# D5.6. Congestion Management demonstration: Final Evaluation report and lessons learnt

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**Quality Review by: ED**

**Abstract**
The deliverable assesses the results of the three demonstrators within INTERRFACE Demo Area I (Congestion management). The validation of piloted business use cases is described in conjunction with key performance indicators and learnings devised during the project. In addition, the impact and socio-economic implications are analysed, considering both the current and the expected future situation.

**Official Submission Date: 31 December 2022**
**Actual Submission Date: 16 January 2023**
**Dissemination Level: Public version**

*This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824330*

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| aFRR | Automatic Frequency Restoration Reserve |
| API | Application Programming Interface |
| BESS | Battery Energy Storage System |
| BRP | Balance Responsible Party |
| BUC | Business Use Case |
| CHP | Combined Heat and Power |
| COP | Coefficient of Performance |
| DER | Distributed Energy Resources |
| DG | Distributed Generation |
| DH | District Heating |
| DR | Demand Response |
| DSF | Demand Side Flexibility |
| DSO | Distribution System Operator |
| EC | European Commission |
| EHPA | European Heat Pump Association |
| EMRS | Energy Resource Management System |
| EU | European Union |
| EV | Electric Vehicle |
| FCR | Frequency Containment Reserve |
| FCR-D | Frequency Containment Reserve for Disturbances |
| FSP | Flexibility Service Provider |
| GSMS | Grid Service Management System |
| HP | Heat Pump |
| IDN | Intelligent Distribution Node |
| IEGSA | Interoperable pan-European Grid Services Architecture |
| IH | Information Hub |
| KPI | Key Performance Indicator |
| LV | Low Voltage |
| mFRR | Manual Frequency Restoration Reserve |
| MO | Market Operator |
| MOL | Merit Order List |
| NVSF | Nodal Voltage Sensibility Factor |
| PLT | Power Limit Table |
| PTDF | Power Transfer Distribution Factor |
| PV | PhotoVoltaic |

| | |
|---|---|
| REC | Renewable Energy Community |
| SFP | Single Flexibility Platform |
| SGAM | Smart Grid Architecture Model |
| SPC | Synchronous Power Control |
| TES | Thermal Energy Storage |
| TSO | Transmission System Operator |
| V2G | Vehicle to Grid |
| WP | Work Package |

# Executive summary

The three demonstrators within the INTERRFACE Demo Area 1 (Congestion management, WP5) took place in a total of five countries – Italy, Bulgaria, Finland, Estonia, and Latvia. These demos were: DSO and Consumer Alliance, Intelligent Distribution Nodes, and Single Flexibility Platform.

The common aspect of these geographically diverse demos was the development and validation of solutions for improved congestion management and balancing market efficiency based on the innovative IEGSA architecture. There were also some key differences between the demos in terms of piloting peculiarities, the technologies utilized, market and coordination schemes considered, etc. These differences allowed for a more thorough prototype testing, looking at the challenges addressed from diverse points of view.

In accordance with the Grant Agreement, this deliverable summarizes the results of all the demonstrators in Demo Area 1. Specifically, the results are reviewed in detail and evaluated. The evaluation is done with regard to specific key performance indicators (KPIs), business use cases, market framework, and, additionally, it addresses the socio-economic impact.

The DSO and Consumers Alliance demo validated short-term congestion management using distributed generation; namely, a Combined Heat and Power (CHP) plant (which, together with a TES (Thermal Energy Storage) system, allowed decoupling power and heat generation for maximized flexibility), low-voltage power quality improvement using a battery aggregator and demand response, as well as a renewable energy-producing local energy community smart coordination to reduce the reverse power flows into the TSO network.

The Intelligent Distribution Nodes (IDN) demo validated the concept, which enabled its users to achieve efficient energy use while minimizing its costs. Additionally, it demonstrated how the IDN could be used for the operational congestion management (CM) service in two different ways – as an automatic and a manual CM provider. Similarly, it was shown how the same resources (IDN and the BESS (Battery Energy Storage System) within it) could also be exploited for TSO needs, i.e., for the balancing (frequency restoration) service, also in an automatic (aFRR) and/or manual (mFRR) setting. In general, the IDN management system developed allows for diverse flexibility value extraction and also provides valuable additional tools for its users.

The Single Flexibility Platform (SFP) demo validated the use of existing mFRR and Intraday marketplaces to provide also bids for novel congestion management services, both within the short-term and operational framework. It was found that minimal additional technical developments are needed to enable such a functionality (mostly related to additional locational properties for bids and bid forwarding). The SFP also showed how IEGSA and its processes could be used to perform a two-stage grid qualification that includes resource and bid qualifications to ensure that, for instance, TSO balancing market bid activations from resources connected to the distribution grid do not cause infeasible conditions within the DSO network.

Overall, the business use case validation was deemed as successful. It was shown how congestion management services could be provided in an efficient and innovative way, also combining it with other services (i.e., allowing the resources not to be locked-in solely for one service provision but enabling their participation in several). Moreover, a level of coordination between marketplaces was achieved, and an efficient pre-qualification algorithm was implemented for improved TSO and DSO coordination.

In terms of KPIs, the values of both the technical and user experience related KPIs show that IEGSA and the supplementary systems and processes developed and piloted within WP5 demonstrators, for the most part, manage to function as expected. The KPIs selected at the beginning of the project were successfully fulfilled, while additional indicators allowed a more detailed insight into the piloting results.

At the same time, a number of technical issues were identified throughout the piloting (e.g., in the settlement process and data processing). While some were already addressed within new

iterations of IEGSA, some others remained to be alleviated in future work. Nevertheless, these issues did not hinder the successful demonstration of WP5 solutions.

Furthermore, piloting participants devised concrete suggestions to achieve improvements in user experience. This is a very positive aspect since such insights could only be gained though prototype testing. It also emphasized the importance of involving external stakeholders (i.e., such that were not directly involved in the business process and software development) in the piloting. Third-party users were overall more critical since they lacked the background knowledge that parties involved since the beginning of the project had accumulated. This highlights that, updated more detailed documentation would be needed in order to commercialize the solution, and the platform design ought to strive to be as self-explanatory as possible (i.e., the user should not be assumed to have extensive prior knowledge).

Another major strength of the piloting was the extensive scope of stakeholders involved, e.g., the SFP demo had TSOs, DSOs, MOs (Market Operators), and FSPs (Flexibility Service Providers) as IEGSA users. Such in-depth testing allowed the validation to be as multifaceted as possible. The involved parties identified how IEGSA (or particular sub-processes of it) could already be beneficial to their operations. For instance, the bid (with locational information) forwarding from mFRR and intraday markets to congestion management markets is an effective and technically uncomplicated way to kickstart a CM market when that need arises. The developments in PTDF (Power Transfer Distribution Factor) matrices-based prequalification also is a technical achievement with evident nearly immediate benefit to DSO internal procedures in their evolution towards active system management.

Finally, socio-economic assessment and impact analysis show that the demonstrated solutions can benefit all stakeholders (end users, FSPs, TSOs, DSOs, and even society at large). Improved access to flexibility markets, including novel markets (as for congestion management or the upcoming FCR and aFRR markets in Estonia and Latvia), can bring monetary value to end users. This concerns consumers who directly cooperate with FSPs and partake in flexibility markets and those who are passive. Passive consumers can benefit from reduced electricity or grid tariffs thanks to potentially cheaper ancillary services. Although, of course, the business case for active consumers strongly depends on the costs associated with unlocking their flexibility, as well as on the actual demand (and thus prices) for their flexibility. This, however, is expected to grow in the future, especially due to rising intermittent renewable generation, which needs to be balanced as well as due to a congestion management market increasingly being seen as a viable alternative to network reinforcement.

There are a number of different flexibility sources that can be used to extract these benefits. For instance, it has been shown that heat pumps (HPs) are among the most prospective technologies for the utilization of distributed flexibility. Moreover, actual HP flexibility activations for CM took place in the SFP demo, while HPs are already quite widespread in Finland, rapidly growing in penetration in Estonia and slowly rising in popularity also in the third SFP demo country – Latvia. International industry reports also confirm that this is generally the trend in most of Europe. Evidently, IEGSA could be an invaluable tool to provide HPs and other flexibility resources (such as energy communities, CHPs, and BESS as piloted in the other WP5 demos) the access to ancillary services markets to compete on fair grounds with other service providers, including the conventional ones.

To summarize, a common takeaway of the WP5 demos is an affirmation that IEGSA can aid in facilitating the uptake of flexibility resources. Moreover, flexibility utilization is enhanced when the same resource can be used for several services (e.g., for congestion management and balancing). While the current need for flexibility is varied across the regions, the future development trajectory of the European energy system does indicate that flexibility of all types will become increasingly required. To this end, the INTERRFACE project has provided an excellent starting point with valuable demonstration results.

# 1 Introduction

The three demonstrators within the INTERRFACE Demo Area 1 (Congestion management, WP5) took place in a total of five countries – Italy, Bulgaria, Finland, Estonia, and Latvia. These demos were:

- DSO and Consumer Alliance – Italy
- Intelligent Distribution Nodes – Bulgaria
- Single Flexibility Platform – Finland, Estonia, Latvia

The common aspect of these geographically diverse demos was developing and validating solutions for improved congestion management and balancing market efficiency based on the innovative IEGSA architecture. However, there were also significant differences between the demos in piloting peculiarities, the technologies utilized, market and coordination schemes considered, etc. Nevertheless, these differences allowed for a more thorough prototype testing, looking at the challenges addressed from diverse points of view.

Following the Grant Agreement, this deliverable summarizes the results of all the demonstrators in Demo Area 1. Specifically, the results are reviewed in detail and evaluated. The evaluation is done regarding specific KPIs, business use cases, and market framework and addresses the socio-economic impact.

In the second chapter of the deliverable, the business use cases tested within the demos are summarized, and their main outcomes are outlined. The chapter describes the various services piloted, the demonstration procedures, the actors involved, and the learnings extracted during piloting.

The third chapter deals with key performance indicator (KPI) assessment. It provides a summary of the KPI monitoring during the project, as well as offers more detailed insight into the piloting results through the definition and assessment of additional KPIs. Special attention is provided to user experience concerns, whereby the piloting participants were surveyed to evaluate their experience working with IEGSA and its processes. This allowed for identifying its strengths and weaknesses as well as devising suggestions for future improvements.

Finally, the fourth chapter addresses the socio-economic dimension. It is done both through the results achieved during the piloting and through a more generalized approach. The value that could be extracted in the future by the use of IEGSA or similar market-enabling platforms is discussed from a multitude of perspectives, i.e., both considering the impacts on flexibility providers as well as on the system operators.

# 2 Evaluation of the results of the demonstrations

This chapter provides an evaluation of the different business use cases piloted within the diverse WP5 demonstrators. Special attention is given to the involvement of varying market parties (TSOs, DSOs, BRPs, prosumers, etc.) as well as to the validation success of envisioned coordination schemes and market frameworks.

## 2.1 DSO and Consumers Alliance

"DSO and consumers alliance" (T5.1) demonstrator, which took place in Italy, developed a platform to monitor and handle flexibility resources managed by Flexibility Service Providers (FSP) to mitigate congestion management in DSO (Distribution System Operator) network and enhance network quality. This demo tackles different Congestion Management services in three Business Use Cases (BUCs): SO-Supplier, LV regulation Power quality, and LEC. In particular, the table below presents both the BUCs of the INTERRFACE project and the actors of the demo (DSO is a key actor in all the BUCs and, thereby, is not singled out in the table).

Table 1. DSO and Consumers Alliance demonstration BUCs

| BUC Name | Demo actors | Scope |
| --- | --- | --- |
| a. Congestion management<br>"SO-Supplier" Business Use Case | A large user with a programmable flexibility resource, namely a CHP plant coupled with TES and serving the district heating network | To provide flexibility using power production from a programmable DG system<br>Provide flexibility for congestion management - short term |
| b. Congestion management<br>"LV regulation Power quality" Business Use Case | A Battery Aggregator, with a set of batteries of different sizes and capacity | Use of battery storage and DR (Demand Response) program to optimally exploit the local production of renewable energy<br>Increase power quality in suburban branches of the LV grid with a high share of renewable energy |
| c. Congestion management<br>"Local Energy Community" Business Use Case | Local energy communities:<br>- Neighbourhood REC (LEC1 – Sogno street, LEC2 – Brizi street)<br>- Collective self-consumption building (Astea headquarter) | Exploit the synergies among energy networks in a municipal scale multi-energy microgrids to maximize the self-consumption of locally produced renewable energy<br>Increase the flexibility of the microgrid to reduce the amount of electricity flow back to the TSO |

The Italian demonstration partners defined a set of technical/practical and simulated scenarios reflecting, on the one hand, the test of different real-world flexibility needs of the SOs and, on the other, the simulation of different market aspects of the IEGSA functionalities. The test scenarios contain simulated flexibility bid activations and settlements for a set of use cases.

