic of Latvia and Republic of Lithuania) network. The Baltic States and its TSO's – Elering AS, AS "Augstsprieguma tīkls" (AST) and Litgrid AB, jointly aim to desynchronize from the BRELL network and afterwards transition to synchronous operation with the Continental European network in early 2025 [11].

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In Latvia, in addition to the aforementioned, in the coming years it is expected that a new RES installed capacity of 6046 MW [12] will be connected to the TSO network, which is almost double the current installed capacity of 3305 MW as reported in ENTSO-E Transparency Platform (ENTSO-E TP) under data item "Installed Capacity per Production Type" for the Latvia area [13] . Considering the peak consumption 1237 MW (2021), as reported in ENTSO-E TP data item "Actual Total Load", this rapid increase in connected generation capacity can have a large impact on the stability of the power system.

Network model

The future power system, considering the changes in Baltic States and Latvia, was modelled in Siemens PSS/E. This network model of AST's transmission network includes both 330 kV and 110 kV and was created by AST's Power System Security Service department which specializes in analysing and ensuring secure operation of the power system. The model represents a potential future scenario of summer in 2026, this setting was selected considering that:

1) Baltic States will be in synchronous operation with the Continental European network;
2) Large part of the 6 GW installed capacity of RES is expected to be operational;
3) High temperatures whether reduce the transmission line maximum transfer capacity;
4) Peak PV generation is expected.

The Siemens PSS/E network model generates the base information of TSO's network that is used as the input to OneNet WP7 solution demonstration. However, the full model is not used in the demonstration, a simplified version of the Siemens PSS/E network model is used instead, including only small part of the actual network to be analysed under the demonstration.

The network model for OneNet WP7 solution demonstration is depicted in Figure 5.59 also including DSO network, which is not part of the aforementioned Siemens PSS/E network model. The network model consists of 63 nodes, representing one or multiple substations. Out of 63 nodes, 58 are TSO network nodes and 5 are DSO network nodes. Moreover, the model includes 76 lines of which 71 lines are in TSO network and 5 lines are in DSO network. Regarding TSO's network part, the selection of representative nodes was based on the potential generation and consumption unit location, but some network nodes serve only structural purpose by joining or splitting line connections. Regarding the included network lines, main selection of the representative lines was based on potential future load, the lines with load greater than 80% were included in the TSO's network model to keep track of their congestions during OneNet WP7 solution demonstration. Rest of the lines in the network model serve a structural purpose that all nodes are connected within the network model. In Figure 5.59, each line has an element ID and, in brackets, the load as a percentage value of the line's maximum transfer capacity. However, network lines that are congested (with load >100%) are highlighted in red colour and additionally to load in percentage, the value of overload or congestion is given in brackets in MW.

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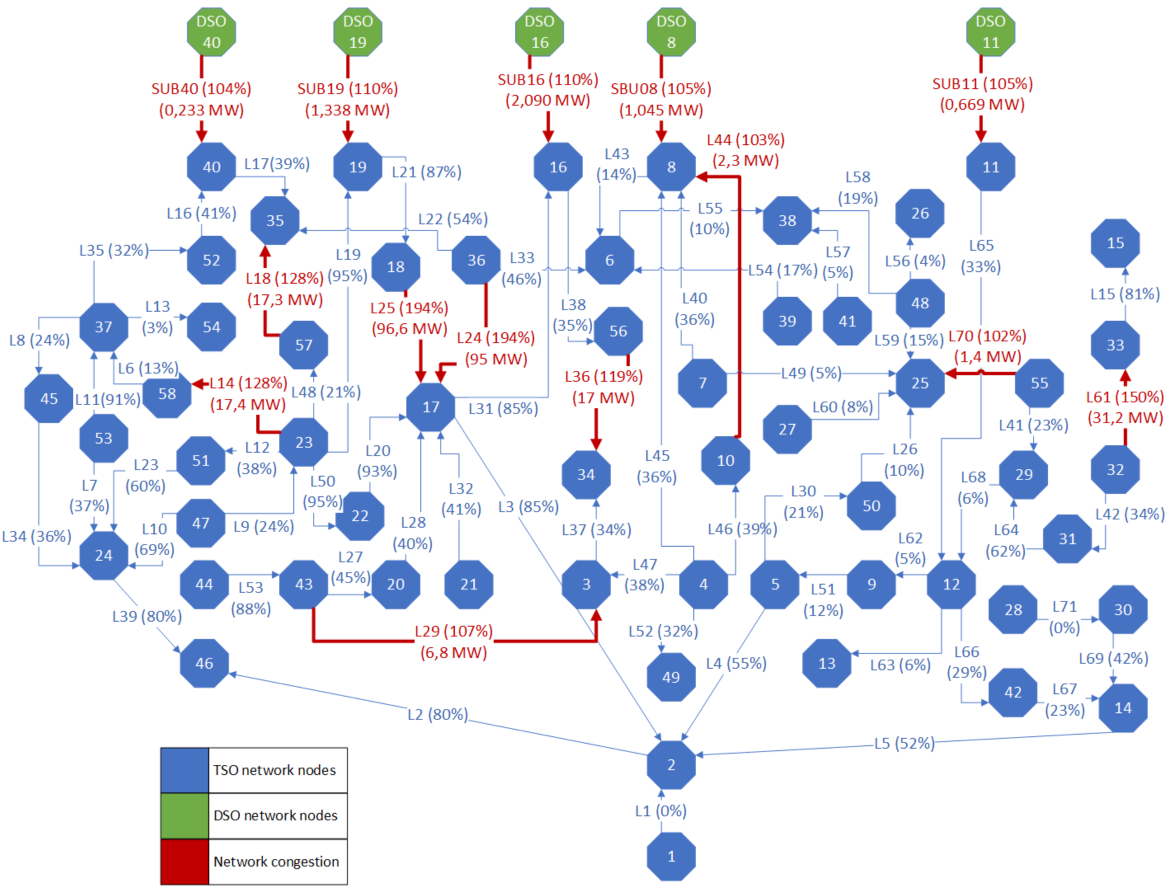

Figure 5.59: Network topology

Network congestions

As depicted in Figure 5.59, the TSO network includes 9 congested line cases, with congestion size ranging from 1,4 to 96,6 MW. Details of all 9 congested line cases are collected in the Table 5.23. Each listed congested line is further used in the OneNet WP7 solution demonstration, considering that only one line is congested at a time and the rest of the congestions are reduced to 80% load, thereby keeping them loaded enough to be considered during the OneNet WP7 optimisation process.

Table 5.23: TSO line congestion summary

Element ID	Network element	Element load	Congestion size, MW
L70	Line	102%	1,4
L44	Line	103%	2,3
L29	Line	107%	6,8
L36	Line	119%	17
L18	Line	128%	17,3
L14	Line	128%	17,4
L61	Line	150%	31,2

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L24	Line	194%	95
L25	Line	194%	96,6

Furthermore, the Figure 5.59 also depicts DSO network congestion, which originate in 5 transformers of the substation, with congestion ranging from 0,233 to 2,090 MW. Details of all 5 transformer congestion cases are collected in the Table 5.24, each listed transformer congestion case is further used in the OneNet WP7 solution demonstration.

Table 5.24: DSO transformer congestion summary

Element ID	Network element	Element load	Congestion size, MW
SUB40	Transformer	104%	0,233
SUB11	Transformer	105%	0,669
SUB08	Transformer	105%	1,045
SUB19	Transformer	110%	1,338
SUB16	Transformer	110%	2,090

Flexibility resources

Flexibility resources used in the OneNet WP7 solution demonstration are split in two types – real-reference resources and synthetic resources. The real-reference resources include all system resources that currently provide balancing services and reserved capacity [14] which is a developing system resource with the potential to provide system services in the future. Moreover, since most of the resources in this type are still developing and have not participated in the TSO's balancing market, an assumption was made that the amount of flexibility to be offered for system services is equal to 10% of their maximum installed capacity, with minimum threshold of 1 MW. In total, real-reference resources refer to set of 70 resources, including 53 generation and 17 consumption units, and the overall details of these resources is collected in the Table 5.25. These resources are used as the flexibility resource in demonstration of OneNet WP7 solution. Moreover, table also highlights that flexibility for downward regulation is three times greater than upward regulation, which might impact solving congestion cases. In the scenarios the resources are used in the form of market bids, representing 93 bids, including 23 UP and 70 DOWN regulation bids, and their size per resource referred is 10% of resource's installed capacity.

Table 5.25: Real-reference resource summary

	Type	Installed capacity, MW	Available flexibility, MW		Network location
			Up	Down	Node
Generation	Solar	4780	0	479	8, 9, 10, 11, 13, 23, 28, 29, 31, 32, 35, 37, 42, 43, 44, 45, 48, 50, 51, 53, 56, 58
	Hydro	1558	156	156	3, 4, 5, 7

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	Wind	1012	0	101	18, 23, 24, 46, 47, 52, 53, 55, 57
	Mixed RES	128	0	13	18, 54
	Gas	1039	104	104	6, 8
	Type total	8517	260	853	–
Consumption	–	304	33	33	9, 11, 13, 15, 20, 21, 25, 26, 27, 36, 37, 38, 39, 40, 41, 49
Total	–	8821	293	886	–

The other resource type used is synthetic resource. Synthetic resources are not based on any existing resource, but rather have a fixed 200 MW amount of flexibility, which is simultaneously available in both upward and downward regulation direction. In the network model depicted in Figure 5.59, the synthetic resources are located in all nodes except nodes 1 and 2, with the maximum flexibility of 200 MW for both upward and downward regulation. The utility of the synthetic resources is to examine a more flexible future potential and to examine whether specific network congestion cases can be solved with more flexibility or rather grid reinforcement is inevitable.

Scenario 1: TSO network congestion solving.

Objective of the scenario is to examine the potential to alleviate line congestions in the TSO network with system resources of the TSO network. This will show which congestions are feasible to solve and indicate where in the TSO's network there is a lack of flexibility available.

Scenario setup:

- Used network model as depicted in Figure 5.59;
- Includes 9 congested line cases, as listed in Table 5.23, with only one congestion occurring at a time and the rest of the line congestion cases have their loads reduced to 80%;
- Includes separate case runs for TSO's real-reference and synthetic resource types. Cases are run separate to achieve comparable results between the estimated flexibility capability and a more theoretical flexible future capability. Represented in the process as 93 bids for the real-reference variant and 112 bids for the synthetic variant;
- Includes separate case runs for system balance state neutral and impacted congestion management, by allowing or restricting congestion management service to cause system imbalance;
- Demonstrating product NRT-P-E.

Scenario 2: TSO-DSO cooperative congestion solving.

Objective of the scenario is to examine the added benefit of cooperation between the TSO and DSO in solving their network congestions. This will show the capability of the DSO's network resources to solve TSO's network

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congestion and the added benefits of solving both TSO and DSO network congestions jointly for the standpoint of efficient utilization of available system resource – flexibility resources.

Scenario setup:

- Used network model as depicted inFigure 5.59;
- Includes all successfully solved TSO congestion cases of Scenario 1 with only one congestion occurring at a time and the rest of the line congestion cases have their loads reduced to 80%;
- Includes TSO network real-reference resources per Table 5.25, and DSO network flexibility resources covered in Table 5.22. Represented in the process as 103 bids, 93 TSO and 10 DSO (1 bid per TSO connection point with UP/DOWN direction);
- Includes separate case runs for system balance state neutral and impacted congestion management, by allowing or restricting congestion management service to cause system imbalance;
- Demonstrating product NRT-P-E.

Scenario 3: Capacity to mitigate congestions caused by outages.

Objective of the scenario is to examine an unsuccessful congestion mitigation that results in congested element outage and thereby potentially causing additional congestions in other parts of the TSO's network. In the scenario capacity is procured proactively in order to reserve flexibility resources for the goal of mitigating congestions results from network line outages.

Scenario setup:

- Used network model as depicted inFigure 5.59, but with excluded DSO network;
- Includes all unsuccessful solved TSO line congestion cases of Scenario 1, collected inTable 5.28, which each individually represent the outage cases.
- Includes only TSO network synthetic resources, represented as 112 bids;
- System balance state is not considered in the product, because the process only reserves capacity, but the actual delivery would be done under NRT-P-E product;
- Demonstrating product LT-P-C.

5.2.3.6 TSO demonstration results

Scenario 1: TSO network congestion solving.

This scenario focuses on solving only the TSO network congestions listed in Table 5.23 and done so from a real-reference and synthetic flexible resource potential perspective, as well as from a system balance neutral and impacted congestion management process. Moreover, the system balance state before any congestion optimization is balance neutral. The results are presented in two tables – Table 5.26, including the synthetic resource results, and Table 5.27, including real-reference resource results. The results in Table 5.26, represent

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the synthetic resource cases. These results show the full potential of the optimization algorithm utilized in the project OneNet WP7 solution as due to the use of synthetic resources, the optimization algorithm has no limitation from flexibility resource availability standpoint. Thereby, the optimization process can find a solution for all TSO's network congestions in both balance neutral and balance impacted setups. However, it is also important to not only solve congestions but solve them efficiently by utilizing less of the available flexibility resources (activated volume). The congestion solution outcome efficiency is calculated by the equation below where result with lower percentage represents better efficiency:

$$CSE = \frac{AV_{Total}}{CS_{Solved}}, \%$$

Where:

- CSE – Congestion Solution Efficiency, %;
- AV_{Total} – Total activated volume from flexibility resource bids, MW;
- CS_{Solved} – The solved amount of congestion, MW.

The average Congestion Solution Efficiency (CSE) score for the Table 5.26 results is 213%, with 264% and 162% for balanced and impacted balance states respectively. The results are as expected, considering network losses and flow division in the network, the actual efficiency to reduce congestion in a specific network element is not equal to the activated volume. Moreover, considering the utilization of synthetic flexibility resources in these cases, the achieved results reflect the best congestion solution outcome for each specific congestion occurrence.