### 2.1.1 SO-Supplier use cases

In the "SO-Supplier" Business Use Case, Congestion Management is tackled in a real technical and market scenario. In particular, experimental tests in the pilot are related to a large user with a programmable flexibility resource, namely a CHP plant (acting as FSP) coupled with TES and serving the district heating network.

The energy flexibility of the CHP plant comes mainly from its operational strategy, by varying the ratio of electricity vs. thermal energy produced. The CHP plant, composed of a natural gas engine cogeneration system with a nominal electrical power of 1.2 $MW_{el}$ and thermal power of 1.3 $MW_{th}$, can be used in the BUC scenario when coupled with thermal storages and heat pumps to exploit both up and down flexibility.

The demo area could face different congestion scenarios to be solved, namely operational congestion management (dealing with nearly real-time issues, i.e., the activation decision is made one hour in advance) and short-term congestion management (with day-ahead activation decisions).

To achieve the aim, extensive tests on the pilot were carried out during 2021 and the initial months of 2022, based on several iterations with the IEGSA infrastructure developed during the project. Furthermore, due to technical reasons and additional monitoring functionalities to be realized, an additional software platform for FSPs has been realized and tested in parallel with IEGSA.

The developed software platform functions and their role in the interactions with IEGSA have been detailed and described in the previous deliverable, D5.3.

In the "SO-supplier" BUC, there are not all the actors needed to build a real market; thus, some interactions between IEGSA and the developed software (SW) platform are performed manually, and some market actors are simulated: day ahead and intraday bids that include the Asset ID, group ID, price, quantity, period for the CHP plant are put in the SW platform and then forwarded to IEGSA, and a virtual SO can manually buy the flexibility, see the MOL and activate bids directly from IEGSA. Settlement results are available for download on the SW platform as well.

The main outcomes reached within this BUC are:

- the chance to handle both operational and short-time CM problems through FSPs in a well-defined area,
- the effectiveness of using multi-energy networks to address CM problems (in this case, electricity and district heating),
- the chance to use IEGSA as the common architecture to participate in the pan-EU market, although there is a strong need to handle and properly use grid data (in a real-time manner) to measure and assess the effects of flexibility (not only from the settlement point of view but also related to the benefits brought to the grid).

### 2.1.2 LV regulation Power quality

In the "LV regulation Power quality" BUC, the Congestion Management in the Italian pilot is tackled in a real technical scenario while exploiting the potential for the creation of a new market (the size of the involved resources makes it not possible for the FSP to participate in the actual market).

Experimental tests in the pilot are related to the increase of LV power quality in particular branches of the grid using a set of battery storages of different sizes to optimally exploit the local production of renewable energy.

Three 6.4 kW/6kWh battery storages, and a 100 kWh power rack with Pylontech M1 series batteries (with 100 kW of instant charge/discharge power) have been installed and are acting as an aggregator (namely Batteries Aggregator in the previous deliverables), the FSP of this BUC.

To achieve the goal and measure the results, a set of tests in the pilot site were carried out during late 2021 and early 2022, based on different iterations with the IEGSA and the additional software platform, namely "Battery Aggregator", realized and tested in this project (see the deliverable 5.3 for the complete description and functionalities).

As in the "SO-supplier" BUC, also in the "LV regulation Power quality" there are not all the actors needed to run real market operations. Furthermore, the size of the equipment considered for this

BUC would have made it impossible to participate in the actual flexibility market due to Italian regulations.

As in the "SO-supplier" BUC, some interactions between IEGSA and the developed SW platform are performed manually, and some market actors are simulated: intraday bids and related information are put in the SW platform and then forwarded to IEGSA, and a virtual SO can manually buy the flexibility, see the MOL and activate bids directly from IEGSA. Settlement results are available for download on the SW platform as well.

The main outcomes reached within this BUC are:

- the chance to handle operational CM problems in terms of LV grid quality through an FSP in a well-defined area, also considering small-size devices,
- the role of a small DSO in the new European internal market for electricity, as a super-party facilitator for global ancillary services and purchaser of local ancillary services
- the chance to use IEGSA as the common architecture to participate in the pan-EU market also for small-scale DSOs.

### 2.1.3 Local Energy Community

In the "Local Energy Community" BUC, the Congestion Management in the Italian pilot is tackled in a real technical scenario while exploiting the potential for creating a new market as a new set of economic possibilities for the participants of a LEC.

Experimental tests in this BUC are related to the increase of LV power quality in particular branches of the grid, exploiting the synergies among LV end users (prosumers) equipped with storages to maximize the self-consumption of locally produced renewable energy.

A set of 8 households with 2 PV plants and 100 kWh of batteries in Sogno street and Brizi street have been provided with the necessary communication and monitoring hardware and are involved in this pilot and are acting as an FSP.

To test and assess the potential of the BUC, a set of experiments in the pilot site were carried out during late 2021 and 2022, based on some iterations on IEGSA and the additional software platform, this time namely "LEC Aggregator" (see the deliverable 5.3 for the complete description and functionalities).

As for the "LV regulation Power quality" BUC, also in the "Local Energy Community" BUC, the size of the equipment and the number of households considered would have made it impossible to participate in the actual flexibility market due to Italian regulations.

Thus, some interactions between IEGSA and the developed SW platform are performed manually, and some market actors are simulated: intraday bids and related information are put in the SW platform and then forwarded to IEGSA, and a virtual SO can manually buy the flexibility, see the MOL and activate bids directly from IEGSA. Settlement results are available for download on the SW platform as well.

The main outcomes reached within this BUC are:

- the chance to handle operational CM problems through the prosumers of a Local Energy Community, acting as an FSP in a well-defined area, also considering small-size devices,
- the testing of different incentive mechanisms for Local/Renewable Energy Communities based on flexibility services,
- the chance to use IEGSA as the common architecture to participate in the pan-EU market also for LECs.

## 2.2 Intelligent Distribution Nodes

The Intelligent Distribution Nodes (IDN) is an intelligent system that has the capacity to coordinate different actuations for a battery energy storage system (BESS) installed in a residential building or an energy community with the aim of integrating it into the grid. From a logical perspective, the IDN concept is developed around three specific applications: Information Hub (IH), Energy Resource Management Systems (ERMS), and Grid Service Management System (GSMS). The IDN has been developed, installed, and validated in the demonstrator for the provision of grid support services devoted to improving grid regulation and congestion relief. The IDN is a complex high-level system that combines hardware elements, distributed control systems, and cloud computing for providing ancillary and flexibility services to the power grid and arbitration services to optimize end-user energy utilization. The services provided by the IDN are the ERMS and GSMS, two modules of optimization container implemented in the cloud-based operational platform of the project. The asset portfolio in this demo includes PV generation, conventional demand, and a centralized BESS. Taking into account that only the BESS operation point can be fully regulated, the ERMS still aims to minimize the building energy bill considering all assets, while the GSMS will determine optimal bids for participation in service markets. Additionally, ancillary services are implemented in the IDN power converter controller.

### 2.2.1 IDN Energy Resource Management

This is the application used to organize the aggregation and manage the Distributed Energy Resources (DERs) of a given energy community within a given power grid and market. This application is addressed to optimize the use of the community’s energy assets to reach the most efficient and profitable use of energy for the community/building members, satisfying energy needs for such end-users while energy cost is minimized. In addition, in coordination with the IH, this application can provide relevant information to the SOs regarding demand performance and response.

The Energy Resource Management System (ERMS) optimizes the operation of the building’s energy assets while meeting customer demands. The main objective is to generate an optimal schedule for all the assets aggregated at the IDN, maximizing the benefit of the building’s users. The building’s assets portfolio consists of PV generation, conventional demand, and a centralized BESS whose usage is optimized according to market and operating conditions. The objective of the ERMS is to reduce the cost of energy for the building’s end-users by:

- Consuming as much energy as possible from the PV generation either directly or indirectly. Directly means that the energy of PV is consumed as it is produced. Indirectly means that PV excess generation is stored in the BESS for later use.
- Exploiting the energy price variability (arbitrage) with energy storage in the BESS when the price is low to satisfy the demand in later periods when the price is high.

### 2.2.2 IDN Congestion Management

The purpose of this service is to provide grid support in terms of active and reactive power when the network is physically congested so that operational elements do not violate voltage and thermal limits. This demonstrator encompasses operational congestion management (OCM) in an operational timeframe, where a dispatcher takes the activation decision manually during market time. The overall target is that DSO could use flexibility with locational information for internal congestion management during the operational hour. Two different services have been implemented in this demonstrator, i.e., automatic and manual congestion management.

- **Automatic Congestion Management (aCM)**: Active/reactive power reserve available to relieve congestion in an automatic fashion according to control parameters set by the SO.
- **Manual Congestion Management (mCM)**: Active/reactive power reserve to relief congestion according to SO enquiries; performed up to 15 min prior to activation time.

### 2.2.3 IDN Frequency Restoration Service

The frequency restoration service aims to restore the system frequency to the nominal frequency and/or restore the power balance to the scheduled value. TSOs and DSOs should cooperate to facilitate and enable the delivery of FRR services by units located in the distribution systems. FRR can be activated both automatically and manually.

These reserves are not referenced points for the BESS operation but operational limits, which allow a flexible response of the BESS system to compensate for system imbalances. Therefore, this reserve can be activated entirely, partially, or not used at all, depending on the conditions of the system during real-time operation. The two services implemented for frequency restoration are:

- **Automatic Frequency Restoration Reserve (aFRR)**: Active power reserve available to restore system frequency to the nominal value or to restore power balance to the scheduled value in an automated fashion. This service can be provided in both directions, up and down.
- **Manual Frequency Restoration Reserve (mFRR)**: Manual Frequency Restoration is a manual change in the operation set-point of the reserve (mainly by re-scheduling) in order to restore system frequency to the set point value frequency and for a synchronous area to restore power balance to the scheduled value. This is performed up to 15 min before activation time. This service can be provided in both directions, up and down.

The main outcomes reached within this BUC are:

- No ERMS response such that BESS output is attributed to GSMS
- The BESS output schedule and limits were a result of both the ERMS and GSMS services. This revealed how the BESS behaved with multi-service provision while the potential economic gains were compared to the base case.
- As there are no market-based ancillary services in Bulgaria, the prices for FRR and CM were emulated.

### 2.2.4 IDN Additional Services

The IDN power converter is equipped with a synchronous power control (SPC) structure, enabling the power converter to have multiple ancillary functionalities, such as primary frequency regulation, synthetic inertia, power oscillation damping, or primary voltage regulation apart from the main active power regulation. The control system comprises a frequency and voltage droop controller, a power loop controller (PLC), and a virtual admittance block.

The operation of the IDN in the INTERRFACE project is managed from a cloud-based platform, which allows calculating optimal schedules for the BESS to optimise energy utilisation and provide flexibility services to the grid. In addition, the cloud-based operational platform has an Information Hub (IH), which is an application that analyses the IDN dataspace to make predictions, e.g., for forecasting demand and PV generation, and to process the IDN's operational data, e.g., to generate statistical data and to detect characteristic patterns. The IH can integrate data from different sources and formats, running different analyses and becoming a crucial asset in the system. In addition, the IH enables the system to minimize uncertainties during exploitation, increasing efficiency and providing unified data information for all the information consumers.

### 2.2.5 IDN Value Stacking

The different nature of the services targeted yields a multi-objective optimization framework that must cope with the time mismatch associated with the variety of market structures. For this, a value stacking approach that enables the unification of the different objectives was adopted in the optimization process, where:

- The ERMS optimized the operation of the building's energy assets while meeting customer demands. The main objective was to generate an optimal schedule for all DER assets aggregated at the IDN, maximizing the benefit of all participants. Asset portfolio: PV generation, building conventional demand, BESS characteristics, and energy market and IDN operating conditions.
- The GSMS objective was to increase overall income for building owner (also applicable to an energy community) by managing the asset portfolio to provide flexibility and ancillary services to grid operators. The GSMS calculated optimal bids to be offered to operators through IEGSA to participate in corresponding service markets and/or agreements. For the transmission system operator (TSO), the FRR service was provided, divided into automatic and manual activation modes. On the other hand, for the distribution system operator (DSO), the CM service was provided, also divided into automatic and manual activation modes. For TSO, it was considered: aFRR up/down and mFRR up/down, and for the DSO, it was considered operational aCM up/down and mCM up/down.