Table 5.26: Synthetic resource run results

Case	Congestion		Market setup		Activated volume, MW			Results		
	TSO		Bid source	Balance state	Up	Down	Total	Resulting conges-tion size, %	System imbalance MW	CSE, %
	Locat-ion	Size, MW								
S01a	L70	1,4	TSO	Balanced	1,8	1,8	3,5	0%	0	250%
S02a	L44	2,3	TSO	Balanced	3,1	3,1	6,3	0%	0	274%
S03a	L29	6,8	TSO	Balanced	9,1	9,1	18,2	0%	0	268%
S04a	L36	17	TSO	Balanced	19,8	19,8	39,6	0%	0	233%
S05a	L18	17,3	TSO	Balanced	22,9	22,9	45,8	0%	0	265%
S06a	L14	17,4	TSO	Balanced	21,8	21,8	43,7	0%	0	251%
S07a	L61	31,2	TSO	Balanced	33,5	33,5	67,0	0%	0	215%
S08a	L24	95	TSO	Balanced	161,8	161,8	323,6	0%	0	341%
S09a	L25	96,6	TSO	Balanced	135,1	135,1	270,1	0%	0	280%
S01b	L70	1,4	TSO	Impacted	0,0	1,9	1,9	0%	-1,9	136%
S02b	L44	2,3	TSO	Impacted	3,4	0,0	3,4	0%	3,4	148%
S03b	L29	6,8	TSO	Impacted	10,9	0,0	10,9	0%	10,9	160%

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S04b	L36	17	TSO	Impacted	0,0	22,6	22,6	0%	-22,6	133%
S05b	L18	17,3	TSO	Impacted	0,0	24,8	24,8	0%	-24,8	143%
S06b	L14	17,4	TSO	Impacted	24,8	0,0	24,8	0%	24,8	143%
S07b	L61	31,2	TSO	Impacted	42,5	0,5	43,0	0%	41,9	138%
S08b	L24	95	TSO	Impacted	0,0	201,8	201,8	0%	-201,8	212%
S09b	L25	96,6	TSO	Impacted	96,6	141,1	237,7	0%	-44,5	246%

Table 5.27: Real-reference resource run results

Case	Congestion		Market setup		Activated volume, MW			Results		
	TSO		Bid source	Balance state	Up	Down	Total	Resulting conges-tion size, %	System imbalance MW	CSE, %
	Locat-ion	Size, MW								
R01a	L70	1,4	TSO	Balanced	1,8	1,8	3,5	0%	0	250%
R02a	L44	2,3	TSO	Balanced	7,2	7,2	14,4	0%	0	626%
R03a	L29	6,8	TSO	Balanced	43,2	43,2	86,4	0%	0	1271%
R04a	L36	17	TSO	Balanced	38,8	38,8	77,5	0%	0	456%
R05a	L18	17,3	TSO	Balanced	147,8	147,8	295,5	52%	0	3559%
R06a	L14	17,4	TSO	Balanced	78,2	78,2	156,3	83%	0	5284%
R07a	L61	31,2	TSO	Balanced	42,0	42,0	84,0	96%	0	6731%
R08a	L24	95	TSO	Balanced	144,5	144,5	289,1	82%	0	1691%
R09a	L25	96,6	TSO	Balanced	0,0	0,0	0,0	100%	0	–
R01b	L70	1,4	TSO	Impacted	0,0	1,9	1,9	0%	-1,9	136%
R02b	L44	2,3	TSO	Impacted	8,7	0,0	8,7	0%	8,7	378%
R03b	L29	6,8	TSO	Impacted	4,0	51,7	55,7	0%	-47,7	819%
R04b	L36	17	TSO	Impacted	40,3	37,0	77,3	0%	3,3	455%
R05b	L18	17,3	TSO	Impacted	3,7	147,8	151,5	52%	-144,1	1824%
R06b	L14	17,4	TSO	Impacted	2,7	78,2	80,9	83%	-75,5	2735%
R07b	L61	31,2	TSO	Impacted	0,0	42,0	42,0	96%	-42,0	3365%
R08b	L24	95	TSO	Impacted	13,8	144,5	158,4	82%	-130,7	926%
R09b	L25	96,6	TSO	Impacted	0,0	0,0	0,0	100%	0,0	–

The results in Table 5.27, represent the real-reference resource cases. The results show that the real-reference resource in the TSO's network cannot solve all congestion cases. Moreover, what is interesting is that, comparing balance state neutral and impacted setups the congestion outcome is exactly the same, which highlights that there are not enough flexibility resources in the system to solve all of the individual congestions even without balance state impact restrictions. This lack of resources in the system is clearly seen in the last congestion case, where both in balanced and impacted setup, 'R09a' and 'R09b', no activation occurred due to all of the available resources not having any positive impact on the specific line congestion case.

Considering the CSE results, the average is only calculated for the solved cases, the average CSE is 549%, with 651% and 447% for balanced and impacted balance states respectively. Compared average of 549% to the synthetic resource case result average of 213%, the real-reference flexibility resources need around 2,5 times

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more system flexibility resources utilized to solve the same line congestions. However, one out of the four solved line congestion cases was able to achieve the most optimal outcome, compared to synthetic resource run. Cases 'R01a' and 'R01b' and synthetic resource cases 'S01a' and 'S01b' achieved the same CSE scores – 250% for balanced and 136% for impacted system state results, indicating that the estimated system flexibility through real-reference flexibility resources in the TSO's network is sufficient and highly effective in solving L70 line congestion. The three other solved line congestion cases – R02, R03 and R04, unfortunately do not closely resemble the efficiency of similar synthetic resources cases – S02, S03 and S04, requiring on average two to five times more flexibility resources to activated, compared to the same case results of the synthetic resource runs. The greatest inefficiency can be seen in L29 line congestion case results, where real-reference flexibility resources, in cases 'R03a' and 'R03b' solved the case with CSE of 1271% (balanced) and 819% (impacted) compared to around five time more efficient outcome by the synthetic resources in cases 'S03a' and 'S04b' with CSE only of 268% (balanced) and 160% (impacted). Comparison of R01 ('R01a' and 'R01b') and R03 ('R03a' and 'R03b') case effectiveness further highlights that solving network congestion can have a wide range of outcome efficiency and that this is directly impacted by the flexibility resource's location in the network, the amount of flexibility each resource possesses and flexibility regulation direction.

Solving line congestions for cases - L18, L14, L61, L24 and L25, is not possible, due to lack of flexibility resources in the TSO network. Further analysis of these case runs show that even by activating all available flexibility resources that affect specific line loads, the line congestion cases cannot be fully solved and at best can be reduced to – 11% (L18), 53% (L14), 96% (L61), 68% (L24), 100% (L25).

Table 5.28 provides results of an in-depth analysis of nods and their respective regulation directions, which would have a considerable impact, impact resulting in flow change >10% of the flexibility volume activated, on reducing the corresponding line congestion case. The availability of flexibility resources in these nodes, with aforementioned regulation directions, would have the potential to alleviate the respective line congestions with adequate CSE score.

Table 5.28: Flexibility impact with node and regulation direction

Element ID	Node	
	UP	DOWN
L18	–	57
L14	58	–
L61	32, 33	15
L24	–	18, 35, 36, 57
L25	18	–

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Scenario 2: TSO-DSO cooperative congestion solving.

This scenario focuses on solving both the TSO and DSO network congestions listed in Table 5.23 and Table 5.24 and do so from a system balance neutral and impacted congestion management process. Moreover, the system balance state before any congestion optimization is balance neutral. The results are presented in three tables –Table 5.29, including simultaneous TSO and DSO congestion solving with TSO and DSO flexibility resources, Table 5.30, including TSO congestions with DSO only flexibility resources, and Table 5.31, including DSO congestions with TSO and DSO flexibility resources.

The results in Table 5.29 represent the simultaneous congestion cases in one of the TSO network lines and in all 5 DSO connection points, per Table 5.24. Additionally, for the solving of these simultaneous congestion cases, both TSO and DSO network flexibility resources are utilized, where TSO network resources are the real-reference resources per Table 5.27 and DSO network resources per Table 5.22. All congestion cases examined are successfully solved by removing network congestions, achieving CSE of 380%, with 419% and 341% for balanced and impacted balance states respectively. Notable is the more efficient CSE result, compared to CSE of 549% for TSO only network congestion results using real-reference resources in Scenario 1 Table 5.27, achieving on average 31% more effective congestion management process. Furthermore, Table 5.29 cases 'TD01a' and 'TD01b' with CSE score 159% (balanced) and 107% (impacted) achieved more efficient CSE score even compared to the synthetic resource results in Scenario 1 Table 5.26 with 'S01a' and 'S01b' achieving only 250% (balanced) and 136% (impacted). Although all results of Table 5.29 are more efficient than Table 5.27, case 'TD03a' displays another interesting outcome as to solve the 12,2 MW system congestion, including L29 line congestion with all 5 congested DSO connections, it takes only 77,1 MW of activated system flexibility, compared to case 'R03a' where solving of 6,8 MW TSO network congestion in line L29 took 86,4 MW. In comparison, the CSE of 'TD03a' (632%) is twice as efficient than 'R03a' (1271%) and the optimization also resulted in 11% less system flexibility utilization while solving 79% larger network congestion.

Table 5.29: Congestion in TSO & DSO network with all FSPs.

Case	Congestion				Market setup		Activated volume, MW			Results		
	TSO		DSO		Bid source	Balance state	Up	Down	Total	Resulting congestion size, %	System imbalance MW	CSE, %
	Location	Size, MW	Location	Size, MW								
TD01a	L70	1,4	All grids*	5,4	TSO / DSO	Balanced	5,4	5,4	10,8	0%	0	159 %
TD02a	L44	2,3	All grids*	5,4	TSO / DSO	Balanced	11,8	11,8	23,6	0%	0	306 %
TD03a	L29	6,8	All grids*	5,4	TSO / DSO	Balanced	38,5	38,5	77,1	0%	0	632 %
TD04a	L36	17	All grids*	5,4	TSO / DSO	Balanced	64,7	64,7	129,4	0%	0	578 %

TD01b	L70	1,4	All grids*	5,4	TSO / DSO	Impacted	5,4	1,9	7,3	0%	3,5	107%
TD02b	L44	2,3	All grids*	5,4	TSO / DSO	Impacted	14,3	0	14,3	0%	14,3	186%
TD03b	L29	6,8	All grids	5,4	TSO / DSO	Impacted	9,4	51,0	60,3	0%	-41,6	494%
TD04b	L36	17	All grids	5,4	TSO / DSO	Impacted	67,0	61,9	128,9	0%	5,1	575%

**All grids refer to all 5 DSO network connection points per* Table 5.22.

The overall more efficient CSE scores, surpassed synthetic resource results and the reduced system flexibility utilization while solving larger overall network congestions show the potential benefit of TSO and DSO joint congestion management.

The results in Table 5.30, represent the TSO congestions solved by only DSO network estimated flexibility as per Table 5.22. All the results show that the DSO's network estimated flexibility is not enough to solve any of the TSO's network line congestion cases and the best results can be achieved by allowing system imbalance. Considering the CSE results, only results for L36 line congestion, cases 'T04a' and 'T04b', will be assessed, because other partially solved line congestions – L70, L44 and L29, are partially solved with high inefficiency. The solving potential and thereby efficiency of the DSO network flexibility resources is highly limited and impacted by the small DSO network sample size of only 5 connection points (Table 5.22), because in reality TSO and DSO network are interconnected by more than 100 connection points, which would ultimately result in more availability of flexibility resources.

Table 5.30: Congestion in TSO network with FSPs located in DSO network only.

Case	Congestion		Market setup		Activated volume, MW			Results		
	TSO		Bid source	Balance state	Up	Down	Total	Resulting congestion size, %	System imbalance, MW	CSE, %
	Location	Size, MW								
T01a	L70	1,4	DSO	Balanced	12,0	12,0	24,0	63%	0	4569%
T02a	L44	2,3	DSO	Balanced	12,0	12,0	24,0	69%	0	3387%
T03a	L29	6,8	DSO	Balanced	4,3	4,3	8,7	97%	0	3764%
T04a	L36	17	DSO	Balanced	12,7	12,7	25,4	64%	0	417%
T01b	L70	1,4	DSO	Impacted	20,5	6,1	26,6	48%	14,4	3690%
T02b	L44	2,3	DSO	Impacted	6,1	14,7	20,8	68%	-8,5	2822%
T03b	L29	6,8	DSO	Impacted	12,7	14,0	26,6	88%	-1,3	3368%
T04b	L36	17	DSO	Impacted	14,0	12,7	26,6	64%	1,3	437%

Table 5.31: Congestion in DSO network

Case	Congestion		Market setup		Activated volume, MW			Results		
	DSO		Bid source	Balance state	Up	Down	Total	Resulting congestion size, %	System imbalance, MW	CSE, %
	Location	Size, MW								
D01a	All grids	5,4	TSO/DSO	Balanced	5,4	5,4	10,8	0%	0	200%

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D02a	All grids	5,4	TSO	Balanced	0,0	0,0	0,0	100%	0	–
D03a	All grids	5,4	DSO	Balanced	0,0	0,0	0,0	100%	0	–
D04a	SUB08	1,0	DSO	Balanced	1,0	1,0	2,1	0%	0	200%
D05a	SUB11	0,7	DSO	Balanced	0,7	0,7	1,3	0%	0	200%
D06a	SUB16	2,1	DSO	Balanced	2,1	2,1	4,2	0%	0	200%
D07a	SUB19	1,3	DSO	Balanced	1,3	1,3	2,7	0%	0	200%
D08a	SUB40	0,2	DSO	Balanced	0,2	0,2	0,5	0%	0	200%
D01b	All grids	5,4	TSO/DSO	Impacted	5,4	0,0	5,4	0%	5,4	100%
D02b	All grids	5,4	TSO	Impacted	0,0	0,0	0,0	100%	0,0	–
D03b	All grids	5,4	DSO	Impacted	5,4	0,0	5,4	0%	5,4	100%
D04b	SUB08	1,0	DSO	Impacted	1,0	0,0	1,0	0%	1,0	100%
D05b	SUB11	0,7	DSO	Impacted	0,7	0,0	0,7	0%	0,7	100%
D06b	SUB16	2,1	DSO	Impacted	2,1	0,0	2,1	0%	2,1	100%
D07b	SUB19	1,3	DSO	Impacted	1,3	0,0	1,3	0%	1,3	100%
D08b	SUB40	0,2	DSO	Impacted	0,2	0,0	0,2	0%	0,2	100%

The Table 5.30 cases 'T04a' and 'T04b' for their partial congestion reduction show slight improvement in CSE score, achieving 417% (balanced) and 437% (impacted), compared to Scenario 1 Table 5.27 cases 'R04a' and 'R04b', achieving 456% (balanced) and 455% (impacted). This shows that DSO network flexibility resources have a slight edge in solving specific congestion case, but in the current network model there is not enough DSO network flexibility to fully solve any of the TSO network line congestion cases.

The results in Table 5.31, represent the DSO congestions solved by only the TSO's or only by the DSO's or both network resources. The results for cases D04a/b to D08a/b show that in case of a one DSO's network congestions occurs at a time, the estimated available DSO's network flexibility is sufficient to remove the congestions regardless of the resulting system balance state. It is also clear by the case results 'D02a' and 'D02b' that the TSO's network resources cannot aid the DSO's network in solving the congestions. Furthermore, interesting results are achieved in cases 'D03a' and 'D03b' where in the system balance neutral case 'D03a' no activation occur as congestion management cannot be done when system balance is to be strictly maintained, however, by allowing the imbalance to occur, case 'D03b' the DSO's network congestions can be fully removed. This shows that by restricting or allowing to impact system balance state can also have a great impact on congestion solving. Lastly, cases 'D01a' and 'D01b' show the added benefit of TSO and DSO network cooperation, as individually TSO and DSO network resources in cases 'D02a', 'D02b and 'D03a' could not solve DSO's network congestions, but by collaboration of the networks DSO's congestions can be solved even in a balance state neutral way. The CSE score results of these cases is very optimistic as the DSO network is represented as lossless, thereby Table 5.31 CSE score values are not used for direct comparison with other results, but, considering simplified representation, the CSE score results are as expected.