## 2.3 Single Flexibility Platform

### 2.3.1 Congestion management use cases

In the Single Flexibility Platform (SFP) demo, the Congestion Management service is tackled in two use cases: **operational CM** and **short-term CM**. The principal difference between these use cases lies in the timeframe when they are procured.

Operational CM deals with near real-time issues, i.e., activation decisions are made by a dispatcher one hour in advance. On the other hand, for short-term CM, a short-term planner must make the activation decision in the day-ahead or intra-day timeframe. In terms of flexibility procurement, when it is to be done mostly depends on the reason for the congestion the flexibility is intended to alleviate, e.g., to solve congestions during pre-planned asset maintenance, the procurement could be done up to a month in advance, whereas in the case of unplanned outages it is closer to the time of delivery, up to the operational hour.

In the CM use cases of the SFP demonstration, the CM product descriptions are generally derived from the standard mFRR product, with the added requirement for locational information. This is primarily to boost liquidity by simplifying the provision of CM services by flexible assets and by enabling the same flexibility sources to be used for addressing varied system operator (SO) needs (such as congestion management and balancing). On the other hand, coordination between SOs is paramount to ensure that CM bid activation to aid one SO does not cause issues elsewhere.

Consequently, the **objective** of the SFP CM use case piloting was to **demonstrate direct activation and coordination mechanisms between TSOs and DSOs to ensure flexibility bids won't cause further congestion in grids**.

To achieve the objective, extensive piloting was carried out by the participants of T5.3 during 2021 and 2022 in several iterations of the technical platform and procedures based on the **IEGSA architecture** developed during the project. The technical intricacies of the developed solutions and the additionally required and performed internal developments to ensure smooth piloting are described in detail in the **prior deliverable D5.5** [1], as well as in the strictly technical deliverables from WP4 (e.g., [2]). D5.5 also contains detailed insights into the testing procedures and their outcomes.

As the piloting in the Finnish-Baltic region was done in three countries by a number of distribution and transmission system operators, there were both **common and distinctive features** in the demonstration activities of each partner. The main commonality in terms of the piloting methodology was in the ambition of **validating the end-to-end process** for CM while putting a major emphasis on **TSO-DSO coordination** (i.e., the upload and successful utilization of grid data for qualification purposes). The main shared outcome of the demonstration activities was the

**verification of the qualification services** and overall favourable feedback regarding the functioning of the various sub-process involved in the end-to-end operation of the CM use cases.

A brief summary of the main differences in CM use case piloting per demonstrator location is provided in Table 2 below, while the distinctive outcomes are outlined in Table 3.

Table 2. Key differences in SFP demo CM piloting approach per location

| Finland (operational and short-term CM) | Estonia (operational CM) | Latvia (operational CM) |
|---|---|---|
| • Using mFRR bids with locational information to provide operational CM to TSO and DSOs<br>• End-to-end validation in seven test scenarios built on real-world flexibility needs (although in a simulated DSO network)<br>• A contract with an external party (through cascade funding via WP8) to bid and activate actual physical flexibility assets (FSP with heat-pump assets in seven locations)<br>• Integration of Nord Pool intraday marketplace with IEGSA to pilot using locational intraday bids for short-term CM, and enabling FSPs to place intraday bids directly in the SFP | • One end-to-end test scenario, but special attention to proper TSO and DSO grid data uploading<br>• Test scenario built on the case of a major town in Estonia (albeit with anonymized grid information), investigating potential voltage issues if grid reconstruction/investments are postponed and not alleviated by appropriate flexibility measures<br>• Potential of flexible (non-firm) grid connection contracts as a source for additional flexibility (see section 2.3.3 for more details) | • Using real TSO network data and simulated DSO data<br>• Six test scenarios to validate six distinctive functionalities/characteristics of the SFP: large user support, large resource portfolio support, resource management, system stability, market bid updating, and TSO-DSO coordination |

Table 3. Key unique results in SFP demo CM piloting approach per location

| Finland | Estonia | Latvia |
|---|---|---|
| • The pilot with integrated intraday and CM markets was successful and required relatively minor modifications in internal processes, which means that SOs, FSPs, and other parties could engage an intraday-based flexibility market with few technical changes required<br>• In addition, Finnish partners particularly extensively tested a PDTF matrix-based grid qualification service and found it to be operating up to the specifications in varied situations | • The Estonian demo highlighted the importance of the proper usage of grid data with both congestion and flexibility resource locations as key enablers of the resource and bid qualification processes<br>• Due to almost identical definitions of balancing and CM products, there are no apparent differences from the FSP perspective in offering the services | • Processes related to FSP portfolio management and TSO-DSO coordination are found particularly valuable for the Latvian case, as there is currently no existing alternative for these in the market |

### 2.3.2 Balancing use cases

The balancing use cases include the **well-known** and **standardized** products: manual frequency restoration reserve (mFRR), automatic frequency restoration reserve (aFRR), and frequency containment reserve (FCR).

In the piloting activities of the SFP demonstration, only the **mFRR** product was fully tested. This is primarily due to, at present, it being the only balancing service procured locally in the Baltic power systems. Moreover, it was seen as the more attractive option for aggregating distributed flexibility resources. Additionally, the TSO-DSO coordination processes for prequalification and the overall end-to-end processes would expectedly not significantly differ for the aFRR and FCR use cases. In practice, this means that testing the SFP for mFRR provision also aids in the future development and potential integration with the aFRR and FCR services, which are planned to be deployed in the Baltic States by 2025 at the latest [3].

Since, as opposed to CM, the mFRR balancing energy market is already well established in the three countries of the Nordic-Baltic demonstration, the **focus** in the balancing use case piloting was primarily **on FSP participation in the market through the SFP** and, likewise, **on TSO use of the SFP for flexibility procurement**.

The common characteristic in the national implementations of the SFP piloting was **invoking all the major steps of the use case** (registration, qualification, trading, and settlement), which were deemed functional and beneficial at the end of the piloting to the prospective users of the SFP.

In terms of the differences, it should be noted that for the Finnish demonstration case, the mFRR service was already closely linked to the CM use case (i.e., as mFRR bids with an additional locational information attribute were used for piloting CM), thereby it is meaningful to separately compare the Latvian and Estonian pilots, where provision through the SFP was piloted exclusively. The key differences in piloting approaches are outlined in Table 4, whereas in the achieved results – in

Table 5. More details about the piloting methodology and results are available in the **deliverable D5.5**.

Table 4. Key differences in SFP demo balancing piloting approach per location

| Estonia | Latvia |
|---|---|
| • Test scenario with sample data, with simplification for consent services and grid qualification<br>• Piloting registration of at least three resources, creation of a resource group and bid submission from an FSP's point of view, and piloting bid activation and balance settlement from the TSO's point of view<br>• Involvement of an independent FSP, providing data and using the platform's APIs | • Utilizing real TSO network information and interface to the Baltic balancing market<br>• As DSO network data was not used, then only TSO-connected resources were considered at this stage<br>• A market participant provided data (of real resources) necessary for testing the SFP<br>• Four piloted scenarios reflecting the respective sophisticated test cases: partial bid activation, bid activation modification, settlement of non-delivery, and stable and consistent IEGSA operation during prolonged testing |

Table 5. Key unique results in SFP demo balancing piloting approach per location

| Estonia | Latvia |
|---|---|
| • Automatic product qualification validated<br>• The tools provided by the SFP (and IEGSA in general) enable not only the participation in the balancing market to various size and technology FSPs but also to alternative market operators<br>• The need for new approaches to verify the contracted service delivery by small, distributed resources is highlighted | • Bid partial activation by both delivery volume and activation period were tested, whereby for the latter, it was found that improvements need to be made in the settlement module. Other minor suggestions for further improvements to the settlement functionality arose from the prolonged automated testing of the platform<br>• Activation order modification was successfully validated<br>• Non-delivery settlement was also successfully validated<br>• Overall, the SFP (and IEGSA) provide high operational reliability and offer valuable functionalities addressing future and current needs in Latvia |

### 2.3.3 Flexible grid contracts use case

**Flexible grid contracts** are a form of connection agreement whereby the injection/withdrawal capacity is higher than it would normally be based on grid constraints alone. The increase in capacity is achieved by marking a part of the contracted capacity as flexible, which enables the SO to restrict it at times when there are risks of overloading grid elements. However, during normal operating conditions, the customer has **full use** of the contracted capacity.

The flexible grid contracts use case was tested in the SFP demonstration by handling (conversion, forwarding, activation) in IEGSA's two currently existing flexible grid contracts (connected to the TSO network) in Estonia. Within IEGSA, these contracts were to be added to a **merit order list** (MOL). In total, three functionalities were tested: adding flexible grid contracts to a local MO system, converting the contracts to bids for the respective time periods, and forwarding the bids to IEGSA for visualization and common MOL creation. Activation was not tested due to existing contractual limitations.

While from the technical point of view, the piloting of the flexible grid contracts was a success, and all the processes functioned as expected, several required **business process improvements** were identified. These were mostly connected to contractual issues concerning activation conditions and subsequent imbalance settlement. Nevertheless, a number of potential solutions were also identified, striving to align the flexible grid connection as a product to other flexibility products, primarily CM. To this end, it is also required to clarify the role of third-party aggregators and enable their access to utilize the flexibility available via flexible grid contracts efficiently.

### 2.3.4 Single Flexibility Platform demonstration main results

The SFP demonstration allowed **validation of the market framework** and confirmed the technical soundness of the **tested coordination schemes** deployed within IEGSA. However, it also showed the necessity for certain improvements in selected processes both from a technical and business standpoint. Moreover, it paved the way for significant future improvements in the coordinated and efficient use of flexibility by highlighting the directions for further developments during the **evolution of IEGSA**.

The **key learnings** in terms of market processes and coordination are briefly summarized below:

- In the initial stages of the INTERRFACE project, the **flexibility resource register** was foreseen as a key enabler of efficient flexibility marketing and procurement. During the piloting phase of the SFP demo, its envisioned role was confirmed since it proved to be a major part of the overall IEGSA and was paramount in sharing prequalification information, streamlining distributed flexibility asset registration and grouping, and also providing ease-of-use for both FSPs and SOs in, respectively, selling and buying flexibility.

- There are multiple technically valid ways to perform **grid prequalification** to ensure that flexibility bid activation does not create unwelcome conditions. During the SFP demonstration, both the power-limit table and PTDF matrix-based approaches were tested and verified.
- The integration of **locational mFRR** and **intraday** bids with the CM market provides the option of significantly improving the potential liquidity of CM. As the mFRR and intraday markets currently are quite liquid, it was proven that with little technical modifications to share information and include a locational attribute, it would be possible to jumpstart a CM marketplace when the demand for congestion management increases to such a level as to require it.
- **Harmonizing the CM product** to the existing balancing products is, in general, also an enabler for better utilization of small-scale flexibility and its access to the markets. To this extent, it is found necessary for IEGSA to be flexibility **technology-agnostic,** and additionally, open also to **third-party market operators**. This was achieved by defining a separate role for MOs. Even though during the piloting, that role was undertaken by the procuring SOs, the separation, in principle, allows access to independent MOs, which is a very positive aspect in terms of competition and innovation. Moreover, this principle was specifically validated with the integration with the Nord Pool intraday marketplace in the Finnish instance of the demonstration.
- The practical piloting with **actual flexibility activations** served well to validate the end-to-end process, but it was also crucial in identifying potential issues where additional attention must be given in future developments and/or the practical use of small-scale flexibility. One such issue is a **level of uncertainty** during small-scale flexibility activations, especially if the location of the activated asset is of importance (as is the case for CM). Both the SOs and the FSPs need to account for this uncertainty and react appropriately; this also needs to be considered in the delivery settlement.
- Room for improvement was also identified in the **settlement processes** for certain edge cases.
- Positive effects of data interoperability were demonstrated with IEGSA and Common Information Model, but further harmonisation is possible to facilitate data flowing seamlessly.
- Additionally, future iterations of the platform ought to dive deeper into more holistic market coordination to **maximize the SOs' benefits** from any single flexibility activation and enable the flexibility providers to extract the full value of their offers (e.g., through increased **value stacking**). To achieve these objectives, advanced optimization techniques need to be included in the TSO-DSO coordination function in order to expand its role from ensuring safe bid activations through prequalification to also enable optimized CM bid selection.