Summarizing the results of this scenario, the scenario showed that TSO and DSO cooperation in congestion management service increases the service efficiency by reducing the amount of flexibility resources activated/utilized in comparison to the total size of system congestion occurrence, as indicated by CSE score. The lower CSE score is the more efficient congestion management service is provided. TSO and DSO cooperation has the potential to improve CSE score by 31% comparing solved cases of isolated TSO network congestion management (549%), Table 5.27, and TSO-DSO cooperative congestion management (380%), Table 5.29, However, the CSE of TSO-DSO cooperative congestion management cases 'TD04a' (578%) and 'TD04b' (575%), Table 5.29, is the exceptional outlier where compared to isolated TSO network congestion management cases 'R04a' (456%) and 'R04b' (455%), Table 5.27, the TSO and DSO cooperation hinders efficiency of the congestion management service. Similar more efficient CSE score was achieved in TSO network congestion case partially solved by only DSO network flexibility resources, which in cases 'T04a' (417%) and 'T04b (437%)', Table 5.30, compared to TSO-DSO cooperative congestion management cases 'TD04a' (578%) and 'TD04b' (575%), Table 5.29, was more efficient based on CSE score. This shows that although on average TSO and DSO cooperation in congestion management is more efficient per CSE score, the complexity of the system model and congestion situation being optimized can also result in less efficient outcome compared to congestion situation occurring only in the TSO or DSO network at a time. However, if the TSO and DSO network congestions do occur simultaneously, solving them separately and sequentially will certainly result in worse efficiency than achieved in cases 'TD04a' (578%) and 'TD04b' (575%), Table 5.29.

Scenario 3: Capacity to mitigate congestions caused by outages.

Table 5.32. Outage causes congestion mitigation

Outage ID	Congestion			Market	Activated resources				Results		
	Line ID	Size, MW	Total size, MW	Bid source	Node ID	Direc-tion	Volume, MW	Total, MW	Resulting congestion size, %	System imbalance, MW	CSE, %
L14	L6	21,8	21,8	TSO	58	UP	73	73	0%	73	335%
L18	L19	3,4	7,1	TSO	22	UP	8,9	22,9	0%	8,5	323%
	L20	1,1			23	UP	6,8				
	L50	2,6			19	DOWN	7,2				
L61	L42	52,5	52,5	TSO	32	UP	142,8	256,6	0%	256,6	489%
					15	UP	113,8				
L24	L19	14	36,6	TSO	23	UP	60,8	121,1	0%	102,3	331%
	L20	7,9			22	UP	50,9				
	L21	4,6			19	DOWN	9,4				
	L50	10,1									

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This scenario focuses on solving congestions caused by outages, where the outages examined are selected based on unsuccessfully solved line congestion outages in Scenario 1Table 5.27. The line outage cases include – L14, L18, L61 and L24, but excludes L25 due to information source network model in the Siemens PSS/E having issues once the line is disconnected. These cases are demonstrated using only the TSO network synthetic flexibility resources as the real-reference resources were not able to solve the congestions resulting from the outages. The results are collected in Table 5.32.

The results in Table 5.32 show that if the congestions in lines L14, L18, L61 and L24 are left unsolved, the outage of these lines can cause other congestions in the TSO network. However, the OneNet WP7 solution optimization algorithm using the synthetic flexibility resources was capable of finding the optimal solution for each additional congestion triggered by outage of un-resolved congested line. The average CSE score of all cases is 369%, representing score for allowed impact to system balance state, compared to the comparable Scenario 1 Table 5.26 case S01b to S09b average CSE of 162%, results with twice as much system flexibility resources to be utilized to solve resulting network congestion than the initial congestion occurrence. Therefore, in comparing these two synthetic scenario outcomes it can be concluded that it is more efficient to solve the initial line congestion than the congestions resulting from the initial congested line outages. Moreover, considering that the line congestions in Scenario 1, Table 5.27, and their outage caused congestions in this scenario, Table 5.32, could not be solved by the future estimated potential flexibility resources – real-reference resources, indicates the need for network reinforcement of these network elements or growth in system flexibility in nodes as indicated in Table 5.28 and Table 5.32.

5.2.4 Lithuania

5.2.4.1 State of Art of flexibility in Lithuania

The concept of flexibility is relatively new in Lithuania, emerging with the introduction of terms like flexibility, demand response, and aggregation in the country's Energy of Electricity law in 2021. Currently, services related to demand side response and aggregation can be offered to the balancing market (managed by Litgrid, the Lithuanian TSO) and the DSO flexibility market (managed by ESO). Despite the theoretical capability of ESO to procure flexibility, practical procurement hasn't materialized due to several factors. ESO commenced a large-scale rollout of smart meters towards the end of 2022, prior to which there was insufficient grid data to assess flexibility needs. Although more data is now available, smart meter installation remains incomplete, resulting in limited data accumulation for certain grid areas, hampering predictive capabilities. Additionally, there is a lack of expertise in this domain. Various methods and tools are being considered to better estimate flexibility requirements in the ESO grid. Meanwhile, the Lithuanian TSO Litgrid has enabled independent aggregators to participate in balancing market. However, the market supply is underdeveloped, with nine licensed aggregators, of which only two are active in the balancing market. Considering the increasing presence of RES, the planned

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synchronization of the Baltic States with Continental Europe, and the rising electrification of transportation and heating sectors, the need for flexibility in Lithuania is expected to escalate in the coming years. Lithuania also has hydro pumped storage power plant (four units 225 MW each) and additional 110 MW unit is foreseen to meet growing flexibility needs.

5.2.4.2 Lithuania demo

The Lithuanian demonstration involves four main participants representing distinct roles within the energy market:

- Transmission system operator – Litgrid
- Distribution system operator – ESO
- Flexibility service provider – KTU (Kaunas Technology university)
- Market operator – Piclo (for ESO use case)

During the demonstration phase, Litgrid and ESO, as SO, evaluated two different flexibility services. Litgrid chose to assess the NRT-P-E product, while ESO opted to test the LT-P-C/E product. Each of these products went through separate testing procedures tailored to different usage scenarios, allowing the operators to exploit their effectiveness in specific contexts.

Lithuanian TSO Litgrid indicated the need to reduce congestion in near real time trying to not alter system balancing or not consider it and most relevant product is NRT-P-E.

ESO has chosen to test LT-P-C/E product, since this product is designed to address congestion issues within the grid. Typically, LT-P-C/E is procured months to years in advance and is later activated during specific time periods. This product aligns well with the ESO use case, as ESO can forecast when congestion is likely to occur in a specific grid. In areas with numerous heat pumps, congestion is expected during winter due to increased consumption, while areas with many solar panels connected may experience congestion from electricity flow into the grid during summer. Consequently, the operator can reserve flexibility for these periods. When the anticipated period arrives, ESO can activate the procured product based on more accurate weather forecasts and data from grid surveillance.

KTU, serving as the flexibility service provider, played a crucial role by offering flexibility services for both use cases. To facilitate these services, KTU utilized two of its buildings, one with a power consumption of 200kW and the other with a consumption of 250kW. The controllable units central to these tests were a heat pump of 50 kW and a cooling facility consisting of 7 chillers with cumulative capacity of 290 kW are installed within KTU's infrastructure. KTU also has a solar power plant on one of their rooftops with the power of 380kW.

The high-level architecture of the Lithuanian demonstration, illustrating the interactions among market participants and OneNet platforms is depicted in Figure 5.60.

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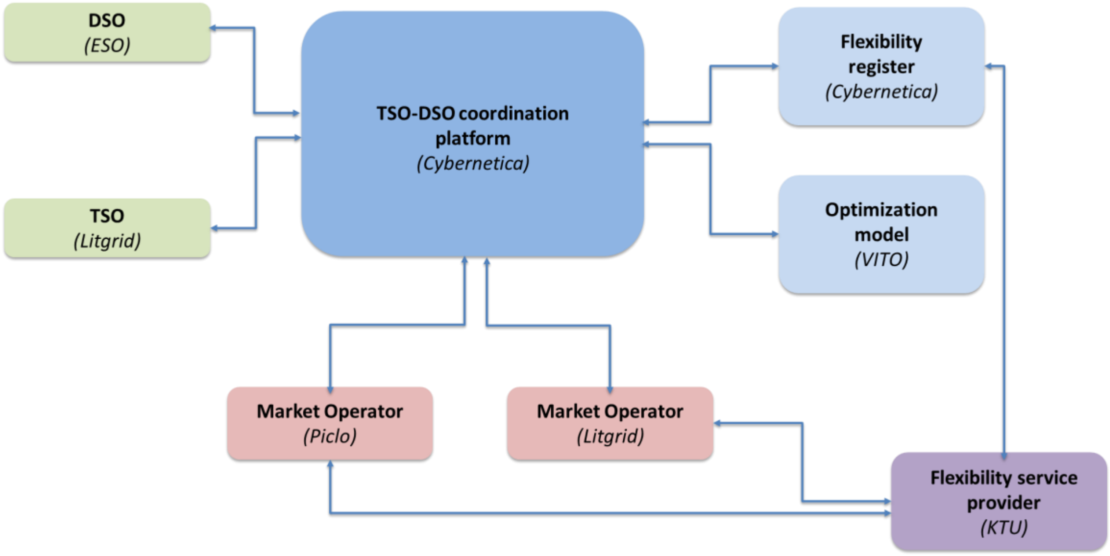

Figure 5.60: The scheme of Lithuanian demonstration

5.2.4.3 ESO demonstration

ESO context and use case

At that moment when flexibility needs were evaluated in OneNet project ESO did not have many cases where flexibility services could be applied. From that time analysis the most suitable need seemed to be congestion solving. The recurring problem which was quite apparent at the beginning of the project was congestion from increased heat pumps production and increased prosumers production back to the grid from their solar plants.

The example illustrating a case of congestion in the distribution grid from the usage of heat pumps is depicted in Figure 5.61.

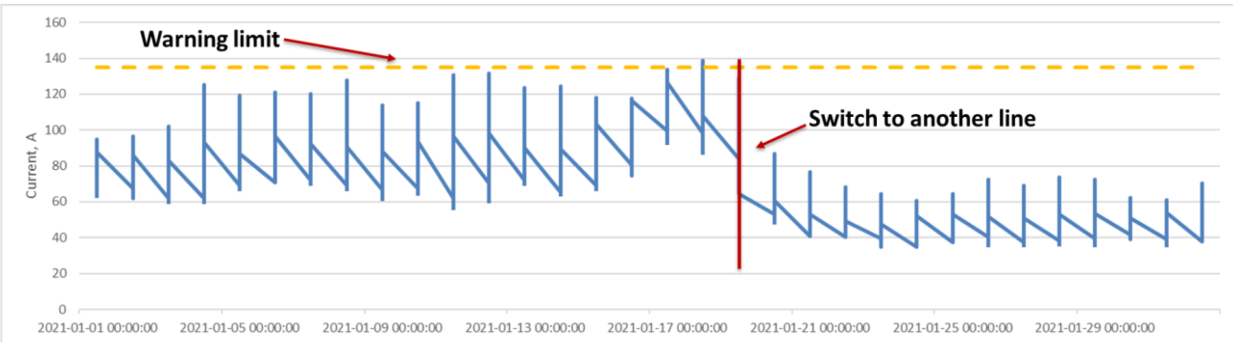

Figure 5.61: Consumption at 10 kV line, 2021

The consumption pattern is taken from a 10kV line servicing approximately 3200 consumers. A significant proportion of these connected consumers reside in private homes and rely on heat pumps as their primary heating source. The Figure 5.61 illustrates notable spikes in electricity consumption on certain days in January, attributed to extremely low temperatures prompting intensified use of heat pumps.

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In this case, the line's capacity is set at 140 A, and consumption rises proportionately with declining outdoor temperatures. When consumption approaches the 135 A threshold, internal systems trigger alerts, necessitating immediate action. Without intervention, continued consumption growth would lead to congestion, potentially resulting in a blackout affecting all 3200 connected customers.

While reinforcing the grid could address this issue, the sporadic nature of consumption spikes during winter's coldest periods suggests a more efficient approach is warranted. Procuring flexibility emerges as a preferable solution, offering a means to manage these relatively infrequent challenges effectively.

Considering the previously mentioned example, ESO has opted to focus the OneNet demonstration on addressing periodically occurring congestion issues. This involves predicting potential congestion in specific grid areas ahead of time, allowing for the estimation of approximate time periods when such congestion may occur.

ESO Grid model

Initially, ESO contemplated testing multiple use cases. However, recognizing that they all address the same issue, the decision was made to proceed with focusing solely on the case involving KTU and modeling congestion in the grid area where KTU assets are connected.

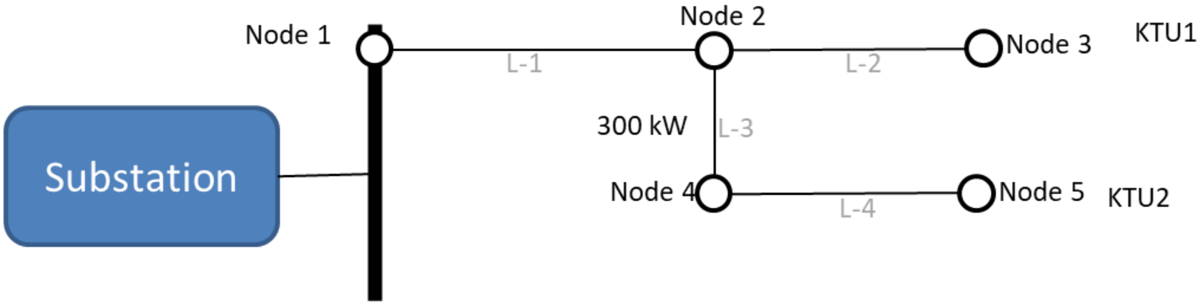

Figure 5.62: ESO demonstration grid model

The grid model utilized for the ESO demonstration was derived from actual grid data but was adjusted to better align with the specific use case. The selection of KTU as the flexibility service provider (FSP) in this scenario influenced the choice of location for their buildings. Both KTU buildings are situated in close proximity to each other and are connected to separate lines leading to one substation. Given the substantial consumption and sizeable solar plant associated with each building, no other units are linked to these lines or substation. Furthermore, the substation to which the buildings are connected is interconnected with other substations and lines. Due to the complexity of representing the entire grid area with its various connections, it was deemed necessary to simplify the grid model. Therefore, the focus was narrowed to include only these two buildings and the corresponding substation. This simplified grid model is illustrated in Figure 5.62.

The capacities for lines were taken from real data, however the base flows were adjusted to create artificial congestions.

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Time period

For this particular use case, a specific time period was not designated. This decision was made due to the absence of actual congestion in the grid where KTU assets are connected. Instead, demonstration timeframes were coordinated with KTU, considering that their primary flexibility provider is heat pump. The only requirement for the demonstration was that the weather would feature lower temperatures to ensure the heat pumps were actively operating. Consequently, there were two demonstration runs in total: one in October involving two flexibility procurements for both up and down regulation, and another in January with two flexibility procurements solely for up regulation. To streamline the demonstration process, the procurement phase, where power is reserved, occurred several days prior to the demonstration, rather than months in advance, to minimize wait times for partners. Additionally, for the activation phase, KTU received notification of the required activation 24 hours in advance.

Bids, parties, and resources

The summary of ESO demonstration runs is provided in Table 5.33.

Table 5.33: ESO use case demonstration runs

The flexibility need for reservation	The flexibility need for activation	Direction	The reservation phase	The activation phase	Resource which provided flexibility
70 kW	70 kWh	Up	October 19th	October 20th	Heat pump
45 kW	45 kWh	Down	October 19th	October 20th	Cooler facility
50 kW	50 kWh	Up	January 9th	January 10th	Heat pump
50 kW	50 kWh	Up	January 9th	January 11th	Heat pump

The demo runs were conducted through the Piclo marketplace. KTU, acting as the flexibility service provider, obtained credentials to access the Piclo marketplace. Through this platform, they could access information regarding ongoing procurements, submit their proposals, view the outcomes, and receive notifications about awarded capacity reservations and necessary activations.

Results

After conducting four demonstration runs, both the baseline and adjusted baseline were calculated. Across all cases, the outcomes were notably similar. For instance, the results obtained from the activation on January 10th are illustrated in Figure 5.63. On the left side of the graph, ESO's metering data alongside the calculated baseline and adjusted baseline for the activation hour are presented. Meanwhile, the right graph displays data from KTU asset data. It's evident that KTU sharply reduced heat pump capacity by 50 kWh starting from 15:00 and didn’t resume operation until 16:00. This reduction in energy consumption is also observable in ESO’s data.

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However, upon calculating the baseline, it indicates a reduction of 31.14 kWh or 34.45 kWh (depending on whether the baseline or adjusted baseline is used) in consumption within the KTU building. Although the adjusted baseline appears to be more precise, it still doesn't align perfectly with KTU asset data. This discrepancy can be attributed to KTU asset data functioning as a sub-meter, whereas ESO utilizes data from a smart meter at the connection point to the KTU building. Therefore, other devices may have influenced the overall consumption within the KTU building.

These findings prompt a conceptual question whether submeter data or system operator data should be used to assess the provided flexibility. On one hand, submeter data would offer a more accurate portrayal of asset actions. On the other hand, if no disparities are evident at the connection point, then from a network perspective, the procured services have provided the full extent of its service.

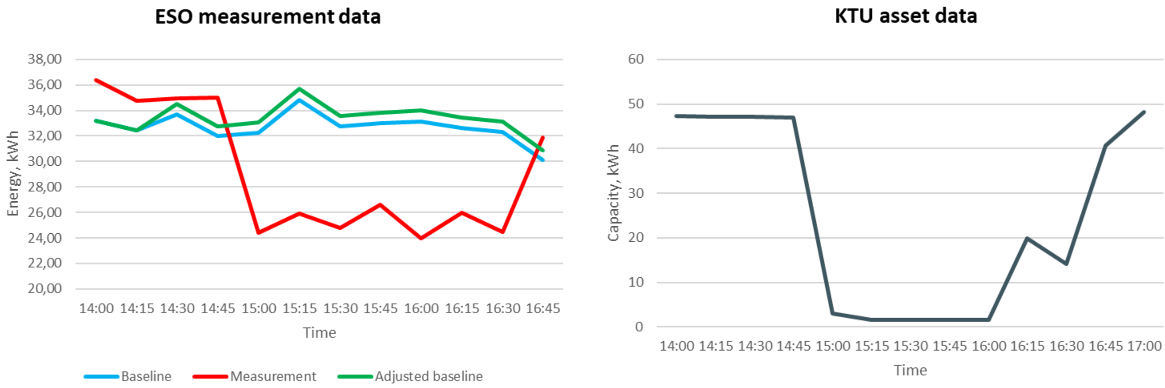

Figure 5.63: ESO demonstration results

5.2.4.4 Litgrid Demonstration

Litgrid Grid Model

In the Lithuanian transmission grid, no congestions appear during regular operation modes, however during maintenance, faults or in future perspective, considering the increase of RES and consumption, congestions could arise requiring to be managed. The Vilnius region was selected for transmission grid demonstrations. The objective is to evaluate the effectiveness of this service in addressing congestion in the chosen grid region.

To identify the impact of the flexibility resources on the congested line PDTFs matrix was created. Vilnius region transmission grid, like many others, is intricately meshed, introducing complexity to its structure. For Litgrid demonstrations, the grid topology was simplified based on the impact to the congested transformer node (TN_2), according to the PDTF matrix, as depicted in Figure 5.64. Demonstration captures specific operation modes during maintenance of a transformer (Congestion 1) and increased RES generation in the TSO network (Congestion 2).

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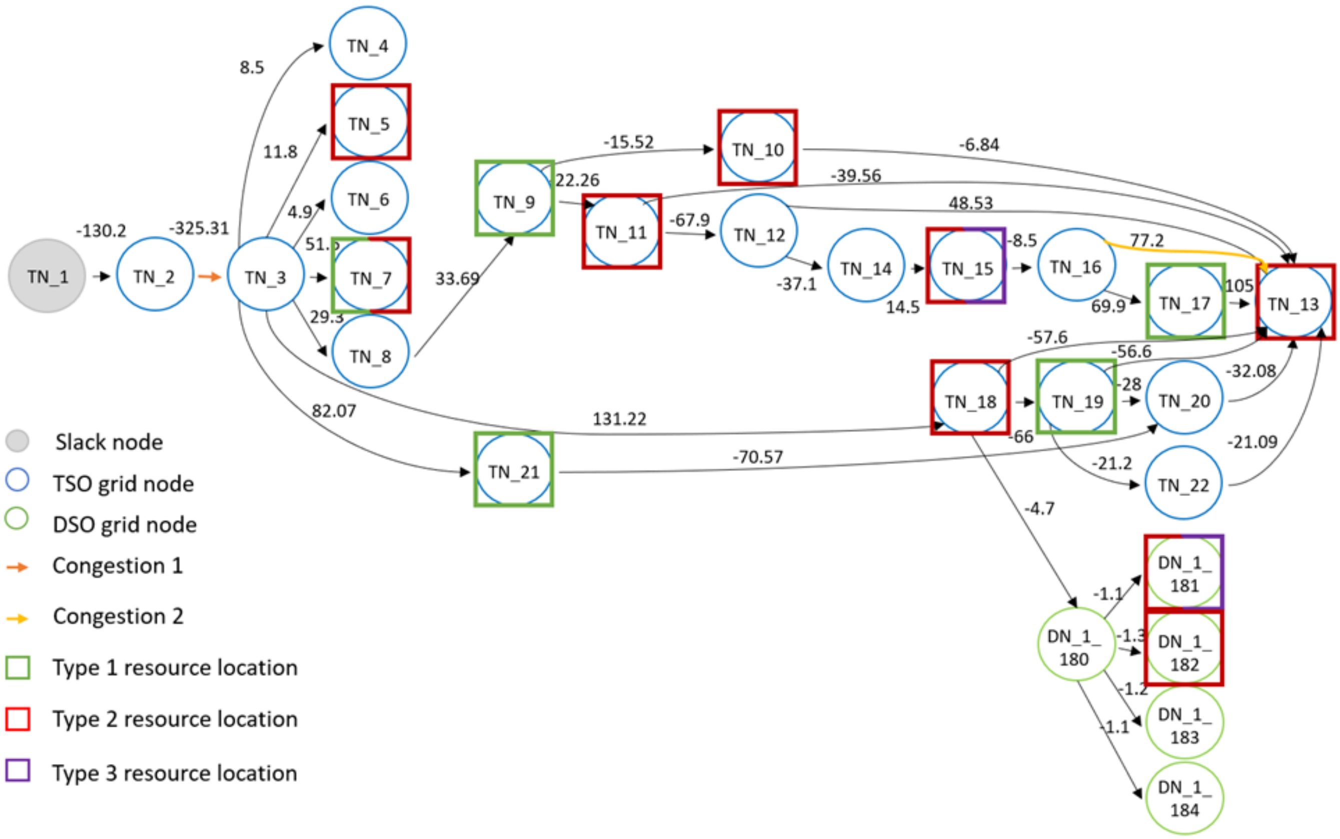

Figure 5.64: Schematic diagram of simplified Vilnius region network used in demonstrations

The grid model comprises of: 330kV nodes (TN_1 and TN_2), 110kV (TN_3-22), and a single connection to the DSO grid of 10kV (DN_1_180-184). This simplified grid model enables a focused evaluation of the congestion management service's efficacy in addressing specific challenges within this dynamic grid environment.

Resources used in Litgrid demonstration are categorized into the following types:

- Type 1 - Simulation of Large Traditional Assets. These assets represent the conventional energy infrastructure and are used as reference points.
- Type 2 - Simulated Flexible Demand and Prosumer Assets. These resources simulate the behavior of flexible demand or prosumers.
- Type 3 - Real Assets Managed by KTU. This category includes actual physical assets, such as heat pumps, battery storage systems, and other flexible assets.

Litgrid Use Cases

Litgrid demonstration is organized into two distinct groups based on resource types. Group 1 exclusively utilizes simulated resources (Resource types 1 & 2), while Group 2 incorporates real assets (Resource type 3) managed by KTU. Within Group 2, demonstration 2.1 utilizes solely real resources, while demonstration 2.2 introduces competition between real and simulated resources. Across all cases, assets are drawn from both TSO

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and DSO grid. Demonstrations maintain a consistent grid topology with minor adjustments to line capacities. The NRT-P-E product, aligning with mFRR requirements, is universally employed for congestion management purposes. Analyses of congestion during maintenance mode (congestion 1) and increasing RES generation (congestion 2) are conducted.

Demonstration group 1 – Simulated Assets

Group 1 comprises four distinct cases, each leveraging the grid topology illustrated in Figure 5.64. The primary objective centers on examining the diverse engagements of simulated resources in alleviating congestion issues (Congestion 1 & Congestion 2) within the grid. Through these cases, different resource types are assessed to discern their efficacy in addressing grid constraints and optimizing system performance.

Resources in Demonstration group 1

Group 1 showcases distinct categories of resources and their participation in flexibility services. Case 1.1 emphasizes the simulation of traditional demand and generation asset involvement, labeled as Type 1 resources, with bid sizes exceeding 5MW. Five simulated resources situated solely within the TSO grid are modeled based on operational profiles of large factories and power plants. Conversely, Case 1.2 simulates the engagement of prosumers and flexible demand assets (aggregating households, offices, commercial buildings, EV charging points, and heat pumps), designated as Type 2 resources, with bid sizes less than 5MW.

Bids in Demonstration group 1

Litgrid currently does not procure congestion management services. The pricing for such services is uncertain. However, the NRT-P-E product aligns with mFRR requirements, where multiple participants compete. Notably, the mFRR market is predominantly composed of traditional service providers.

For group 1 resources, both type 1 & 2, the average mFRR price in the Baltic region was adopted: upward regulation cost 219 EUR/MWh, and downward regulation was priced at 20 EUR/MWh. Considering a range of ±20 EUR/MWh, NRT-P-E bids were generated. Importantly, these bids were influenced by the resource's maximum, minimum, and average operating power. Each generated bid was randomly assigned to be either fully divisible, fully indivisible, or partially divisible with minimum bids of about 1MW.

Given the dominance of traditional resources in the mFRR market, it sheds light on the potential cost implications for Type 1 assets. While increased participation of prosumers and flexible demand assets (Type 2) could theoretically reduce prices, it remains uncertain. To maintain simplicity, we utilized average mFRR prices for both types of simulated resources. This approach provides valuable insights into the feasibility and cost-effectiveness of congestion management strategies in the Baltic region.

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Demonstration group 1 results

Table 5.34 details the optimization results across the Demonstration group 1 cases. The table is divided into two main sections: Input and Output, summarizing the main parameters used for carrying out optimization and its results.

Table 5.34: Litgrid demonstration group 1 optimization results

	Demonstration group 1		Case 1.1	Case 1.2	Case 1.3	Case 1.4
Input	Congestion location		1	1	2	1+2
	Total congestion size, MW		25.31	25.31	27.21	52.52
	Type of resources used		1	2	1+2	1+2
	Sum of upward bids, MWh		240	38.3	195.3	195.3
	Sum of downward bids, MWh		83	23.3	106.3	106.3
	Actual imbalance position, MW		0	0	0	0
	Allowed imbalance post optimization, MW	Min	-50	-50	-50	-50
		Max	50	50	50	50
	Total cost cap, EUR		100000	100000	100000	100000
Output	Cleared bids, MWh	Upward	0	0	0	0
		Downward	36.68	23.3	48.4	44.9
	Congestion, MW	Resolved	25.31	15.84	2.88	24.33
		Unresolved	0	9.47	24.33	28.19
	Imbalance position after optimization, MW		-36.68	-23.3	-48.4	-48.4
	Total cost, EUR		-177.16	33.9	-289.1	-289.1

Demonstration group 2 – Inclusion of Real FSP

Demonstration group 2 consists of two distinct cases, each using the grid topology depicted in Figure 5.64 to alleviate Congestion 1. The key difference from Demonstration group 1 lies in the utilization of real physical assets owned by KTU and Litgrid 9 (resource type 3). In Demonstration 2.1, real assets are solely utilized, while in Demonstration 2.2, they compete with simulated assets (resource types 1 & 2) employed in Demonstrations 1.3 and 1.4. This demonstration group focuses on real asset usage, exploring their marginal operational costs for delivering flexibility services. Each case in this demonstration group consists of 3 subcases focusing on allowed imbalance after optimization.