Despite the identified required improvements, the piloted solutions are already expected to bring benefits to the involved parties in the foreseeable future. Firstly, the **modular nature** of the IEGSA platform and its related solutions allows individual SOs to adapt the functionalities that best suit their immediate needs. These needs, however, are varied in the **Finnish-Baltic region** due to unequal circumstances the respective power systems are subject to. For instance, one of the most pressing current issues for the Latvian and Estonian power systems is the preparation for **desynchronization** from the Russian/Belarussian (IPS/UPS) synchronized power system by 2025 or possibly sooner. Because of this, there is a major need to increase the **available**

**balancing resources** significantly. To this effect, small-scale flexibility is, as of yet, an untapped resource, and thereby the functions related to flexibility registration, organization, and delivery verification are of obvious interest. On the other hand, the notable technical development in devising and validating prequalification procedures can serve as a **foundation** for a wide array of flexibility market/platform or SO coordination solutions.

The SFP demonstration as a whole has also allowed the participating organizations, both SOs and FSPs, to identify potential issues and **priority directions** for further developments in their internal processes to better prepare for the situation when flexibility used to alleviate congestion issues becomes a more pressing matter in the region.

Another immediate venue to benefit from and exploit the SFP demonstration results is the Horizon 2020 framework project **OneNet**, where a lot of the key partners of the SFP piloting activities also participate, building on the solutions created during **INTERRFACE**. Several shortcomings and identified development gaps are being addressed in OneNet, providing an opportunity to put the achieved learnings to use.

## 2.4 Summary

The three demonstrators within the INTERRFACE WP5, which were piloted in a total of five countries, allowed the evaluation of a diverse set of business use cases centred on the overall theme of congestion management. Moreover, additional streams were explored to extract the value of flexibility while using IEGSA and other bespoke technologies and approaches developed within the project.

For instance, the **DSO and Consumers Alliance** demo validated short-term congestion management using distributed generation; namely, a CHP plant (which, together with a TES system, allowed decoupling power and heat generation for maximized flexibility), low-voltage power quality improvement using a battery aggregator and demand response as well as a renewable energy-producing local energy community smart coordination to reduce the reverse power flows into the TSO network.

The **Intelligent Distribution Nodes** demo validated the IDN concept, enabling its users to achieve efficient energy use while minimizing costs. It also demonstrated how the IDN could be used for the operational congestion management service in two ways – as an automatic and manual CM provider. Similarly, it was shown how the same resources (IDN and the BESS within it) could also be exploited for TSO needs, i.e., for the balancing (frequency restoration) service, also in an automatic (aFRR) and/or manual (mFRR) setting. In general, the developed IDN management system allows for diverse flexibility value extraction and provides valuable additional tools for its users.

Finally, the **Single Flexibility Platform** demo validated the use of existing mFRR and intraday marketplaces also to provide bids for novel congestion management services within the short-term and operational framework. It was found that minimum additional technical developments are needed to enable such a functionality (mostly related to additional locational properties for bids and bid forwarding). The SFP also showed how IEGSA and its processes could be used to perform resource and bid grid qualification to ensure that, for instance, TSO balancing market bid activations from resources connected to the distribution grid does not cause infeasible conditions within the DSO network.

Overall, while some technical issues were encountered during the piloting activities within WP5, the business use case validation was deemed successful. It was shown how congestion management could be provided in an efficient and innovative way, also combining it with other services (i.e., allowing the resources not to be locked in solely for one service provision but enabling their participation in several). Moreover, a level of coordination between marketplaces was achieved, and an efficient pre-qualification algorithm was implemented for improved TSO and DSO coordination.

A more detailed introspection into the key performance indicators (KPIs) achieved during the piloting, as well as user experience considerations, technical successes and shortcomings, and impact assessment, is provided in the following chapters.

# 3 Monitoring of Key Performance Indicators

## 3.1 Initial KPI selection and monitoring

Identifying the **most relevant KPIs** to evaluate the success of the three distinctive and geographically diverse demonstration tasks within INTERRFACE WP5 (T5.1, T5.2, and T5.3) followed a **multi-step process**. These steps were: initial selection before the beginning of the piloting activities (with continuous monitoring during the piloting), harmonization during and post-piloting, and finally, additional KPI definition and value extraction.

The initial selection of relevant KPIs took place during the early stages of the project. They were provisionally selected by demo leaders and reported in the **D1.1 Project Management Plan** [4]. For WP5 demos, the provisional KPIs and the envisioned target values are summarized in Table 6. Afterwards, the monitored progress toward achieving the target values during the project timespan is briefly summarized.

Table 6. Initially selected WP5 demonstrator Key Performance Indicators

| Performance Indicator | Framework for Metrics | Achieved Value (Target Value) |
|---|---|---|
| 5-1 Use cases of the different players (prosumers, TSO and DSO) | 5-1-1 number of cases | 3* (4)<br>*two use cases were merged into one |
| 5-2 Engagement of final users | 5-2-1 number of consumers/prosumers involved in an early stage | 14 (5) |
| 5-3 Correctness of trades (in the market/procurement process) | 5-3-1 level of correctness of transactions | n/a (90%) |
| 5-4 On the design and construction of the IDN | 5-4-1 In time IDN design and engineering: Percentage of engineering outcomes generated on time<br>5-4-2 In time IDN procurement and construction: Percentage of IDN systems constructed on time | 95% (≥ 80%)<br>95% (≥ 80%) |
| 5-5 On the development of the IDN applications | 5-5-1 In time IDN applications development: Number of IDN applications working on time | 95% (≥ 2 out of 3) |
| 5-6 On the IDN integration in the operation system | 5-6-1 In time IDN applications integration: Number of IDN applications integrated into the building and operator systems on time | ok (≥ 2 out of 3 for both the building and operator systems) |
| 5-7 on the IDN validation and analysis | 5-7-1 In time IDN validation and analysis: Number of the test covered and validation reports presented on time | ok (≥ 80%) |
| 5-8 Increase of reliability and quality of the grid | 5-8-1 Reduction in the number and magnitude of deviations in the grid voltage outside the operating range required by the legislation | n/a (≥ 2%) |
| 5-9 Engagement of final users | 5-9-1 number of consumers/prosumers involved in an early-stage Demand Response Program | >20 (at least 10) |

As per **D1.3 Annual Report 1** [5], after the first year of the project, KPI 5-1 had already been achieved, with the devised use cases exceeding the target value of 4. Meanwhile, KPIs 5-4-1 and 5-4-2 had neared their completion, with the achieved engineering and construction progress achieving 70% and 65%, respectively.

By the end of the second year, the engineering and construction were already finished, as reported in **D1.4 Annual Report 2** [6]. Progress was also reported on KPIs 5-5 and 5-7.

In accordance with **D1.5 Annual Report 3** [7], after the project's third year, the KPI 5-2 related to the engagement of final users was completed; as per the report, more than 20 consumers or prosumers had been involved exceeding the target value of 5. The similar KPI 5-9 also was reported as achieved with at least 10 final users[1]. In addition, the IDN-related KPI 5-5 was reported as completed, with 5-6 and 5-7 as nearly achieved.

At the same time, already during the development and piloting phases, a few of the initially selected KPIs were deemed as not applicable. This was primarily due to difficulties in specifying their definition or in obtaining the achieved value. Because of this, KPIs 5-3 and 5-8 are not reported, but similar yet clearer indicators are introduced in the following subchapters (see Table 7 and Table 8).

## 3.2 Additional KPIs

In order to enable a more sophisticated evaluation of the performance of the WP5 demonstrators individually and as a whole, **additional indicators** were selected. The additional KPIs were selected during regular discussions between WP5 partners during the latter stages of the demonstrators and after the piloting activities were completed. Where possible, **harmonization** was pursued to obtain a number of indicators common to all three of the pilots within WP5. However, due to differences in the use cases and technical setup of the piloting activities, there are also a number of indicators unique to each demo.

Overall, the KPIs were classified in accordance with the **Smart Grid Reference Architecture** (SGAM) layers, as seen in Fig. 1 [8]. Consequently, indicators mapped to the Business Layer, Function Layer, and Information Layer were devised. The Communication and Component layers, however, were not considered.

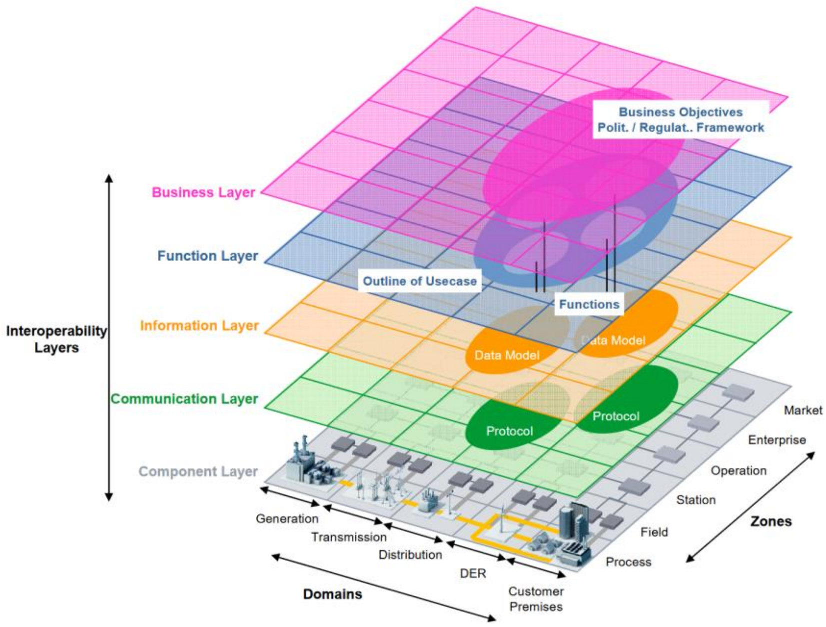


Fig. 1. The SGAM framework

[1] the respective KPIs concerned different demonstrators within WP5

### 3.2.1 KPIs pertaining to the Business Layer

The KPIs are pertaining to the Business Layer deal with business models and/or business use cases. They are summarized in Table 7 below.

Table 7. Additional WP5 demonstrator Key Performance Indicators from the Business Layer

| Business model/use case | KPI | Formula/measurement | Achieved value | Demo scope | Objective |
|---|---|---|---|---|---|
| Reverse power flow reduction | **Reduction of number of hours when electricity is injected into the TSO network** | (Flowback hours in the reference year 2018) – (Flowback hours in the year with flexibility 2021) | Total reduction: **676**<br>In Summer: **612** | 5.1 | Show if energy flow back from DSO to TSO network has been reduced |
| | **Percentage of excess electricity injected into the TSO network** | (Flowback after flex provision/ Flowback before flex. provision)*100% | **4%**<br>**(4.5 GWh)** | 5.1 | |
| Low voltage network power quality increase | **Improvement of quality parameters in suburban branches** | Monitored values | Max. voltage reduction: **2.9%**<br>Min. voltage increase: **5.5%** | 5.1 | Evaluate the ability to increase power quality |
| Maximise the potential of distributed energy resources across sectors | **Flexibility provision by CHP** | MWh of flexibility provided by the CHP plant | Down-flex.: **6.323 GWh** (nominal)<br>Up-flex.: **3.7 GWh** (nominal) | 5.1 | Evaluate improved flexibility utilization |
| | **Flexibility provision by DR (large users)** | Number of DR response hours in the year involving large users | Down-flex.: **5314 h**<br>Up-flex.: **3110 h** | 5.1 | |
| Balancing services | **Balancing services with locational information demonstrated** | Number of demonstrations | **3** | 5.3 | Evaluate balancing services use case piloting success |
| CM services | **CM services demonstrated** | Number of demonstrations | **4** | 5.3 | Evaluate CM services use case piloting success |
| Flexible grid contract | **Flexible grid contract schemes demonstrated** | Number of demonstrations | **1** | 5.3 (EE) | Evaluate flexible grid contract use case piloting success |

Through piloting activities, the DSO and Consumers Alliance demo (T5.1) successfully validated the IEGSA use cases it set out to test. Thanks to better flexibility utilization, including both demand response utilization and more active CHP flexibility use, it was shown how IEGSA could be used for power quality improvement, as well as for reducing reverse power flow (from DSO to TSO grids) that can happen with the rise in distributed generation sources.

Within the T5.3 demonstration activities, there were three demonstrations (i.e., one for each country participating within T5.3) related to the balancing services use case taking into account an additional locational attribute. The balancing product considered was mFRR, which was used as the basis for CM product specification when the additional attribute of locational information was included.

In terms of CM services, there were a total of four demonstrations in the SFP demo – operational CM in Latvia and Estonia, short-term and operational CM in Finland, whereas flexible grid contract business use case, as a unique feature of the Estonian power system, was demonstrated solely in Estonia.

Details regarding the implementation of the demonstration activities depending on the business use case were provided in the previous Chapter 2. Overall, however, it can be seen that the functionalities of IEGSA for the considered services were successfully tested in varied geographical and technical scopes.

### 3.2.2 KPIs pertaining to the Functional Layer

A number of additional KPIs pertaining to the Functional Layer were devised in order to provide a more detailed insight into the achieved functionalities and estimated impacts of IEGSA in selected examples. These are summarized in Table 8.

The KPIs dealing with grid qualification based on power limit tables (PLT) and power transfer distribution factors (PTDF) show the significant increase in grid utilization that can be achieved if using the PTDF-based grid qualification approach compared to the one based on PLT. This PTDF-based qualification approach was piloted in the Finnish instance of the SFP demonstration, and implemented as part of the TSO-DSO coordination functionality of IEGSA. The successful validation of this method paved the way for a more efficient qualification process, enabling significantly higher grid utilization, which also includes allowing flexibility better access to services provision. Details of the simulations carried out to estimate the reported grid utilization KPI values are provided in Annex I of this deliverable.

In the Finnish demonstration, flexibility activation effectiveness in congestion management was studied through four realistic congestion cases. Flexibility was procured successfully for CM through IEGSA, but for various reasons, only one congestion case was fully solved. Lessons were learned considering the FSPs responsibilities in estimating the available amount of flexibility, cold load pickup, load and generation forecast uncertainties, and temporal availability of flexibility.

Together with the TSO-DSO coordination functionality, the single interface to market functionality was another key aspect of IEGSA piloted in the SFP demonstration. As reported in Table 8, a total of 4 market operators[2] were able to provide access to more than one product via IEGSA interfaces.

Finally, the flexibility register was the third major innovation validated during the demonstrations. One way to evaluate the success of its functionalities is by looking at the success rate of resource registration, whereby it was found that it is fully capable of handling all the resource registration attempts, achieving a 100% success rate.

However, there is still some room for technical improvements to the IEGSA platform. For instance, based on data from the Latvian demonstration within T5.3, it was found that the activation and

[2] Including SOs acting as MOs for their respective ancillary services

settlement processes for mFRR achieved full activation and correct settlement for 91% of the total bids.

Table 8. Additional WP5 demonstrator Key Performance Indicators from the Functional Layer

| Functionality | KPI | Formula/measurement | Achieved value | Demo scope | Objective |
|---|---|---|---|---|---|
| Maximization of grid utilization | **Percentage of network capacity available for load and flexibility with PLT-based grid qualification** | mean((actual load + estimated free capacity) / (actual load + actual free capacity)) * 100 % | **61.8%** | 5.3 (FI) | Show the grid utilization degree achievable with the developed bid qualification method |
| | **Percentage of network capacity available for load and flexibility with PTDF-based grid qualification**[3] | mean((actual load + estimated free capacity) / (actual load + actual free capacity)) * 100 % | **89.8%** | 5.3 (FI) | |
| Congestion management | **Effectiveness of CM via IEGSA** | Congestion cases fully solved / total congestion cases | **¼ of congestion cases fully solved** | 5.3 (FI) | Show the success rate of the market-based CM process |
| Single interface to market | **The impact of single interface to market to linking different markets together** | Number of MOs providing access to more than one product | **4** | 5.3 | Show the functionality of the single interface to markets |
| Flexibility register | **Success rate of registering resources** | (The number of resources registered/total number of resources)*100 | **100%** | 5.3 | Show the success of registering new resources to the IEGSA |
| | **Number of resources registered** | The number of resources registered | **17** | 5.1 | |
| mFRR process using IEGSA | **Operational reliability of using IEGSA for mFRR process** | Number of bids fully activated and settled/ total number of activated bids | **91%** | 5.3 (LV) | Show the reliability of the IEGSA for the mFRR market |

[3] PTDF matrices-based grid qualification for normal state and NVSF matrices-based for backup state

### 3.2.3 KPIs pertaining to the Information Layer

The additional KPIs pertaining to the Information Layer are summarized in Table 9. These values are extracted from an in-depth analysis of a sample[4] of the piloting data of a national demonstration instance of SFP (T5.3) from within a specific calendar month. The main purpose of these metrics is to show the success rate of data exchange and processing procedures of the IEGSA platform.

Table 9. Additional WP5 demonstrator Key Performance Indicators from the Information Layer

| Role | KPI | Formula/measurement | Achieved value | Demo scope |
|---|---|---|---|---|
| MO | **Bid processing success** | Bids successfully processed / bids sent | **90.2%** | 5.3 (LV) |
| MO | **Bid activation processing success** | Bid activations successfully processed / bid activations sent | **100%** | 5.3 (LV) |
| FSP | **Activation amount confirmation processing success** | Activation amount confirmations successfully processed / activation amount confirmations sent | **91.2%** | 5.3 (LV) |
| FSP | **Activation delivery metering data processing success** | Activation delivery metering data successfully processed / activation delivery metering data sent | **91.2%** | 5.3 (LV) |
| SO | **Grid limitations processing success** | Grid limitations successfully processed / grid limitations sent | **100%** | 5.3 (LV) |

Overall, the data exchange and processing KPIs show the high reliability of IEGSA while emphasizing the need for further improvements. At the same time, in some cases, it was not possible to pinpoint the exact issues which caused some data not to be fully processed in some instances, especially since, as far as specifically data exchange is concerned, all the exchanged messages received confirmation of successful receipt. This implies that issues could have arisen not during the exchange but at some stage of the processing. However, the number of this cases remains significantly low which highlights the successful validation of the IEGSA concept.

### 3.2.4 User Experience KPIs

To address the **user experience** issue in terms of IEGSA implementations in the various WP5 demos, a brief **user survey** was created and disseminated to two of the three demonstrations[5]. The survey asked the parties involved in piloting activities to evaluate their experience in dealing with several **key IEGSA processes**, namely, adding a new resource, adding a product definition, qualification, bidding, activation, and settlement, and ranking the overall experience working with the piloted technologies. These questions were addressed to the parties undertaking the respective roles for which each of the questions is applicable.

[4] This analysis is limited to a representative sample of the total data gathered during the demonstration due to the large amount of data which needs to be assessed to extract these values.
[5] T5.2 partners did not fill out the survey as their interactions with IEGSA were less pronounced compared to the other two demos. Instead, the IDN (T5.2) demo participants have provided a descriptive assessment of user experience from their respective point of view.

The following evaluation scale was used: 1 – very poor, 2 – poor, 3 – acceptable, 4 – good, 5 – very good. The obtained results are summarized in Table 10.

Table 10. IEGSA user experience evaluation by WP5 piloting parties

| No | Process | Role | Demonstration | |
|---|---|---|---|---|
| | | | DSO and Consumers Alliance | Single Flexibility Platform |
| 1 | Adding a new resource | FSPs | 5 | 3.9 |
| 2 | Adding a product definition | MOs | 4 | 4.2 |
| 3 | Qualification | SOs | 4 | 3.3 |
| 4 | Bidding | FSPs | 3 | 3.6 |
| 5 | Activation | FSPs, SOs | 3 | 4.1 |
| 6 | Settlement | FSPs, MOs | n/a | 3.0 |
| 7 | Overall experience | all | 4 | 3.8 |

The user experience evaluation results for the **DSO and Consumers Alliance** demo were obtained by the consensus of the people involved in carrying out the piloting of the IEGSA procedures. All of the roles, such as FSP (large user, aggregator, local energy community), grid operator (DSO), and implicitly also market operator, were undertaken by the same entity – ASTEA, from which two people were directly working with the processes of IEGSA.

Both evaluators found it easy to add a new resource. On the other hand, in terms of adding a product definition and regarding the qualification process, one user scored 5/5 since they had participated in developing the procedures. However, the other user found them less intuitive since they had joined the project at a later stage and consequently scored them 3/5. The bidding and activation processes had a marginal role in the T5.1 demonstration. As these procedures were developed mainly by other demos (i.e., SFP), both operators found them less intuitive due to lacking background. They were scored 4/5 and 2/5, arriving at a consensus of 3/5. The settlement process was not applicable to the T5.1 demonstration. Finally, the overall experience was evaluated as 4/5 (i.e., good), which almost reflects an average of the individual process scores.

The user experience evaluation results for the **Intelligent Distribution Nodes** demo were obtained by involving all stakeholders in the validation process. The IDN demo had three main parties involved from a user standpoint: TSO, DSO, and IDN Operator (IDNO):

- TSO: The TSO via IEGSA, for both the automatic and the manual FRR, sends flexibility enquiries to potential flexibility service providers. For this demo and given the specific characteristics present in the Bulgarian market, the TSO informs not only the system requirements for FRR services but also the forecasted prices at which such services could be contracted. In addition, the TSO via IEGSA informs the IDN operational platform what are the contracting values and, at a later stage, the dispatch of those contracted resources. Finally, the TSO for this demo also provides a 72-hour PV forecast. On the other hand, the bids placed for FRR services from the IDN operational platform (once an optimization is executed within the GSMS process) are sent through the cloud-based architecture via IEGSA to TSO.
- DSO: similar to the TSO, the DSO informs via IEGSA potential flexibility service providers of the system enquiry for distributed resources to provide congestion alleviation services.

For this demo and given the de singular condition of the Bulgarian power system, with no current congestion management market fully in place, the DSO provides the demo via IEGSA the forecasted price at which congestion management service is contracted together with the system needs for every hour. Moreover, the DSO uses this communication channel as the main means to inform flexibility service providers of the contracted capacity for the congestion management services, as well as the activation of that contracted capacity at later stage.

- IDNO: The IDN's operator uses this gateway for operating the IDN to control actions associated with the IDN optimization, bidding, and dispatching.

The Market Operator is also involved, providing the IDN with the official day ahead market (DAM) prices that will be used within the optimization processes in the ERMS and GSMS modules embedded in the IDN cloud-based operational platform.

Some of the key takeaways from the IDN demo in terms of user experience are summarized below:

- IDNO User Experience: results show the IDN's ability to optimally manage the asset portfolio to maximize revenue from different service provisions.
- DSO User Experience: results show a satisfactory response from distributed assets to DSO economic and technical signals. The tools for communication developed via the IEGSA platform properly enabled congestion service provision from IDN to DSO.
- TSO User Experience: for both automatic and manual frequency regulation, IEGSA provided novel, convenient, and user-friendly channels to enable the proper transaction of services from IDN to TSO.

Finally, the user experience evaluation results for the **Single Flexibility Platform** demo were obtained by distributing the survey to the various parties that had worked with each of the relevant IEGSA processes and taking the average of the evaluations (to one significant figure). Since the SFP demonstration was very closely integrated with IEGSA, the users had an opportunity to test them very thoroughly. Because of this, there are more elaborate comments and suggestions provided regarding each of the processes in the following paragraphs.

Within the SFP demo, there were a total of five parties piloting IEGSA assuming the role of an FSP (two of which were actual aggregators, the other three acting as FSPs for testing purposes), and consequently testing the **new resource addition** process. The average evaluation of 3.9[6] reflects that the process was simple and straightforward. The main reported strengths were sturdy input validation with predefined input formats and checks to disallow the user from entering impossible or faulty information and protection from accidental disruption of the information input process. The main downsides were related to slight issues when updating an already created resource (i.e., some risk of the user losing updated information when changing tabs within the platform), some clumsiness of the entry forms, and minor difficulties in the handling of metering point IDs. Some users also reported a desire for general improvements in the user interface (UI) design. Another issue which raised concerns the overall amount of data input necessary to register a resource, which can quickly become cumbersome in cases of a large pool of resources. In such cases, the registration would rather be carried out with an API. It is also suggested that registration via the UI could be made easier by opening multiple registration forms simultaneously or by using an existing/registered resource as a template for registering a new one. Other improvement ideas are adding tooltips with explanatory information to further improve the usability, supplementing resource and resource group IDs in their respective modal windows, and

[6] One of the participants had only tested the first release of IEGSA and had thus not experienced improvements and fixes introduced in the subsequent versions. This could bring the evaluation slightly down. Concerns and comments valid only for the first release have not been included in the following explanatory remarks.

clarifying the nominal power term since there was some confusion if it concerns the normal or flexible power.

There were three SFP participants involved in the pilot in the role of a market operator[7] , and their average evaluation of the **product definition addition** was 4.2. This was perceived as also a very simple and straightforward process, easily doable within the provided UI. The main strengths were input validation and the possibility to update already existing product definitions. A drawback in terms of user experience was a lack of protection from user mistakes when misclicking outside the input window, which caused it to close without warning, discarding the already input data. While not a critical issue, since product definition is generally expected to be a rarely performed action, it is nevertheless suboptimal from a user-friendliness point of view. Another potential future upgrade suggestion would be to have flexible product parameter selection to have more flexibility in product definition.