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Resources in Demonstration group 2

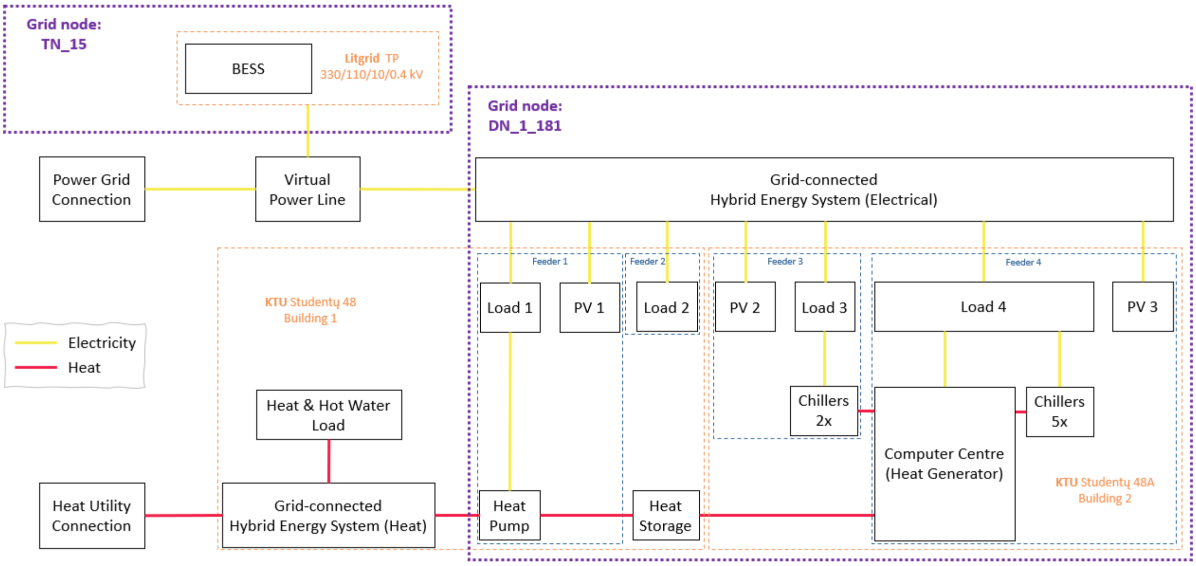

Figure 5.65: Schematic diagram of Virtual Power Plant used in Demonstration group 2 cases

Group 2 is a hybrid energy system consisting of battery energy storage system (BESS) and two buildings with electricity and heat system (power-to-heat system) are treated and dispatched as a single Virtual Power Plant (VPP) while the assets are physically situated at three different locations. The schematic diagram in Figure 5.65 illustrates the various components and their interrelationships in this hybrid system.

A comprehensive operational model for VPP is established, aiming at identifying and harnessing flexibility within the system while ensuring minimal impact on the imbalance position of entire power network. The primary resource for flexibility provision is heat pump with a capacity of 50kW, located in DSO grid, capable of toggling between on and off modes. During the non-heating season only hot water requirements are met, the operation of the heat pump is negligible, taking up to 30 minutes to prepare sufficient hot water for the daily needs. It is technically possible, to make the heat pump more flexible by forcing it to generate heat, this approach is not practical. Doing so would introduce additional load and may require turning on air conditioners in rooms, even though the ambient temperature is already satisfactory during non-heating season. During heating season, the heat pump operates most of the day, utilizing all incoming heat for hot water and heating purposes. In this season, the option to curtail power consumption lies in temporarily halting the heat pump. Given high heat inertia of the building, such measures, if applied for up to one hour daily, have negligible impact on temperature inside the building. Additionally, to counteract the imbalance created by activating the Heat Pump, located in DSO grid (Figure 5.64 node DN_1_181), a BESS, connected at TSO grid (Figure 5.64 node TN_15), of 1MW and 1.1MWh energy capacity is activated in opposite direction by the same amount of power. Figure 5.66 displays the operation of VPP when proving flexibility services in Case 2.1.3.

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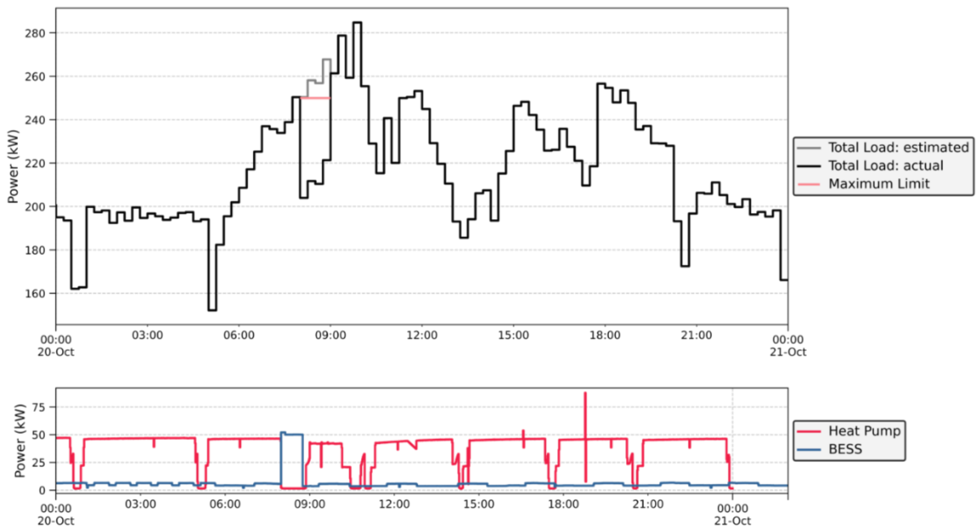

Figure 5.66: Virtual Power Plant Provision of flexibility

The VPP model restricts its operation power to 250 kW between 8:00 and 9:00 to provide flexibility services by turning off the heat pump and mitigating the impact to imbalance by the BESS, connected at a distant grid node, starting to charge at the same power level as heat pump previously operated.

Bids in Demonstration group 2

For the demonstration group 2 real marginal cost for flexibility provision was identified by flexibility service provider - KTU. In Figure 5.67 all components of the marginal costs have been discerned. Given that flexibility assets can be linked to various SOs and considering current subsidy for BESS, the marginal costs exhibit a range from 78.11 EUR/MWh to 209.04 EUR/MWh.

The marginal cost of turning off the Heat Pump is 0 EUR/MWh if turn off lasts up to an hour, as it has minimal impact on indoor temperature, for demonstrations this price was used. Longer turn offs may incur heat recovery costs to address discomfort, considering 2023 average Nord Pool day ahead electricity prices and district heating costs in Kaunas, on average heat recovery would cost about 25 EUR/MWh. Currently, BESS in Lithuania incur no tariffs. For marginal cost of operating VPP for flexibility services, varying Power reservation cost and fixed battery depreciation costs are considered. This marginal cost was included for Group 2 cases. Potential future tariffs of BESS were not factored in, as they exceeded the average price of upward bids (112.79 EUR/MWh) in Group 1 cases. VPP marginal costs would significantly rise if connected to the TSO grid (more than 1.5 times) and if connected to the DSO grid (more than 2.5 times) compared to the current incentivized model, rendering them uncompetitive against simulated resources used in demonstration group 1.

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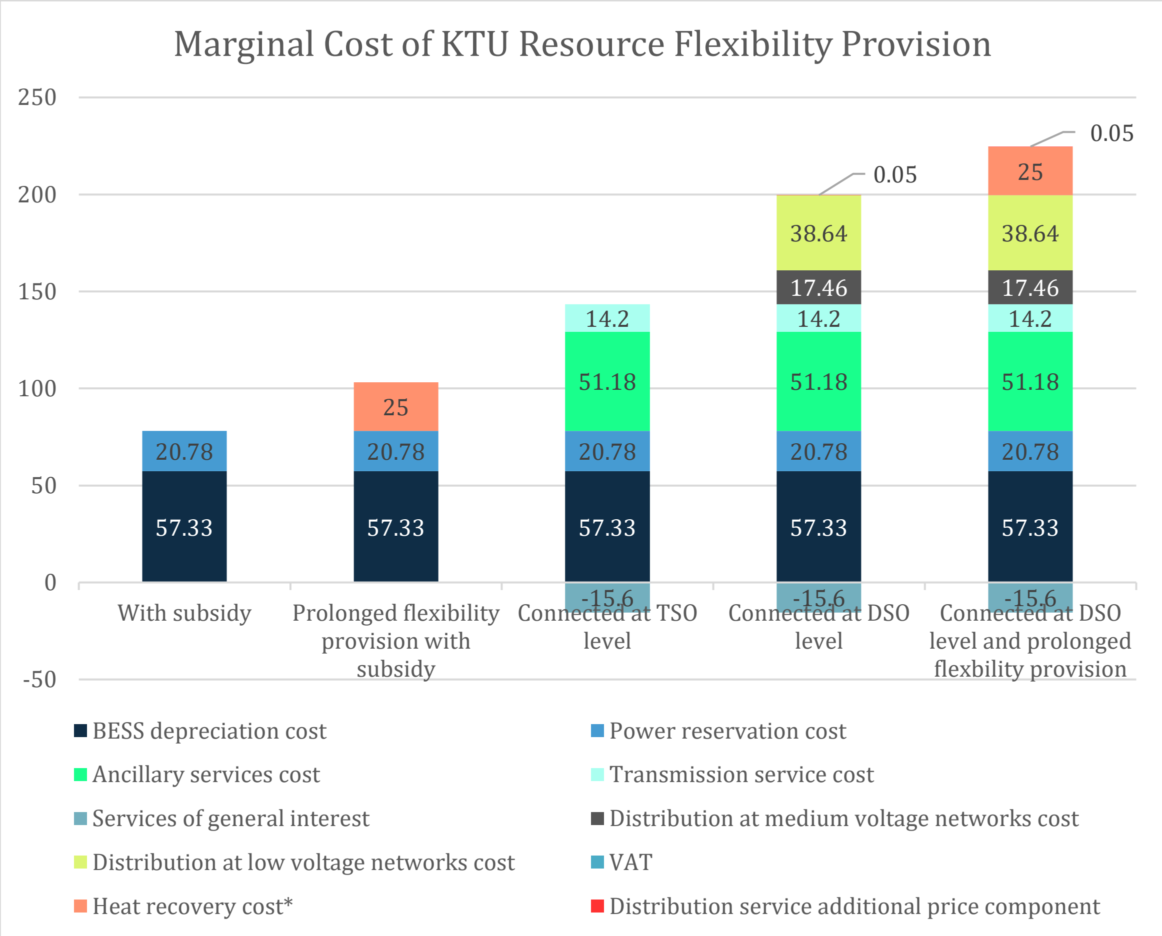

Figure 5.67: Marginal cost of KTU resource flexibility provision

Demonstration group 2 results

Table 5.35 details the optimization results across the Demonstration group 2 cases. The table is divided into two main sections: Input and Output, summarizing the main parameters used for carrying out optimization and its results.

Table 5.35: Litgrid demonstration group 2 optimization results

Demonstration group 2		2.1 – KTU resources only			2.2 – KTU & simulated resources		
		Case 2.1.1	Case 2.1.2	Case 2.1.3	Case 2.2.1	Case 2.2.2	Case 2.2.3
Input	Congestion location	1	1	1	1	1	1
	Total congestion size, MW	0.31	0.31	0.31	10.31	10.31	10.31
	Type of resources used	3	3	3	1+2+3	1+2+3	1+2+3
	Sum of upward bids, MWh	0.05	0.05	0.05	195.35	195.35	195.35
	Sum of downward bids, MWh	0.05	0.05	0.05	106.35	106.35	106.35
	Actual imbalance position, MW	0	0	0	0	0	0

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	Allowed imbalance post optimization, MW	Min	-0.05	0	-0.03	0	-100	-10.31
		Max	0.05	0	0.03	0	100	10.31
	Total cost cap, EUR		100000	100000	100000	100000	100000	100000
Output	Cleared bids, MWh	Upward	0	0.05	0.02	86.85	0	79.94
		Downward	0.05	0.05	0.05	90.25	44.9	90.25
	Congestion, MW	Resolved	0.035	0.001	0.021	1.58	10.31	8.52
		Unresolved	0.275	0.309	0.289	8.73	0	1.79
	Imbalance position after optimization, MW		-0.05	0	-0.03	0	-44.9	-10.31
	Total cost, EUR		0.05	3.96	1.61	11464.1	-324.1	10226.9

5.2.4.5 Demonstration impact to Lithuanian SOs

During the OneNet project, both Litgrid and ESO identified varying needs for flexibility services. Despite this, both system operators acknowledge the necessity for greater coordination.

In the demonstration phase, ESO collaborated with Litgrid by sharing DSO grid information, and no significant challenges were encountered during simulation. However, both Lithuanian system operators now recognize the need for enhanced coordination in real-world scenarios.

Considering the anticipated increase of renewable energy sources and connection of new loads such as heat pumps and electric vehicles, it is expected that majority of flexibility providing assets will be connected to ESO's grid but will participate in Litgrid's ancillary service markets. Internal analysis indicates that flexibility activated by Litgrid which is located in ESO grid can potentially cause congestions in ESO's grid. Furthermore, as ESO is currently not acquiring flexibility, the impact it could have on the power network balance managed by Litgrid remains uncertain.

As a result, both Litgrid and ESO are intending to further investigate the flexibility topic outside of OneNet and examine which insights from the project could be applied in Lithuania. It is important to note that ESO has already integrated the LT-P-C/E flexibility product, tested in OneNet, into its flexibility procurement rules, which were approved by the national regulatory authority. Additionally, both Litgrid and ESO will further work on better coordination between system operators.

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6 Evaluation of demonstrations

The demonstrations were evaluated using pre-defined KPIs specific to the NOCL demonstrators. All those KPIs have been reported in deliverable D11.1 Evaluation of OneNet demonstrators' results [15].

6.1 Generated values for DSOs & TSOs

OneNet's deliverable D7.5 [4], titled "DSO & TSO Value Generation Drivers," focused on to the benefits that system operators derive from employing flexibility-enabling tools, both those developed within the Northern cluster and those outside the OneNet project. Initially, the document examined which tools are most valuable for acquiring flexibility, pinpointing four: the flexibility register, TSO-DSO coordination platform, market platforms, and other internal tools. Furthermore, it outlined a clear list of value drivers stemming from the utilization of these flexibility-enabling tools. It was highlighted that these tools yield various benefits, including enhanced transparency, automation of processes, value stacking, and others.

A key objective of deliverable D7.5 was to compare these identified values with the results of demonstrations. However, since not all demonstrations had concluded at the time of writing D7.5, it was decided to include the evaluation of these results in a subsequent report, which would be presented in this section.

As it was outlined in D7.5, the value drivers coming from flexibility enabling tools will be evaluated by estimating chosen Key Performance Indicators (KPIs). As it was stated in deliverable D7.5, the majority of KPIs were drawn from deliverable D11.1, titled "Evaluation of OneNet Demonstrators' Results." The methodology for calculating these KPIs is elaborated upon in that document. Additional KPIs introduced by task force 7.5 will be explained in this section as well. It's important to note that KPIs were not calculated for other internal tools, as these tools vary among system operators, and measuring them via KPIs in the Northern Cluster demonstrator context was deemed impractical.

Flexibility register

Deliverable D7.5 identified five key value drivers associated with the flexibility register: transparency and visibility, FSP prequalification in regional market, resource quality/integrity, process automation, and process interoperability. Each of these recognized values was assigned corresponding KPIs. The table detailing these KPIs along with the results for each country is presented in Table 6.1.