Four SFP parties tested the resource and bid grid qualification process, and the average user experience rating was deemed to be 3.3. A common commentary was that, for the time being, the UI of the qualification system is simple but not very transparent. Qualification is a very complex process, and it is perhaps the most difficult to make user-friendly. Some of the key drawbacks of the qualification process in terms of user experience are summarized below:

- In grid qualification, only the qualification status is shown. In cases where resource groups are qualified with restrictions, the underlying reason behind the restriction is not shown, although, on the API level, this information is given every time the grid qualification is executed. More logging (notifications) on the possible issues would have been beneficial.
- Bid qualification is largely invisible to the user (DSO). Bids that would cause congestion are removed from the MOL, and the DSO doesn't see removed bids or reasons why they were removed.
- Results per resource and resource group were presented differently, which made things somewhat unclear.
- The qualification results are vague, i.e., the potential congestion is specified only by direction and not by value; thereby, there is room for improvement.
- While it was possible for an SO to manually modify the qualification results (e.g., if they disagreed with the automatic outcome), it was not possible to have this modified result stick since the qualification services automatically reupdated it.

Nevertheless, the automatization of qualification and requalification processes was also recognized as a strength of the process in terms of user experience.

Similarly, as for the resource registration, five user experience survey respondents were also for the **bidding** process within the SFP demonstration, providing an average score of 3.6. The bidding format was clear, and there were no issues with forwarding FSP bids[8] to the platform for validation. The process from the FSP's side is straightforward. Moreover, if there are significant mistakes in the bid message, the bid submission receives feedback on the issue. The slight downside here is that it does not specify where the mistake is found in the bid message, but this is not an issue if the bid is generated by a system rather than a human. There are however suggestions to increase the amount of information available to the user in the UI. It should be noted, however, that one respondent (an FSP) found the bidding process rather complex and challenging, primarily because of insufficient documentation and lacking troubleshooting options.

There were five respondents from SFP evaluating the **activation** process, involving both the FSP and SO points of view. This process was well regarded (easy and smooth) with an average mark of 4.1. Activation, in general, did not create negative user experience issues for neither FSPs nor SOs. An external MO could perform activations inside the platform (CM only) and outside. The

[7] Which for the purposes of the demonstration though, was equivalent to the SO role, for the sake of simplification.

[8] It was not enabled for an aggregator to submit a bid directly to IEGSA but through existing marketplaces.

in-platform bid activation was usable only for CM product, however the process provided valuable information for the SO as each bid is shown by the impacted network nodes, thereby it can be understood where the flow will also be impacted for external activations. However, there was a caveat to such use, whereby the SOs would not see the bids that were blocked during bid qualification, and yet these bids would still be available for activation outside the IEGSA. Recommendations for future improvements mainly concerned visualizations and more intuitive documentation, e.g., IEGSA would have benefitted from an improved visual hierarchy of the MOL[9]. Another suggestion was to make time period filtering more intuitive and automatic. However, one party (SO) did remark negatively about the UI for picking the right bid for activation, which was deemed not sufficiently functional[10].

The **settlement** process was scored by four participants, with the average mark being 3 (average). Understandably, it is of interest to both FSPs and MOs. For FSPs, the settlement results were available in the platform UI and through API communication which provides flexibility of use for the FSP. However, for MO, the settlement results could only be extracted by API communication, which might not necessarily be an issue, but it should definitely be improved to enhance the usability of the platform. The downsides with the user experience of the settlement process are largely connected to the functioning of the process itself. For instance, one user reports that the settlement process does not perform correctly in case the activation period is less than 60 minutes, which is usually the case in real-life balancing market activations. As a consequence, even when an FSP has delivered the activation perfectly, due to the duration being less than 60 min, the settlement service identifies the FSP to be in imbalance. This downside is confusing for the FSP as manually analysing the input data and settlement results will show that FSP might have delivered the activation perfectly. It follows that in future developments, the settlement process needs to support varied activation periods.

Additionally, the users would prefer to be able to view a summary of the settlement results within the UI itself since, currently, the functionality to access the results within the UI is limited to access to data downloading in machine-readable formats. They would also expect (from the FSP point of view) to have succinct explanations of why exactly a non-delivery is identified whenever such an event occurs. FSPs reported instances of settlement document upload failures, the reasons for which could not be determined. Overall, settlement troubleshooting, error management, and logging should be improved and made more transparent

On the other hand, the MO would appreciate an option to introduce a time limit for FSPs to upload their data for settlement (e.g., 24 hours), after exceeding which the delivery could be deemed as failed. Another additional functionality the MOs would like to see in IEGSA settlement-wise would be an option to amend activation requests ex-post, which would shield the FSPs from incurring unfair imbalances if, for instance, due to platform or MO/SO data processing issues the activation request is in a particular instance sent with a delay.

Generally, however, it can be said that the settlement process did, for the most part, function as intended/implemented. I.e., most of the drawbacks can be explained by design choices. However, some issues were reported with API responses indicating success when not always it was necessarily the case. Overall, though, the settlement process was tested comparatively less than the other IEGSA processes due to its completion later in the project. Moreover, it was mostly piloted by TSOs, thereby feedback from DSOs was minimal, although they do emphasize their interest in seeing via a UI the results regarding the actual activations of procured flexibility.

Finally, the **overall user experience** of SFP was evaluated as 3.8 (nearly good) and deemed positive on the whole. The system was easy to use (although at the expense of informativeness), fast, responsive, and stable. Other overall positive aspects concern the strict division of user roles.

[9] Such a solution was discussed at early stages of the project, but ultimately not implemented.

[10] It should still be noted that there were likely discrepancies between the IEGSA releases piloted by each party of the SFP demo, as well as concerning the necessary internal developments and the testing procedures/scenarios selected by each party.

Moreover, thanks to the straightforward design, a user can quickly and intuitively find where specific information is located after a brief experience working with the system.

From a SOs point of view, one unfortunate feature was that activations and trades could be viewed only one day at a time. Looking back into past activations and trades is difficult if one does not remember the exact dates when activations and trades were made. This could be solved by enabling the definition of time intervals for the shown activations/trades or by showing dates with data with a different colour on the day selection calendar. Also, in the future, different kinds of analytics tools could be added to the IEGSA. For an SO, it would be facilitating to see how much flexibility (MW) has been bought and activated in the past, how much is scheduled to be activated, and what has been the price, of course, with different kinds of filtering options included (location, length of the history, product, type of the flexibility resource, etc.).

Another critique pointed out was that sometimes there could be a slight loading delay when a user has a large pool of resources or the market has a large number of bids. While conceding that this could also be an issue of the hardware dedicated to this particular testing instance, and while in testing cases the reported loading delay has been in the order of seconds, there is nevertheless room for improvements in the general optimization of the platform, especially considering that it might be expected to handle a significantly larger pool of resources and/or bids in the future.

A common theme of the respondent commentary is a desire for more flexibility to the end users in how they can utilize the system, and also for more logging, better explanatory notices when something fails, and additional feedback from the various sub-processes (bidding, settlement). It is also generally the consensus that IEGSA achieves what it sets out to do, albeit with some minor logic and UI design shortcomings.

## 3.3 Assessment of achieved KPI values

Overall, the values of both the technical and user experience related KPIs show that IEGSA and the supplementary systems and processes developed and piloted within WP5 demonstrators, for the most part, manage to function as expected. The initially selected KPIs were successfully fulfilled, while additional indicators allowed a more detailed insight into the piloting results.

At the same time, a number of technical issues were identified throughout the piloting (e.g., in the settlement process and data processing). While some were already addressed within new iterations of IEGSA, some others remained to be alleviated in future work. Furthermore, piloting participants devised concrete suggestions to achieve improvements in user experience. This is a very positive aspect since such insights could only be gained though prototype testing. It also emphasized the importance of involving external stakeholders (i.e., such that were not directly involved in the business process and software development) in the piloting. Third-party users were overall more critical since they lacked the background knowledge that parties involved since the beginning of the project had accumulated. This highlights that, in the future, more focus should be given to documentation, and platform design ought to strive to be as self-explanatory as possible (i.e., the user should not be assumed to have extensive prior knowledge).

Another major strength of the piloting was the extensive scope of stakeholders involved (e.g., the SFP demo had TSOs, DSOs, MOs, and FSPs as IEGSA users). Such in-depth testing allowed the validation to be as multifaceted as possible. The involved parties identified how IEGSA (or particular sub-processes of it) could already be beneficial to their operations. For instance, the bid (with locational information) forwarding from mFRR and Intraday markets to congestion management markets is an effective and technically uncomplicated way to kick-start a CM market when that need arises. The developments in PTDF matrices-based prequalification also is a technical achievement with evident nearly immediate benefit to DSO internal procedures in their evolution towards active system management.

Apart from the outlined positive current or near-future impacts, IEGSA can provide additional value also in the longer-term. The socio-economic implications are assessed in the following chapter.

# 4 Socio-economic analysis

## 4.1 Impact assessment approach

The socio-economic assessment provided in this chapter strives to elaborate on the impacts of IEGSA achieved during the piloting phase and with an outlook of the potential future implications. Due to the differences in the piloting settings, internal developments, peculiarities in the regional/national status quo, and differing prospective future needs and expectations, the socio-economic assessment is done for each WP5 demo individually. However, there are several common qualities to these analyses. These mainly are related to exploring the role of IEGSA and particularly its functionalities towards more efficient ancillary services procurement. Another common theme is addressing these issues from the prism of end-user empowerment, i.e., by acknowledging how IEGSA can remove technical barriers to small-scale flexibility utilization, paving the way for more active consumers in the future. The assessment is based on learnings from the piloting, literature analysis, and a broad overview of the current and future trends for flexibility utilization.

## 4.2 DSO and consumer alliance

### 4.2.1 DSO and Consumer Alliance's overall value chain

“DSO and consumers alliance” demonstrator developed an IEGSA API-based connected SW platform to monitor and handle flexibility resources to mitigate congestion management in DSO network and enhance network quality. Actors involved in the demo are the local DSO, a large user, a battery aggregator, and two local energy communities.

In the following, after a brief introduction of the usage of IEGSA in the demonstrator, results will be presented from both a qualitative and a quantitative point of view. They will show how flexibility at the DSO level can improve the power quality of the network, allow for reducing congestion management costs for the DSO, and make possible the participation of small actors in a potential flexibility market.

IEGSA architecture has been integrated into the DSO and Consumer Alliance demonstrator for many of its functionalities, namely Flexibility Register (FR), Single Interface to Market, and Settlement Unit.

Flexibility resources are initiated in IEGSA and the developed SW platform and are composed of physical systems like stationary batteries, buildings, CHP, and other previously described resources. Aggregators of such resources need an SW platform to control and monitor the assets as well as to perform a proper settlement of the CM results and flexibility participation. In a small market like the one presented in the demo, the same aggregator should consider not only the technical side of the work (e.g., access to the flexibility resources, real-time data, etc.) but also the market side and all the related issues (e.g., market participation knowledge, bid optimization expertise, etc.).

The “Single Interface to Market” enables a uniform information exchange interface for all the markets integrated within IEGSA. The “Settlement Unit” assesses whether the traded flexibility was delivered as promised.

There are several APIs to exchange data between markets and IEGSA and between IEGSA and external SW platforms (like the one developed in our demonstrator).

The **main benefits brought by IEGSA** in the context where the “DSO and Consumer Alliance” demonstrator operates are:

**Market benefits**: the strong transparency in all the stages of the market process (all the information on flexibility resources and FSP, history transactions), which brings the possibility for all the small-scale actors involved to optimize their bids and their presence on the market.

**Potential for small-scale DSOs and FSP to participate in different markets** within a single platform, as IEGSA facilitates the usage of small-scale flexibilities to the markets, also allowing end users (consumers) to participate in the flexibility-related CM market.

From a **techno-economic point of view,** the largest part of the benefits is related to the lower congestion management costs for the DSO. This KPI represents the analytical quantification of the costs that the DSO would have had to bear if it had to solve the congestion network problem through the upgrading of the existing one, identified for both cases (Sogno Street and Brizi Street) in the construction of new secondary MV-LV electricity substations with the construction of MV conduits for the connection of the same to the existing MV network, assuming in both cases not to carry out any expansion on the existing LV network.

Two cases for the cost quantification for implementing solutions other than the two BESS installed have been evaluated, namely the secondary MV-LV electricity substations construction in both Brizi and Sogno streets, respectively. For case 1 – Brizi street, the total **avoided costs** are 89,490.00 €; while for case 2 – Sogno street, the total avoided costs are 60,490.00 €.

### 4.2.2 Impact on Power System

The last decade has seen more than doubling renewable generation capacity, mainly driven by photovoltaic (PV) and wind power systems integrated into power grids. This increased penetration of load-decoupled intermittent renewable sources has caused grid congestions, voltage regulation, and stability issues in power networks.