Table 6.1: KPIs values for flexibility register

Value driver	KPI	Finland	Estonia	Latvia	Lithuania
Transparency and visibility	Time required for access to information about flexibility availability, market participants, FSP resources, FSP resources' technical	<1s	<1s	<1s	<1s

	capability, FSP resources' prequalification status (Added by T7.5)				
	Number of iterations (steps) to find information about: flexibility availability, market participants, FSP's resources, FSP resources' technical capability, FSP resources' prequalification status (Added by T7.5)	2 (SO logs in to SO interface of FR and selects the information tab of interest)	2 (SO logs in to SO interface of FR and selects the information tab of interest)	2 (SO logs in to SO interface of FR and selects the information tab of interest)	2 (SO logs in to SO interface of FR and selects the information tab of interest)
FSP prequalification in regional market	Number of demonstrated cross border products	1 (1)	1 (1)	1 (1)	0(0)
	Number of demonstrated joint products	2 (2)	1 (1)	1 (1)	1(1)
	Number of FSPs participating in more than one country	2 (2)	0 (0)	0 (0)	0 (0)
Resource Quality / Integrity	Number of FSPs	3	3	0	1
	Percentage of successfully prequalified FSPs	100 (100%)	100 (100%)	100	100 (100%)
	Verification method accuracy	MAPE=0,35	MAE=11,6% RMSE=12,5 %	RMSE<0,2	MAE=28.8% RMSE=39.8 %
Process automation	Level of automation of SUC process steps (the ratio of automated steps to all process steps)	0	100 %	0	0
Process interoperability	Number of requests for clarification of market requirements	0 (0)	0 (0)	0 (0)	0 (0)

To estimate value deriving from flexibility register task 7.5 added three additional KPIs:

- Time required for access to information about flexibility availability, market participants, FSP resources, FSP resources' technical capability, FSP resources' prequalification status – this value is assessed straightforwardly as the average time in seconds for an operator to access any desired information component.

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- Number of iterations (number of steps) to find information about flexibility availability, market participants, FSP's resources, FSP resources' technical capability, FSP resources' prequalification status - this value is evaluated as the average number of steps for an operator to access any desired information component.
- Number of requests for clarification of market requirements – this value indicates the number of requests made by FSPs to clarify market requirements.

The KPIs table for the flexibility register indicates that the majority of reference values were met, suggesting a smooth execution of the demonstrations. It was verified that all value-generating drivers associated with the flexibility register were successfully attained. This enabled system operators to experiment with various flexibility products designed for joint and cross-border applications, ultimately leading to successful prequalification of FSPs. All information was immediately available for system operators to access the information about flexibility availability, market participants, FSP resources, FSP resources' technical capability, FSP resources' prequalification status with required time lower than one second and only within two steps. Additionally, the flexibility register demonstrated its capability in ensuring the quality of flexibility resources, with a total of 7 FSPs qualifying in the Northern Cluster demonstrations. Furthermore, the process of utilizing the flexibility register was sufficiently clear for market players, as evidenced by the absence of requests for clarification regarding market requirements.

TSO-DSO coordination platform

Three value drivers were designated for the TSO-DSO coordination platform: the constraint setting process, optimization process, and flexibility call for tender process. The results of the KPIs for these value drivers are available in Table 6.2.

Table 6.2: TSO-DSO coordination platform

Value driver	KPI	Finland	Estonia	Latvia	Lithuania
Constraint setting process	Number of conflicts resulting from flexibility product activation	0(0)	0(0)	0(0)	0(0)
	Percentage of avoided technical restrictions (congestions)	100%(100%)	100%(90%)	100 %	60%
Optimization process	Speed of bid optimisation algorithm	ta=0,0468s	ta=0,0468s (<1)	ta=0,25	ta= 0,0664
	Speed of grid qualification algorithm	ta=0,0468s	ta=0,0468s (<1)	ta=0,25	ta= 0,0459

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Flexibility Call for Tender process	Number of coincident tenders for flexibility services (Added by T7.5)	N.A	0 (0)	0 (0)	0 (0)
	Number of times SO needed to contact MO to open a new tender (Added by T7.5)	N.A.	0 (0)	0 (0)	0 (0)

To fully estimate values stemming from TSO-DSO coordination platform two additional KPIs were added by T7.5:

- Number of coincident tenders for flexibility services – this value represents the number of occurrences where a similar or relevant tender for the identified need was already in existence upon initiating the procurement of flexibility services.
- Number of times SO needed to contact MO to open a new tender – this value determines a number how many times system operator needed to contact MO directly to open a new tender instead of opening it through TSO-DSO coordination platform.

As evident from Table 6.2, the TSO-DSO coordination platform also demonstrated successful attainment of the specified KPIs. The demonstrations highlighted the effectiveness of the constraint setting process, as no conflicts arose among connected system operators following the activation of flexibility products. Additionally, in the majority of instances, grid congestions were successfully avoided. These outcomes were largely attributed to the efficiency of the optimization process, which consistently operated within a very brief timeframe, never exceeding one second, guaranteeing optimality of the market clearing results and ensuring the grid safety of cleared flexibility through avoiding clearing bids that can cause or worsen operational issues within the involved grids. Furthermore, the flexibility call for tender proceeded smoothly, with no instances of overlapping tenders or the need for system operators to directly initiate new tenders through contact with the market operator.

Market platforms

Three value drivers were allocated for the market platform: value stacking, harmonized product definition, and centralized activation process. The KPI results from the demonstrations in the Northern Cluster are presented in Table 6.3.

Table 6.3: Market platform

Value driver	KPI	Finland	Estonia	Latvia	Lithuania
Value stacking	Number of implemented cross border products	1 (1)	1(1)	1(1)	0(0)
	Number of implemented joint products	2 (2)	1(1)	1(1)	1(1)

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Harmonized Product definition	Number of implemented products	2	1	2	2
Centralized activation process	Number of activated products/ services (Added by T7.5)	2	30		14

One additional KPI was introduced for the evaluation of the market platform tool:

- Number of activated products/ services –this value is the number of times when flexibility products were traded/demonstrated.

The data provided in Table 6.3 illustrates the successful demonstration of the value that the market platform can offer to system operators. By utilizing the market platform, system operators were able to showcase a variety of flexibility products. In total, 5 flexibility products were demonstrated, with three of them utilized as cross-border products and five as joint products involving system operators from one country. This indicates the platform's effectiveness in facilitating the deployment and management of diverse flexibility products, fostering collaboration between operators across borders and within the same country.

The conclusions drawn from KPIs calculations highlight the successful implementation and effectiveness of flexibility enabling tools tested in enhancing the operations of system operators within the Northern Cluster. The flexibility register demonstrated its capability in enabling system operators to experiment with different flexibility products, leading to successful prequalification of FSPs. Additionally, it ensured the quality of flexibility resources, with multiple FSPs qualifying in the demonstrations. The clear process of utilizing the flexibility register contributed to its effectiveness, as evidenced by the absence of requests for clarification. The successful attainment of KPIs indicates the effectiveness of the TSO-DSO coordination platform and the optimization-based market clearing process. The constraint setting process effectively prevented conflicts among system operators, while the optimization process efficiently managed grid congestions. The flexibility call for tender proceeded smoothly, without overlapping tenders or the need for direct intervention from system operators. The data from the market platform demonstrations showcased its value in facilitating the deployment of various flexibility products. The platform enabled system operators to demonstrate a range of flexibility products, including cross-border and joint products, fostering collaboration among operators both within and across countries. Overall, these conclusions highlight the significant contributions of these tools and platforms in improving the efficiency and effectiveness of system operators within the Northern Cluster, ultimately enhancing the procurement process of flexibility services.

6.2 Impacts

- **End-customer engagement**

The demonstration in Estonia focused on testing the OneNet Flexibility Service provider model for most challenging flexibility transactions located in residential consumer houses. The project selected a combination

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of 14 different houses equipped with Smart meters as well as different types of Distributed Energy Resources located behind the meter including Water Heaters, Thermostat Heat Pumps, Pool Pumps, Home storage as well as Solar PV self-consumption integrated with Smart V1G charging or direct heat pump controls.

Figure 6.1: Demo setup in Estonian case

Novel approaches were tested integrating real-time Dedicated Measurement Device communication installed behind Grid meters to improve consumer access to real-time information while investigating the option to automate flexibility transactions end to end from TSO-DSO flexibility markets down to end users differentiating device flexibility prices per asset indirectly reflecting the complexity of automating associated controls as well as providing real-time dashboards to ensure full control transparency for consumer wishing to drill down through more detailed information.

Several interesting lessons were learnt through the project:

A/ Enabling low-cost real-time exchange is possible through home internet connectivity at zero marginal costs to end users. It however requires DER to be ready for such data exchanges (i.e.be able to include a DMD or provide necessary measurements straight from the assets). Assuming this is the case, new data exchange protocols such as MQTT allow real-time data exchange fitting observability requirements from most stringent near real-time flexibility markets (such as aFRR or mFRR). Some complexity however remains in security associated exchanges and stabilising home router exchange whole failure needs to be incorporated through the flexibility estimation process (to minimise associated risks) as well as mitigated through the integration of device auto reboot functions.

B/ Applying conventional statistical baselines to DMD data does not significantly improve baseline accuracy. Moving further with DMD data requires to consider new near real-time AI base schedule nominations (as considered through a parallel BD4NRG project) leaving FSPs to bear associated risks (as well as TSO-DSO to

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innovative approaches to overview associated schedule accuracy/imbalances) or evolve towards MeterBefore/MeterAfter baselines or price based implicit incentives used down to DMD levels (which then will require TSO and DSO to apply more complex Digital Twin near real-time simulations on their side to validate demand response elasticity and flexibility response on their feeders).

C/ Automating the end-to-end chain for real-time flexibility market to consumers through different DER group aggregation to stack revenue across different flexibility product is technically feasible. Standards like IEC62325 ESMP already incorporate necessary data exchange profiles for all bidding, baseline nomination, activation as well as ex post measurements. This only remaining dataflow to define is related to ex-ante observability for which IEC61850 through MQTT may be a better option (flexibility products should consider stronger alignment on this to facilitate integration of standardised DERs [16].

D/ Significant efforts have been spent in recruiting consumers and educate them on the purpose of the demonstration, particularly illustrating the importance of flexibility for Grid operators through different scenario descriptions. This however did not lead to a very strong consumer implication through the pilot as the demonstration period has unfortunately been too restricted (3 months before project closing) and because of the complexity of associated grid management processes which did not seem to drag consumer attention (although their declared interest to lower their bills and contribute to climate change mitigations). This is not a surprise considering other project examples such as the Innovate Vehicle to Community Vectors which gathered several consumer communities who indicated not to be interested in the details of back-end flexibility processes but simply wanting to access to data related to their energy bill savings, flexibility transaction revenues as well as some form of environmental indicators. Follow up tests have been planned through the next Eddie and Eclipse projects wishing to test the impact of newer generation user interfaces and digital twin tools for prosumers.

- **Definition of common products and use cases (regional approach)**

Northern cluster decided in the very beginning of the project to start with one single business use case covering all market phases from customer onboarding to settlement, satisfying different flexibility needs and products, as well as the being suitable for all participating countries. Each market phase was elaborated further in a small number of system use cases. Common products were proposed, which both TSO and DSO can use and which can serve different needs like congestion management and balancing. Enabling uniform rules in the region facilitates FSPs to enter markets of individual countries with minimum additional investments. Common products help to increase the liquidity because the same flexibility can be used for different purposes at the same time. On the other side, it also brings along value stacking for FSPs.

- **Common tools (FR, T&D-CP etc) and automated flexibility procurement**

The Northern cluster has established an IT architecture for automating flexibility procurement through the development of two distinct tools: the flexibility register and the TSO-DSO coordination platform. These tools

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are designed to facilitate seamless interaction among key stakeholders in the energy market, including system operators, flexibility service providers, and market platforms. The flexibility register serves as a centralized platform for market parties to register their assets in a standardized manner, ensuring harmonization across different system operators and countries. The TSO-DSO coordination platform empowers system operators to provide their specific requirements for flexibility, while the platform itself conducts optimization calculations to efficiently match these needs with available resources. This integrated approach streamlines the procurement process, enhances coordination between stakeholders, and lays the groundwork for a more efficient and responsive energy system within the Northern cluster.

- **TSO-DSO coordinated and joint flexibility market**

There is a growing need for flexibility at the different grid levels (to accommodate generation fluctuation, and increased consumption levels and their simultaneity). At the same time, the volume of available flexibility from the different voltage levels is growing, especially with the increased electrification and digitalization of the consumers' energy space, and the growing integration of storage. Thus, TSOs and DSOs will require the procurement of flexibility to meet their grid/system services' needs, while the flexibility resources available (from the different grid levels) would be accessible to all of them. This presents an opportunity to benefit from the synergies between the needs of the different SOs, as activated flexibility can concurrently meet the needs of different SOs, leading to minimized procurement costs. The Northern demo has successfully benefited from and showcased this value stacking potential of flexibility, by looking at coordinated (and at instances) joint procurement of flexibility for TSOs and DSOs. This allows minimizing the total costs associated with procuring flexibility, ensuring that the procured flexibility bids reliability meet the needs of all SOs involved, while making sure that the procured flexibility does not cause any network constrain violations for any of the grids involved; thus combining optimality with reliability of flexibility procurement and grid-safety. As the total cost of flexibility is decreased, the individual costs that would be borne by each SO would be reduced as compared to running disjoint flexibility markets (i.e. each SO running its own flexibility procurement without coordination), as showcased in the KPI calculations of the OneNet demo, and as analysed in D7.2 [1] as well as proven mathematically in [17]. In addition, the running of disjoint markets opens the risk that an SO procuring flexibility from outside its own grid can lead to network violation in that grid, as its network constraints cannot be considered during market clearing, thus further reinforcing the need for coordination.

This TSO-DSO coordination also showcased that it is possible to also enable forwarding of bids to EU platform for balancing. This necessitates ensuring that the forwarded bids (i) abide by the bid format requirements and product/service requirements of the market to which they are forwarded (e.g. from a congestion-management market to the MARI platform as demonstrated in the northern demo cluster), and (ii) ensuring that the forwarded bids, when activated n the subsequent market, do no cause operational issues and network violations of the local/national grids from which they are originated. TSO-DSO coordination enables the checking of the grid safety of those bids, so that only grid-safe bids can be forwarded.

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- **Grid-impact inclusive optimization-based market clearing**

As the northern demo cluster highlighted, bid optimization and market clearing in flexibility markets should go beyond a simple ranking based on prices (known as the merit order list). Indeed, different bids, based on the location of the flexibility resources in the grid, will have differing impacts on different network elements, and on

i. their ability to deliver the intended services, while
ii. considering their impacts on the overall grid operation to ensure that no additional constraint violations are unintendedly created.

That's especially important when considering location-dependent grid constraints and provision of grid services, such as congestion management and voltage control (among others), considering both transmission and distribution systems[1]. As showcased in D7.4 [3], a cheap bid may proportionally contribute less to reducing congestions as compared to a more expensive flexibility bid based on their locations, making the more expensive bid more efficient to purchase when considering their price per unit reduction of congestions (i.e. their effective value in reducing congestions). When considering meshed systems, TSO-DSO coordination, and complex bids, this problem becomes more complex, as the market clearing has to take into account:

- The impact of each bid on all network elements,
- Limiting the impact of the bid's clearing on the system's balancing position,
- Coupling the grid impact with the market price to determine the value of a purchased bid for the grid,
- The coordination of all grids involved (TSOs and DSOs) and considering the flexibility needs of each grid,
- The bids' technical requirements, which are governed by the bid type submitted, namely: from simple fully divisible price, quantity pairs (that are merely constrained by the submitted quantity), to non-divisible and partially divisible bids, to more complex exclusive bids and multipart parents/children bids, to name a few (e.g. these bid types are also considered in the MARI platform).

An optimization-based market clearing allows the automatic and concurrent accounting for all these elements to generate optimal and grid-safe market clearing results, which result in minimized procurement costs, clear remuneration for FSPs, and grid safety (resolving available grid issues while not creating additional violations). A manual market clearing, or a market clearing that is merely based on a price ranking (known as the merit-order list) is not capable of addressing these simultaneous dimensions, leading to suboptimal or even non-grid-secure market clearing results.

[1] This dimension is also important in energy and balancing markets when considering congestions (interzonal/national, or cross-border) as the location of energy deliver points (i.e., the nodes in the grid) directly impact the resulting meshed network state (power flows, and voltages, etc.).

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The optimization-based market clearing process can be adapted to the needs and requirements of different flexibility products, as showcased by its applicability in the Northern demo to energy as well as capacity products, at different time scales (long-term, short-term, and near real time). The optimization mechanisms can also easily coupled with existing market platforms to enable their optimal market clearing, as showcased through the coupling with Nord Pool's locational intraday market and Piclo's long-term DSO-level reserved markets, from which the flexibility bids are received (through the means of the T&D CP platform) and to which the market results can be posted back to enable their communication to SOs and FSPs for activation.

- **Interoperability and standardization**

The architecture used in Estonia demonstrates the benefits of using CIM standards as derived from the IEC62325 European Style market profile for data exchanges between TSOs also for the communication between Grid operators and Flexibility Service providers offering consistent data ontologies as well as network model topologies/node definitions across markets.

It has also illustrated the interest to expand associated definitions beyond the Flexibility Service Operator down to DER Operators in the residential space to minimise residential consumer integration costs through the reuse of existing DER app connectivities. Preliminary contacts have been established with the TC57 of IEC to further standardise this data exchange through the new IEC62746-4 message profiles for which the use case demonstrated through Eddie is now considered as a reference use case for data exchanges.

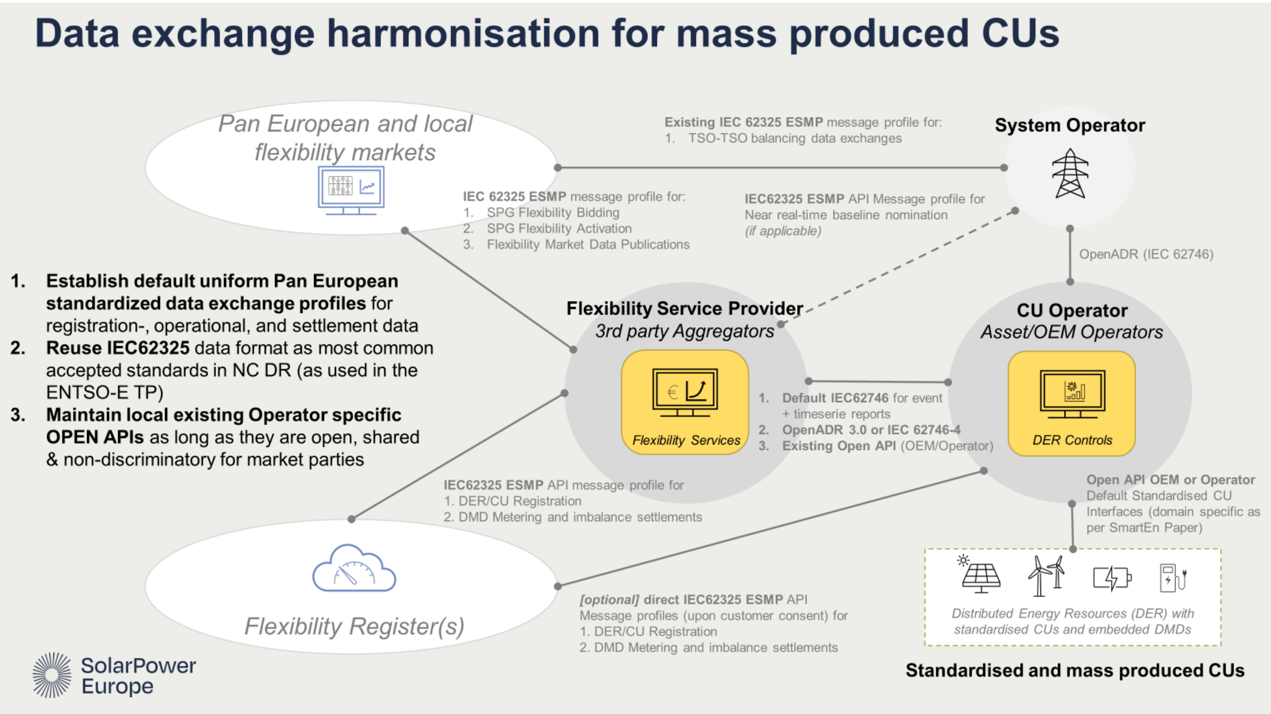

Figure 6.2 Data exchange harmonization

The approach taken is fully aligned with current exchanges through the Demand Side Flexibility Network code where key actors such as SmartEn and SolarPowerEurope are calling for aligning all market API according to the IEC62325 profile as tested and validated through the Estonian demonstration (and illustrated through the following slides extracted from Solar Power Europe request through the DSF flexibility code drafting).

This also confirms CIM should be an essential data ontology to consider for next energy dataspace developments which is the direction taken by some dataspace projects such as Eddie which have fully reimbarked the developments and APIs prototyped through our Norther demonstration for the modelling of data exchanges).

- **Common Baseline definitions**

The Northern Cluster proposed two alternative methods flexibility for verification. Firstly, the FSPs were allowed to submit a schedule for their resource groups, which will be used as the reference value when assessing the delivery of the flexibility service comparing it to the metering data. It was defined that the schedule must be delivered to the FR before the time-period which the bid sent by the FSP concerns. When the schedule is required for the bids beforehand, the System Operators can monitor the accuracy from those time periods where the bid was not activated. Thus, systematic attempts of the FSP to manipulate the reference value will be noticed. Also, the schedule might be a relevant option for the reason, that the FSP needs the information for its own business any case. So, the information exists and it is in the interest of the FSP to make it as good as possible. Otherwise, the FSP won't be able to make any revenues from the market. Lastly, an argument to support the option of schedule is that the FSP has in many cases information about the behaviour or the preferences of the asset owner. Statistical models won't be able to capture such particularities.

The alternative reference value was determined to be a central baseline calculated by the FR. The method used was adjusted High 5 of 10. The background for this choice is presented in deliverable D7.2 [1]. During the demonstration, the baseline calculation model was tested with different metering data from real demand-side resources. The conclusion from these tests was that the use of the adjustment factor increases the accuracy of the baseline, but still the errors are relatively high to be used for the verification of the flexibility service. Resources like EVs or house-hold consumption varies significantly based on the decisions of the end-users. For this reason, the aggregated pool of demand-side resources would need to be relatively high in order to get a baseline that predicts well the behaviour. It is evident, that if central baseline calculation models are to be used broadly, more research and test are still needed. Also, different resources might need to have a different baseline method, since they naturally behave differently. Calculation models like the High X of Y can give reliable results in cases where the aggregated pool is large and where the profile is similar day-to-day. Differences in the amplitude of the load curve can be handled by the model well but not the changes in profile.

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- **Pan-European Approach through OneNet middleware**

The NOCL Single Flexibility Platform is open for external Pan European flexibility market participants through OneNet Framework and OneNet Connector. Common CIM format is the implemented data format.

6.3 Lessons learnt

1. Experiences with real Customer engagement

End customers in Finland have smart meters with a relay making it possible to turn on/off a certain asset (usually a hot water boiler) but only on fixed pre-programmed hours making it possible to use night tariffs. The next generation of smart meters would include dynamic remote control and was planned to be used in the projects for steering through a flexibility contract with the FSP (Vattenfall). End customers were recruited, positive to participate and signed the flexibility contract, but in the end these new meters were not available in time for the project demo and the actual demo was discontinued.

Another Finnish customer engaged was a data centre owner 'Northeast flow' who offered heating load flexibility to the NOCL platform. Due to a considerable flexibility magnitude, i.e. of the order of kWs and based on demo success, it showed keen interest to continue with a flex contract after the project.

OneNet WP7 also organized a federated pilot with another Horizon H2020 project iFLEX. iFLEX project offered heating load flexibility from a residential apartment building in Helsinki. Building occupants were enrolled for piloting activities. The building management system was integrated towards NOCL platform for meeting flexibility needs of SOs as well as minimize carbon emissions and electricity costs by optimal switching between on-site heat pump and district heating supply. The flexibility offerings were subject to slightly sacrificing thermal comfort levels of occupants.

Additionally, Fingrid launched a campaign through its communication channels to find partners interested to pilot their flexibility pools. As a result, two companies, namely, Comsel Systems Oy and Synergi Solutions Oy joined the demonstration as in-kind partners. Comsel Systems Oy offers smart control services to end-customers and industrial companies. In the demonstration, Comsel directly controlled a total of 80 EV chargers, 80 residential heating units and 5 PV systems all located and widely distributed across Finland. The participation of Comsel Systems' resources is described in detail in Chapter 5.2.1.

Synergi Solutions Oy, on the other hand, connects directly to EVs and heat pumps through the vendor interfaces to monitor and control them.

In Estonia people are highly motivated to be flexible but they need a lot of guidance about how to be active in the market.

In Lithuania the customer engagement and involvement is low due to price references for flexibility service is not clear.

2. **Realizing flexibility offering benefits by DER owners**

One of the main challenges usually encountered through residential environment is related to the possibility automate flexibility offers from flexible DERs behind Grid meters on one hand while providing on the other hand real-time information to consumers to be able to analyse the impact of flexibility activation on consumer lifestyle as well as estimate associated transactional benefits for end users.

The D4G multisided Flexibility Service provider platforms managed to demonstrate the feasibility to overcome such challenges while integrating with OneNet standardised market API leveraging CIM based data exchanges. In particular, the following was demonstrated:

a/ Individual DERs have been monitored and control through real-time data exchange leveraging standard low-cost internet-based home router communication, integrating near real-time Dedicated measurements from critical Power and Energy. Associated data streams have been used to provide near real-time DER flexibility calculations linking directly with selected DER asset behaviours (Charging Points, Water Heaters, Heat Pumps) hence offering near real-time evidence of flexibility actions.

b/ DER bid offers have been automatically generated bottom up taking into account DER specific elasticity prices as a multiple of day ahead energy prices. This allows end users to set their DER flexibility preference considering the complexity of achieving associated controls (manual or fully automatized) as well as the impact on its lifestyle (i.e. limited for EV charging delay and high for Heat Pump start/stops)

c/ Flexibility transactions are logged and valued individually offering direct indications of associated daily revenue returns to end users. The objective of this real-time feedback and transparency is to raise consumer awareness and trust on flexibility benefits.

d/ The environment provides 24-7 carbon footprint monitoring of each individual home also providing KPIs and baselines for individual household carbon savings and abatement.

3. **Access to metering / sub-metering data**

- Main meter data is accessible through a central data hub in Estonia but is useful to be complemented with sub-meter data. This is especially the need, where individual residential customer living in a flat does not have its own connection/metering point.
- In the Finnish demonstration all the flexible assets had submetering that could provide more granular data than the main meter. This is often the case with modern DERs. The FSP will firstly need the metering data for its own process. The FSP must be able forecast and monitor close to real time the assets it offers to avoid penalties for non-delivery of the flexibility service.
- In ESO demonstration, system operators smart meter data was used to calculate baseline. It was determined that there exists a notable difference between operator data and asset data. Similar observations were made in Lithuania, where ESO computes a baseline for assets linked to its grid that

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provide flexibility for the TSO (Litgrid). These disparities have sparked discussions among main market parties regarding which approach to baseline calculation offers the greatest advantages for flexibility service providers as well as system operators.

4. **Availability and interpretation of grid data**
   - Estonia: Grid data as required for the optimisation process (topology, line capacities, base flows, PTDFs) are not readily available in TSO and DSO. Automation of these data flows would require further efforts, especially on DSO side.
   - Finland: TSO developed capability to provide the grid data in the format required by the process. Relevant input data for this process exist in the current systems, but automation would still require extensive development. Efficient and correct functioning of the optimization model would require up-to-date information about the state of the grid, which entails that in case of contingencies the new network state would need to be calculated before needed actions can be taken by the demonstrated flexibility market.
   - Latvia: The grid data required for the demonstration from the TSO side was prepared in Siemens PSS/E software and from the DSO side extracted from the legacy GIS system. Utilizing the demonstrated solution in practice the manual process of preparing/extracting information and converting to correct input format would require development to automate as up-to-date information is critical for best results.
   - Lithuania: TSO using NTC capacity calculation approach, but for congestion management PDTFs of all networks would be needed which requires additional effort from the SO.
5. **Pricing of flexibility**
   - The marginal costs of flexibility provision from BESS and heat pumps is currently competitive compared to mFRR prices in the Baltic balancing service market, as identified by KTU. This suggests commercial viability for FSPs, particularly with the NRT-P-E product that is based on mFRR. The absence of tariffs for BESS in Lithuania is a critical factor in maintaining their market competitiveness. Heat pumps can provide short-term services without impacting indoor comfort, making them a practical resource for flexibility during the heating season. However, it’s important to note that marginal costs and operation modes may vary among different FSPs.

   In the D4G demonstration, different flexibility bidding prices have been considered for each residential DER equipped with Dedicated Measuring devices, allowing residential users to set the elasticity of their various individual home DERs. DER are aggregated per Group associated to flexibility products (NRT-P-E) which allows to automatically generate aggregated offers according to top down forecasts of associated flexibility prices and bottom-up flexibility revenues expected from residential prosumers (hence turning prosumer into implicit DER elasticity providers).
6. **Aggregation of flexibility resources at different network levels**

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Flexibility from different grid levels can be used to offer flexibility services on any grid level. That said, aggregation of these resources to offer a specific service is not trivial. During the demonstration a decision was made regarding the process, that all resources of a resource group is aggregated to the lowest common node in the grid. This entails that when the flexibility needs of the system operators change, the aggregated group might also need to be changed to respond to the need. Using the aggregated pools to provide services to higher grid levels, than the node to which the flexibility is aggregated, is always possible. But when going to a lower level, the assets are spread in different ways in the network, which thus would require a regrouping. An example of this would be a resource group pooled from all the feeders of a distribution transformer to help relieve the congested component. Then, if one of the feeders under that transformer was congested, the same aggregated pool would not be suitable.