Thanks to the INTERRFACE project, it was possible to test and validate BESS integration at the LV distribution level and test different aspects of IEGSA functionalities in a virtual environment that can mitigate congestion management in the DSO network as well as enhance network quality. As reported previously, the main outcomes from business use cases tested in the Italian demo are:

**-Congestion management "SO-Supplier" Business Use Case**: Tests related to congestion management involving a programmable DG system (CHP plant) and providing up and down flexibility bids. Bids are created and activated, and finally, the settlement process occurs. It was also possible to define the number of DR response hours in the year in which the CHP unit can provide flexibility.

**-Congestion management "LV regulation Power quality" Business Use Case**: Tests related to the increase of LV power quality by means of BESS. In this case, it was possible to quantify the contribution made by the BESS introduction in the selected suburban branch: The maximum voltage reduction obtained is 2.9%, while the minimum voltage increase in percentage is 5.5%.

In addition, real test Bids for different storages are created on IEGSA, activated, and finally, the settlement process takes place.

**-Congestion management "Local Energy Community" Business Use Case**: The test aims to exploit the synergies among energy networks in a municipal scale multi-energy micro-grid in order to maximize the self-consumption of locally produced renewable energy. This involves the creation and activation of bids from storage and the settlement of the results.

### 4.2.3 Impact on society

The previous section presents the positive impact on the power system (from a technical and economic point of view). In this section, we will broaden the scope with the potential implication for citizens and society while presenting some of the lessons learned.

The electricity price is mainly determined by the demand and production curves and the higher use of flexibility resources in a congestion management scenario (the one tackled in the demonstrator) would model the demand curve to better match the production one, potentially resulting in a cheaper electricity price for end users.

Apart from having economic advantages and a better welfare perspective for citizens, this scenario may also bring more convenience in investing in renewable sources (by mitigating the intermittency production problems) with respect to fossil fuels. The consequence of such a situation could be an even higher penetration of green energy and a reduction of greenhouse-gas emissions, bringing in a series of well-known advantages for the planet and for humans.

However, this scenario still needs some effort in communication, education, and sensibilization before being wholly exploited. For example, during the pilot setup, there were problems related to technology acceptance by citizens (related to the BESS installation on the street, concerning both electromagnetic compatibility and the visual impact).

This aspect is worth of a mention because BESS is supposed to be a well-known everyday technology while being one of the key systems to implement a proper flexibility program.

## 4.3 Intelligent Distribution Nodes

### 4.3.1 Demo's description

An Intelligent Distribution Node (IDN) has been developed, installed, and validated in the IDN demo for the provision of grid support services devoted to improving grid regulation and congestion relief. The IDN is a complex high-level system that combines hardware elements, distributed control systems, and cloud computing for providing ancillary and flexibility services to the power grid and arbitration services to optimize end-user energy utilization. The IDN demonstrator is allocated in Sofia, Bulgaria, in the Goldline building, a multi-user building connected to the distribution system, equipped with a portfolio of energy assets (consisting of BESS, photovoltaic generation, electric vehicles, and conventional load) so as to provide grid flexibility with aggregated demand response and load control. The IDN demo can manage the building's energy consumption, providing congestion management, and balancing services to the grid operators (TSO/DSO). The IDN is able to process 200 kW of power and manage over 400 kWh of stored energy.

### 4.3.2 Impact on different stakeholders

Effective electricity storage solutions that decouple energy use and production are central to the green energy transition. In particular, in the residential sector, the implementation of such solutions should boost the potential of nearly zero-energy buildings to reduce primary energy consumption and greenhouse gases emission and towards greater energy self-sufficiency.

- **Impact for TSO**: it has been demonstrated that balancing services can be provided by small users connected to distribution systems while IEGSA enables direct communication.
- **Impact for DSO**: it has been demonstrated that congestion services can be provided from small users connected to distribution systems.
- **Impact for IDN operator**: creating the means to maximise the economic exploitation of the assets and giving value to the information obtained locally. In addition, the Information HUB is an application that analyses the IDN dataspace characterizing historical events and operating conditions to perform forecasting for parameters of interest.
- **Impact for DER vendors**: boosting the technology and niche market for batteries, panels, etc., in Bulgaria. Power distribution networks are being transformed by connecting distributed energy resources (DERs) like rooftop solar, electric vehicles, and battery energy storage solutions.
- **Impact on the final user**: End-users will dramatically change their role in power systems of the future. They will not be simple passive loads supplied by an energy services provider (ESP), but they will be at the centre of the energy systems of the future, generating power from local renewable resources, trading energy among them according to local markets through smart bilateral agreements implemented on safe digital platforms (block-chain),

participating in wholesale markets, and trading grid support products in corresponding services markets. The group of end users from a residential building could be also constituted as an energy community joining other neighbours in the same distribution area.

### 4.3.3 Results

The services provided by the IDN were assessed through a systematic validation campaign for a long enough representative period, being the IDN performance validated under the provision of a set of services that ranged from ERMS to FRR and CM in both modes, automatic and manual. Auxiliary voltage and frequency services were also validated. Different pricing schemes (hourly spot price and flat pricing) were considered during such validation tests. Since the Bulgarian power system did not allow the IDN to participate in hourly spot pricing, and there was not an explicit market for FRR and CM services, reasonable pricing assumptions were taken for validation purposes. Some representative uses cases for a different combination of services have been selected for discussion and included in Deliverable 5.4- Intelligent Distribution Nodes: Demonstration Description and Results [9]. These examples are as follows and summarized in Table 11:

- Energy Resource Management System
  - Base case
  - Pricing: two schedules considered for the wholesale energy prices
    - Flat wholesale price scenario (FWP)
    - Variable wholesale price scenario (VWP)
- EMRS and Grid Service Management System (GSMS) with Frequency Restoration Reserve: in addition to the ERMS operational schedule for the BESS, the FRR services (automatic and manual- aFRR and mFRR) were also activated
  - Pricing: following the same rational as with the previous use case, two energy prices schemes were used for EMRS (FWP and VWP)
  - Activation: activation mode for FRR services
- ERMS and GSMS with Congestion Management (CM): the ERMS and CM services (automatic and manual- aCM and mCM) were asked to provide the BESS power schedule and limits for congestion relief
  - Pricing: two schedules (FWP and VWP)
  - Activation: manual and automatic
- EMRS and GSMS: all services were activated such that the full capabilities of the BESS to provide multiple services were validated, as well as the economic gains and differences with the previous uses cases
  - Pricing: two schedules (FWP and VWP)

Table 11. Summary of services for different representative validation use cases

| FWP: Flat wholesale price, VWP: Variable wholesale price | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Use case** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** |
| **ERMS** | FWP | VWP | VWP | VWP | FWP | VWP | FWP | VWP | VWP | VWP | VWP | VWP | VWP | VWP |
| **aFRR** | | | ■ | | | | | | ■ | | | ■ | ■ | |
| **mFRR** | | | | ■ | | | | | | ■ | ■ | | ■ | |
| **aCM** | | | | | | | ■ | ■ | ■ | | | ■ | | ■ |
| **mCM** | | | | | ■ | ■ | | | | ■ | ■ | | | ■ |

As an example, use case 12, which involved the activation of the manual GSMS services in different time periods along with ERMS services, is detailed. aCM service was activated between 00:00 to 8:00 and 16:00 to 23:00 and aFRR from 8:00 to 15:00, while ERMS was activated during all periods of time. Fig. 2 depicts the optimal schedule for ERMS, aFRR, and aCM services during a representative day.

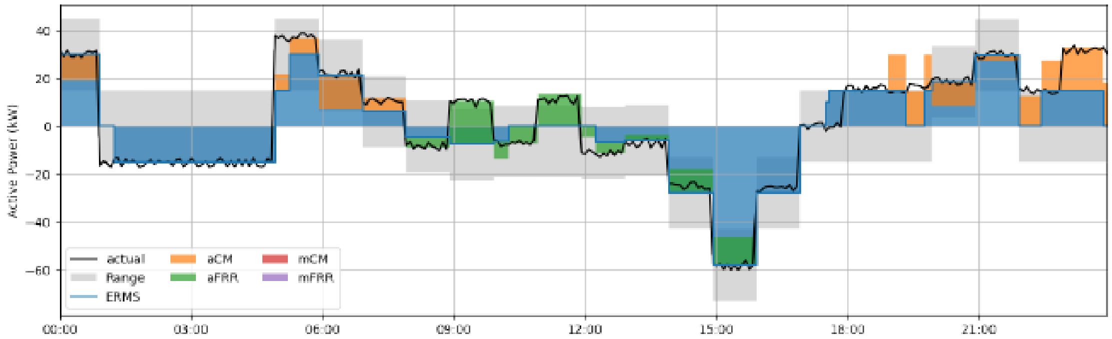


Fig. 2. ERMS variable price, aFRR, and aCM. BESS active power output

From an economic perspective, results are presented in Table 12. In this case, the actual results were worse than the presented by the planned schedule. In the planned schedule, the profit was 53.52 € for that day. In the actual plan, profits were worse than the planned scenario obtaining 45.79 €. Therefore, planned aCM and aFRR products profits were 23.05 € and 21.82 € respectively, but in the actual scenario, total benefits were 19.44 € and 17.19 €.

Table 12. Economical daily results for validation use case 12

| | | ERMS | aCM | aFRR | mCM | mFRR | Total |
|---|---|---|---|---|---|---|---|
| **Planned** | **Revenue** | 45.03 € | 24.52 € | 22.48 € | - € | - € | 69.04 € |
| | **Cost** | 36.38 € | 1.48 € | 0.66 € | - € | - € | 43.28 € |
| | **Profit** | 8.65 € | 23.05 € | 21.82 € | - € | - € | 53.52 € |
| **Actual** | **Revenue** | 42.71 € | 20.84 € | 17.99 € | - € | - € | 81.54 € |
| | **Cost** | 33.55 € | 1.40 € | 0.79 € | - € | - € | 35.75 € |
| | **Profit** | 9.16 € | 19.44 € | 17.19 € | - € | - € | 45.79 € |

Typical daily operation values during the validation period were used for analysing the revenue streams for the value stacking along the BESS lifespan, presented in Fig. 3. Although results for the ERMS were poor, the revenue stream from the aFRR and aCM services compensated the costs for the ERMS with an expected IRR of 21.79 %

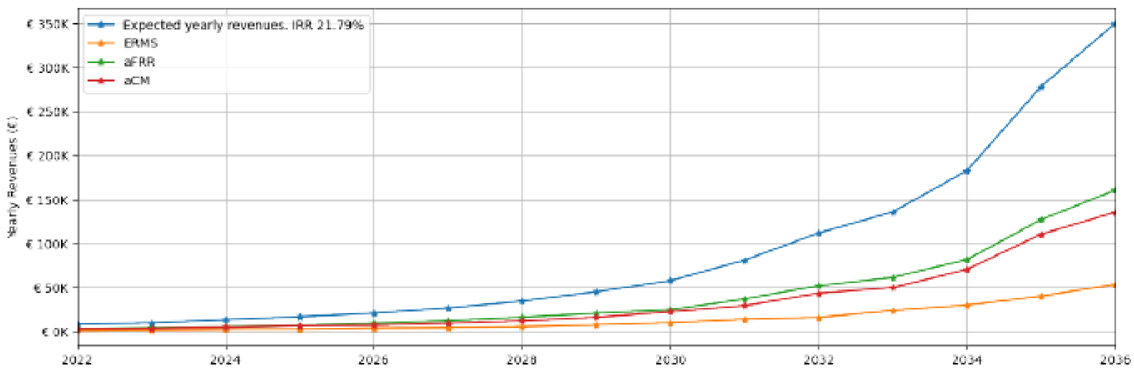


Fig. 3. Long-term analysis stacking value for ERMS and automatic GSMS services for the validation use case

### 4.3.4 Impact conclusions

As a summary of this description, it can be concluded that several exploitation lines can be enabled by integrating a BESS and renewable generation in a residential building or energy community. Such a BESS entails very interesting freedom degrees to the building/community, allowing optimal dispatch of energy for covering its needs according to a given market, generation, demand, and grid conditions. In this manner, it would be possible to make optimal bids and reduce the energy cost for the building/community. In addition to such immediate economic benefit, the BESS can provide different services to TSO/DSO to increase system security, reliability, and resilience. These local services will allow system investment deferral with a reduced operational cost, resulting in additional revenues for the BESS owner. Finally, the intelligent IH will allow the collecting and processing of information from different data sources and serving different consumers with tailored information according to their particular exigencies in a systematic and formally established manner, which enables the building/community to provide certified information services and participate in future energy information markets.