This challenge highlights other inherent characteristics of using DERs for flexibility services. If in the example given above, the capacity of the resource pool under the distribution transformer is in total 2 MW and it offers a given time 1 MW up-regulation, it is not known how the activation will be divided between the feeders. This is in the control of the FSP using the aggregated pool. This, again, exemplifies the point that the same pool is not usable on the lower network levels.

7. TSO-DSO coordination in flexibility markets: procurement and settlement

The analysis and demonstration activities in WP7 have showcased the possibility for TSOs and DSOs to cooperate on setting up common processes for flexibility procurement (i.e. flexibility register, TSO-DSO coordination platforms, etc.). The coordination in the procurement of flexibility was also shown to minimize total flexibility procurement costs thus benefiting all participating SOs. To realize this potential, a coordinated generation and processing of network models/representation is needed. As was observed in the Northern demo, the derivation of network models (when considering, for example, power transfer distribution factors, i.e. PTDFs) is not always readily available due to various reasons, a primary one of which is the effort needed to produce such network models (periodically) from the original full network representation (i.e. ability to generate PTDFs from the full AC power flow models). The use of PTDFs is, however, a simple representation of the grid that allows not sharing the full network information for efficiently including network representations in the market clearing processes. The inclusion of full network models is in general also possible, but this would face data exchange challenges as well as computational challenges. As such, efforts to enable period creation of the needed network representation is key to allow SOs to actively procure flexibility from the flexibility markets. The value thereof was also demonstrated as part of the Northern cluster demonstration activities. In addition, another challenge is to combine and coordinate the network models received from the different SOs. The northern demo cluster has overcome this challenge by (i) enabling the creation of the needed network representations, while capitalizing on the possibility of abstracting regions of the grid that are deemed to not be at risk of congestions, and (ii) processing and combining the received network model through the T&D coordination platform. This highlights the need for and importance of such coordination mechanisms/methodologies to support the creation of efficient TSO-DSO coordinated flexibility markets (at national, regional, or EU levels).

Another key element within TSO-DSO coordinated flexibility market is the settlement phase at the SOs level, which looks at how the costs of the jointly procured flexibility are to be allocated to the different participating SOs. As the different SOs have different needs (e.g. different services at TSO and DSO levels, and different required flexibility volumes) the allocation principles must take into account these various factors to ensure a fair allocation. This also applies to penalties for non-deliveries, as when FSPs pay penalties for non-delivered flexibility, these payments should be made back and split among the SOs who were affected by this non-delivery. These questions typically also face general political and regulatory challenges regarding the payment structures that TSOs and DSOs would take, and how that should be organized.

8. Compatibility challenges between local flexibility market and European balancing markets

Maximizing the value potential of flexibility requires enabling FSPs to easily offer their flexibility in different flexibility markets. This creates a cycle for the FSPs through which they can maximize their returns, which would then enable them to further invest in flexibility assets, thus augmenting their flexible capacity and its offering to the grid. This as a result also augments the flexibility pool available to the SOs, and the liquidity in the markets, contributing to their increased efficiency [18]. A mechanism for enabling this process is bid forwarding [19], through which bids unused in local/national/regional flexibility markets are forwarded to subsequent market layers (e.g. EU balancing markets) opening up additional opportunities for their use. However, this automatic forwarding faces a number of challenges, including (as has been detailed in OneNet D3.3 [20]:

- Requirement for alignment on the product requirements (attributes and their values) in the different markets, thus naturally making bid forwarding more favourable between markets trading services that share similar characteristics,
- Requirement on alignment on the bid formats permitted in the two markets (bid types, simple and complex bids, minimum bid sizes, bid granularity), allowing bids to be eligible to participate in subsequent markets,
- Alignment on prequalification needs, reducing the need for repeated prequalification especially in cases in which the service requirements in the different markets is practically similar,
- Coordination of gate opening and closing times between markets, as their temporal misalignment would block the ability to forward bids or participate in subsequent markets,
- Reducing entry to barrier and participation requirements in each market, for example enabling the use of "free bids" instead of limiting the participation in the activation stage to only capacity that had been previously reserved,
- Ensuring that the forwarded bids, if cleared by the subsequent market, would not cause grid violations in the grids from which the flexibility originated, referred to as grid-secure bid forwarding.

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Addressing all these key aspects is essential in enabling bid forwarding or the general participation of flexibility to provide different services through different markets.

The Northern cluster has primarily focused on forwarding of bids from congestion management markets (in particular, for near real-time active energy product, NRT-P-E) to the MARI platform for mFRR, as these products share similar technical characteristics. Indeed, the use of the same product for congestion management and mFRR has been a common practice in different countries (e.g. in Belgium and in the Nordic countries, among others). Moreover, the northern demo has designed the timeline of the NRT-P-E product to enable the subsequent participation of flexibility in MARI as scheduled activations (SA). In addition, the northern cluster has implemented a *MARI_check* and a *Grid-check* mechanisms, as part of its optimization process, to make sure that only bids that (i) abide by MARI bid formats, and (ii) that are grid safe for the local/national grids are forwarded.

9. Intertwined congestion management and balancing

An additional element of importance linking local flexibility services and balancing services was also observed in the northern demo cluster. When purchasing bids for congestion management, these bids will have an impact on the balancing position of the system. This impact has been controlled in the Northern demo through the purchase offer submitted by the SO, indicating the actual balancing position of the system (before the run of the flexibility market) and the allowed imbalance range, indicating the minimum and maximum balancing position by which the optimization algorithm should abide (i.e. making sure that the cleared bids result in an acceptable balancing position). However, it is noted here that the TSO can indicate the minimum and maximum to be equal to 0 MW, thus asking the optimization process to not only solve congestions in the grids but to also balance the TSO's system. This can also induce a reduction in costs (at many instances) as compared, for example, to the case where the balancing position is not permitted to be modified (i.e. setting the minimum and maximum of the provided range to be equal to the actual imbalance position before the run of the market, indicating that no change to the system's balancing position is permitted). For example, consider a case in which lines are overloaded, and their congestions can be managed by a reduction of load (upward flexibility provided by a reduced consumption). If the balancing position is not permitted to change, an equal amount of downward flexibility would have to be procured to keep the balance, leading to additional costs (or revenues depending on the sign of the prices of downward flexibility activated). As such, the procured flexibility can help in managing imbalances as a biproduct of managing congestion while potentially leading to cost reduction. Nonetheless, the cost reduction element does not always hold as it depends on the directions of flexibility activation for congestion management and the submitted prices, so it can be observed that at instances balancing while performing congestion management can lead to a reduction in costs while at other instances it can lead to an increase in costs. However, this concurrent balancing faces the challenge that it is only performed at the level at which the congestion management market is run (e.g. at a national or regional level), so it does not take into account the overall system (e.g. European grid level) imbalance position. Hence, balancing actions at this scale

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does not take into account netting effects which can take place, which can lead to overall suboptimality. In addition, this process can face regulatory challenges, regarding whether TSOs are allowed to perform partial balancing of their grids before participation in the EU balancing platforms (such as MARI). As such, it is important to address this point to enable an overall efficient procurement of flexibility for the delivery of different grid and system services. Bids cleared in congestion management markets and bid cleared in subsequent balancing markets are not necessarily coordinated, so they can have opposing effects or can miss on possible value stacking opportunities as the optimization and market clearing is done separately. OneNet D3.3 [20] has investigated some mechanisms to enable this alignment. However, such key elements necessitate further research and discussions between the key stakeholders involved.

10. How cooperation between TSO and DSO was managed in practice?

- Estonia: Cooperation requires engagement from different departments/units on both sides – in terms of right people, time resource. Motivations and maturity levels of TSO and DSO are different. Stronger regulatory incentive to cooperate would be useful.
- Finland: In the early phase of flexibility market uptake the cooperation has been straightforward. The possible controversies might arise when the actual operational implementation is later done and discussions about the use of same flexible resources for the needs of many SOs is taken. These controversies can be avoided by continuing the upfront discussion. The Network Code for Demand Response will also mandate the SOs to commonly decide these questions, and the OneNet project and its discussions have provided a good starting point.
- Latvia: TSO and DSO has multiple departments on each side responsible for specific activities, cooperation was done by first discissions between the team leaders at each SO and then internally the required information was discussed further and information prepared or gathered. Considering that no real flexibility providers were involved in the demonstrations there were no issues in collaboration between the TSO and DSO as everything was done on a theoretical level. However, in the process it was identified that the TSO has more detailed models of the network than the DSO, which had an impact on network data quality and ease of preparing network data.
- Lithuania: Dedicated data exchange process was created for the demonstration purposes and indicated the need for proper API data exchange between SO for future flexibility engagement.

11. Customer Data privacy and protection

- Interfacing to external proprietary systems is effort intensive as data and endpoints are not always standardized. Standardization ex moving to CIM need extra attention and budget by market participant.
- IT Technological frameworks are rich of ready-made data-privacy functionalities. Choosing the right blend is key to an effective IT solution and need careful preparation at the inception phase.

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12. Accuracy of baselines provided by FSP (Ex-ante) and FR (Ex-post)

The proposed D4G demonstration has been using real-time information from Dedicated Measurement devices in residential environment to real-time estimate flexibility from DER as well as offer most accurate DER performance monitoring whether ex-ante and ex-post. The proposed FSP solution illustrates the feasibility of such approach for specific DERs whose flexibility is recurrently operated – such as EV charging, hybrid storage with solar as well as smart water heating systems for which statistical calculations on traditional Smart metering information does not fit the purpose.

While the OneNet demonstration did not specifically focus on improving baseline calculations as such (the nominated baselines being based on historical last 10 days calculations), the proposed architecture allows to go beyond that step and envisage near real-time baseline nominations leveraging AI and measurement data acquired just before gate closure. A specific deep dive on such approach has been done in parallel to OneNet project through BD4RNRG project showing significant potential for accuracy improvement for similar houses as the one considered for this project (leading to reduce deviation for large non statistical assets) as illustrated through the following graph (source BD4NRG cascading fund project).

Overall, this demonstrates the importance to evolve current residential flexibility models towards Dedicated Measurement Devices as they offer much more accurate flexibility KPIs for DER assets behind a Grid meter than what a Smart meter offers with statistical baseline methods. Beyond this grid observability also provides transparency to consumers as they directly reflect DER real operating modes as locally observed by consumers through their local DER apps.

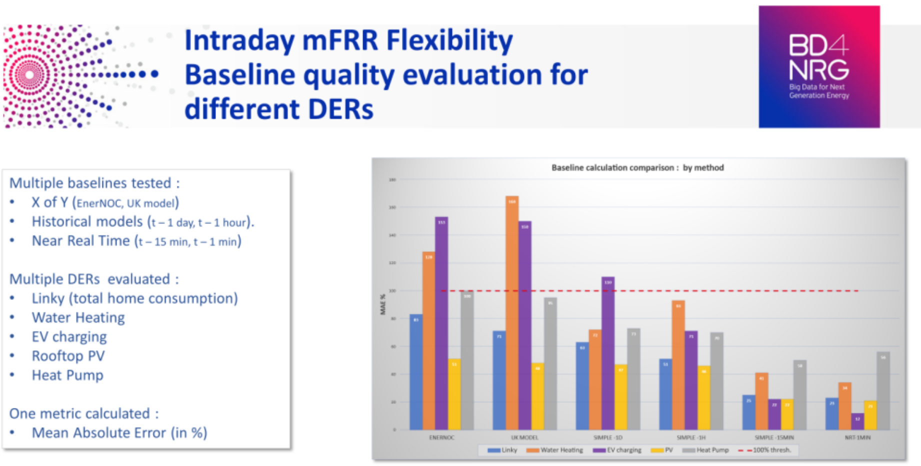

Figure 6.3 Baseline quality evaluation

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7 Conclusions

This deliverable summarized all the findings of the OneNet WP7 NOCL demonstrator which focused on the complete mechanism of engaging end-customer and up-taking market-based flexibility through network coordination. The report discussed NOCL flexibility platform architecture, market processes, actors involved including new flexibility market roles as well as integration to OneNet middleware supporting pan-European approach. The solution was implemented and tested in TSO-DSO pairs using different marketplaces. The implemented scenarios depicted key functionalities of the flexibility platform and demonstrated how developed use cases tackle challenges and solve multiple system operators' needs cost-effectively. The following conclusions can be drawn from the NOCL demonstrations:

- The universal flexibility market concept is compatible with energy system stakeholders from different geographies across Europe for solving multiple needs of multiple SOs enabled by using harmonized products.
- The central data repository known as flexibility register (FR) is essential to manage and share data and access rights among stakeholders, streamline processes, and expanding the visibility of flexibility resource providers and FSPs both within country borders and across the border.
- The driving factors for end-user engagement and market participation were analysed through a comprehensive survey that fed into FSPs' bid formation and flexibility pricing.
- Flexibility products should accompany with cost-effective solutions for steering, control, and measurements to be able to attract end-customers. In this respect, lack of sub-metering is identified as a potential barrier for impeding the harnessing of flexibility.
- The developed platforms, processes, and tools play a positive role in achieving NOCL goals, such as easing market entry by introducing harmonized flexibility products, flexibility activation process using real-time network states, ensuring availability of flexibility to increase market liquidity.
- Identified new roles enabling the flexibility market, also included in the ongoing network code of demand response. The roles include FR, service qualifying responsible, product pre-qualifying responsible and baseline provider.
- Identified and addressed challenges in flexibility market implementation, e.g. consent issues in shared facilities, automating trading preparation processes, mismatch of baselines etc.
- Developed optimization-based grid-impact aware market clearing tool that can be used for simultaneously resolving network congestion as well as power balance management.
- Flexibility procurement by TSO-DSO joint market mechanism significantly reduces procurement costs, increases resource utilization efficiency, resolve multiple grid issues via activating same flexibility enabling value-stacking potential.
- Power balance impact-free congestion management may require a higher flexibility utilization

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- Un-resolved or partially resolved grid congestions can lead to line outages which can create further congestions in the network.
- Estimated marginal cost of flexibility provision.
- Implemented TSO-DSO cost split mechanism to divide flexibility procurement costs based on the value realized to each impacted SO.
- Devised penalty mechanism for partial or failure to deliver the cleared amount of flexibility.
- Identified the need of a remuneration model between retailer and FSP for compensating imbalances imposed due to flexibility activations.
- Identified key aspects within FSP contracts and rewarding frameworks targeted at customer engagement.

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8 Future Works

The NOCL partners Fingrid and Volue Oy will commercially exploit OneNet flexibility market concept. In Finland, National TSO Fingrid is setting up a local flexibility market with a few DSOs experiencing congestions due to increased electrification of heating sector. This initiative regarding local flexibility market pilot in Finland is planned to go live in on 1st of October 2024. Volue Oy is acting as a consultant. The competencies of different marketplaces will be examined in relation to the features presented in the OneNet framework, such as TSO-DSO coordination, common registry mechanism, verification and settlement etc.

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