The IDN was validated as a value-stacking service provider. Day-ahead and intraday optimization modes were deployed to correct schedule deviations due to forecast (PV output and demand) errors or operational contingencies such as building power supply outages. It was shown that the IDN correctly followed optimized day-ahead schedules and service requirements within operational bands. The activation of intra-day optimization refined the IDN output, maximizing incomes while meeting all operational constraints. Additionally, the design of the IDN system allowed the operator, which had precise supervision and a deep understanding of the system operation, to decide whether automatic activation or manual activation had been used for grid services. The ERMS service generally accounted for 70 to 90% of the daily energy traded, while flexibility services accounted for 30 to 10% of that share. ERMS was the main source of income. It made profits coming from energy arbitrage, charging during low-price periods and discharging at high-price periods, thereby maximizing incomes. Depending on the particular use case, services provide extra income to the IDN. From the results presented in this deliverable, total daily profits can go up to 20 €/day, while in some other tested use cases, there were no profits or even slightly negative profits. The economic analyses of each service participation revealed that the IDN could generate attractive profit in the long run (within a span of 15 years).

## 4.4 Single Flexibility Platform

### 4.4.1 Single Flexibility Platform value chain

Since IEGSA architecture (Fig. 4) was implemented in the Single Flexibility Platform (SFP) demonstrator almost in its whole entirety, a brief introduction to IEGSA functionalities is presented here to highlight the value chain within the SFP demonstration.

IEGSA's architecture comprises four main modules, as shown in Fig. 4: Flexibility Register (FR), TSO-DSO Coordination Platform (TDCP), Single Interface to Market, and Settlement Unit. The FR is a metadata register that manages the flexibility resources and grants them access to specific market products and visibility to the flexibility buyers about where the resources are located, their technology, responsible FSP, etc., among others. The TDCP handles the qualification processes, which ensure that market actions do not violate the grids' technical limits. The single interface to markets enables a uniform information exchange interface for markets communicating with IEGSA. Finally, the settlement unit identifies whether the traded flexibility was delivered as promised and communicates these results.

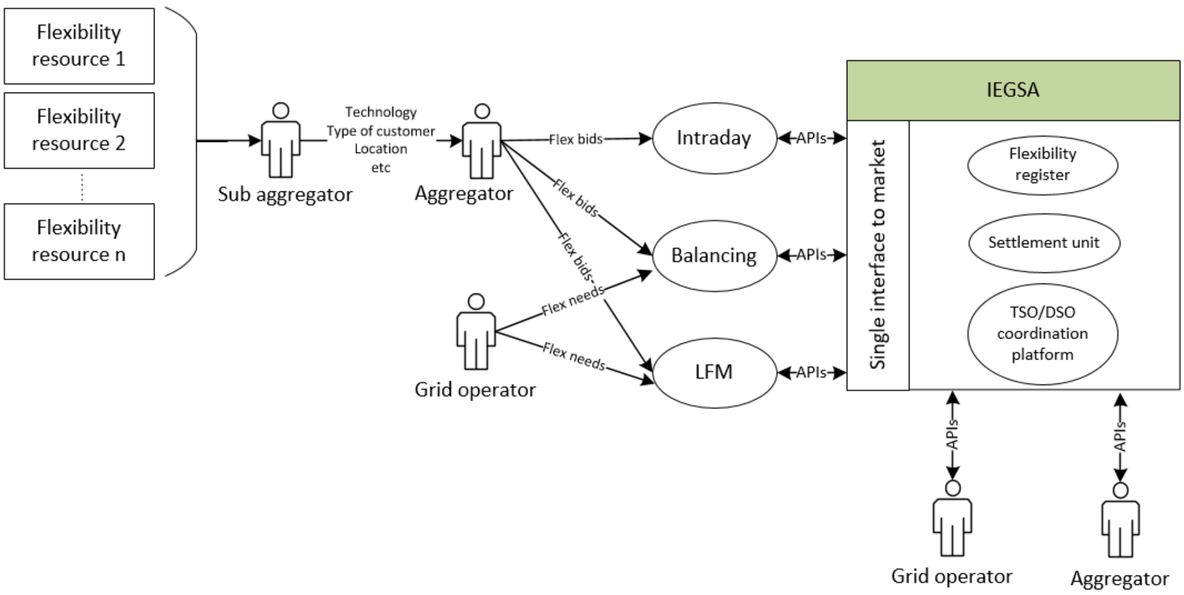


Fig. 4. IEGSA architecture in relation to the markets and flexibility sources

As shown in Fig. 4, several steps must be taken to connect flexibility from a resource to a market. Starting from the left of the diagram, flexibility is initiated from physical resources like HPs, EVs, stationary batteries, etc. The resources might be owned by households, small and medium-sized enterprises, or large-scale industries such as pulp and paper, chemical and metal process industries, and district heating (DH). Sub-aggregator[11] is a party with a direct contract with the asset owner or is the owner himself and therefore authorized to control the flexibility source and share the benefit with the asset owner. Sub-aggregator requires access to the flexibility asset and install control devices if not already existing. The control commands are usually dispatched through the public internet, and the sub-aggregator needs an IT system and necessary interfaces for control and monitoring. A sub-aggregator may lack market participation knowledge and bid optimization expertise; therefore, an aggregator[12] can take over the market side. In fact, the sub-aggregator in this model takes care of the flexibility resource, and the aggregator focuses on the market side[13] , including the market price forecasts, bid optimization, and market participation. The aggregator could utilize flexibility for different purposes (portfolio optimization, balance cost management, and ancillary service provision) and therefore participate in various markets such as day-ahead, intraday, balancing (mFRR, aFRR), reserves (e.g., FCR-N, FCR-D), local flexibility market (LFM) for congestion management, etc.

There are several APIs to exchange data between market platforms and IEGSA. Markets benefit from IEGSA mainly in two ways. Firstly, their bids are exposed to a bigger pool of potential buyers, increasing the chance of transaction thanks to the single interface to market module. For example, a bid from LFM entering into IEGSA could be purchased by a TSO for balancing needs. The second benefit is that there might be arrangements where the same bid is sent to several markets, and market coordination prevents double trade of the bid by automatically deleting it (i.e., from other markets) when it is accepted in a market. IEGSA is therefore enhancing the liquidity of flexibility in an organized way, encouraging FSPs to increase the flexibility provision. The more flexibility the markets have, the more the buyers of the flexibility may trust the availability of flexibility when needed.

[11] Also known as a technical aggregator.
[12] Also known as a commercial aggregator or FSP.
[13] It should be noted that the proposed business model of figure 1, is one way of handling the flexibility of sources. For instance, a sub-aggregator and aggregator might be one company. Nevertheless, unbundling the business, like what is presented in Fig. 4, allows the separation of costs and revenues with a higher resolution.

Similarly, several APIs connect grid operators and FSPs to IEGSA. The main advantage of IEGSA, particularly the TDCP module for grid operators, is that TDCP ensures that grid capacities are not violated due to a flexibility trade because network capacity limits are taken into account in the merit order list (MOL) creation stage. Each bid is examined against the network capacity limits, and if a violation occurs, the bid is dismissed. As another benefit, IEGSA enables grid operators to browse a large pool of flexibilities, including locational information, and buy the most cost-effective bid.

One main benefit brought by IEGSA is the reinforcement of transparency in different stages of the market process. The information on a flexibility resource's grid and product prequalification, technology, location, responsible FSP, history of previous market participation, etc., provide a great deal of transparency all in one place for both grid operators and FSPs. Using that through FR, the market participants can better optimize their presence in the markets and plan with a better understanding of the existing situation.

For the grid operators, the transparency that IEGSA provides, in addition to interoperability and harmonization of flexibility products, namely balancing and congestion management products, can lead to more cost-efficient balancing and congestion management. Therefore, the benefit can be felt on the end customer side by cheaper grid tariffs, the faster grid connection for new customers like renewable energy sources, and the possibility of maintaining larger market pricing zones. In addition, as IEGSA facilitates the usage of small-scale flexibilities to the markets, the end customers can monetize their flexibility not only in balancing and reserve markets but also for congestion management at the TSO and DSO levels.

### 4.4.2 Distributed flexibility in the Finnish-Baltic region

In the power system context, flexibility is the active management of an asset. To that end, distributed flexibility concerns a wide range of assets connected to the distribution network, which can provide flexibility: from conventional generation plants to industrial or small consumers dispersed in the system with demand management capability, including storage facilities and manageable RES [10]. These assets are also referred to as distributed energy resources, and their combined flexibility can support a more secure, sustainable, and efficient energy system if adequately utilized.

As the potential of centralized large-scale flexibility sources is often already extracted, the SFP demo pursues the idea of unlocking distributed small-scale flexibility. Thus, this section analyses some of the most prominent flexibility asset types whose potential is still untapped or is believed to become especially valuable for the Finnish-Baltic region in the near future, namely heat pumps (HPs) and electric vehicles (EVs). Consequently, the following subsections discuss the importance of the mentioned technologies and their current penetration level in Finland, Estonia, and Latvia, where SFP was piloted. In addition, the potential flexibility from HPs, EVs, and other demand-side flexibility (DSF) assets at the EU level in the near future is provided. Moreover, the most essential regulatory aspects that enable or hinder the full extraction of demand-side flexibility potential in the Finnish-Baltic region are discussed.

#### 4.4.2.1 PROSPECTIVE RESOURCES

In a recent expert study commissioned by SmartEn and performed by DNV[14] quantifying the potential benefits of demand-side flexibility in the EU, it has been assessed that the flexibility from buildings, electric vehicles, and industries in 2030 could reach 164 GW and 130 GW of upward and downward flexible power respectively on the wholesale markets[15] [11]. Furthermore, it was modelled that 397 TWh of upward DSF and 340.5 TWh of downward DSF could be activated

[14] DNV is an independent assurance and risk management provider, operating in more than 100 countries.

[15] In the context of the specific DNV study, 'wholesale' is defined as forward, day-ahead, and intraday electricity markets (explicitly excluding balancing markets / ancillary services).

through the wholesale markets. To put the flexibility values in perspective, in 2020, the gross electricity production in the EU was 2781 TWh [12].

From the different types of industrial, residential, and other flexibility sources modelled by DNV in [11], the most significant contributors to DSF on the wholesale level could be **EVs** and **electric heating**[16]. Namely, the largest share of flexibility in terms of the available upward flexible power (74 GW or 45%) is estimated to be sourced from EVs primarily thanks to smart charging in 2030. Smart charging could help reduce the EV charging power and avoid peaks in distribution grids. The most significant downward flexible power is attributed to residential electric heating (heat pumps) (73 GW or 56%).

However, as concerns the activated flexibility, the largest contribution comes from **residential electric heating** (heat pumps) with 195.5 TWh or ~54% in either direction, according to modeling results for the EU in 2030 [13]. As a technology that couples electricity to the heating and cooling systems, HP has a flexibility potential both on a residential and industrial scale. In the residential sector, a building, including its body and indoor air, can be seen as energy storage, and therefore, flexibility extraction could be realized by shifting the usage time of the HPs. The flexibility from the industrial sector due to the much larger scale of individual units and more advanced centralized control compared to the distributed residential flexibility might be extracted with less effort. The activated upward flexibility from **industrial electric heating** (e.g., electric boilers) is expected to reach 140.7 TWh (~36% of the total upward flexibility) in the EU in 2030 [13]. The next largest modeled flexibility activation comes from EVs with a total upwards flexibility of 127 TWh (32%) and 130 TWh downwards (or 38% of the total) [11].

While the above-mentioned modelling study mainly focused on the wholesale markets, it also assessed the benefits obtainable from DSF to the security of supply (incl. via balancing markets), distribution grids (e.g., reduced investment needs due to avoided congestions), and customers (i.e., cost reduction). Similarly, the **Single Flexibility Platform** demonstration in the **Finnish-Baltic region** enabled by the IEGSA developed within INTERRFACE could bring a range of benefits across the whole value chain when the solution is rolled out on a larger scale (national/regional/European level). For example, it could enable participation of distributed flexibility sources in different marketplaces by facilitating the coordination between DSOs and TSOs in employing these so-far untapped power system flexibility resources. To assess the attainable socio-economic impact of SFP deployment, the potential of some of the region's most prospective small-scale sources of distributed flexibility, such as heat pumps and electric vehicles, is analysed in continuation.

By and large, the European Commission (EC) recognizes the heating and cooling sector as a priority to achieve decarbonisation and reach the set energy efficiency targets [14]. Heating and cooling in the built environment account for almost 40% of Europe's total final energy demand [14]. Heat pump technology (Annex. II) efficiently produces heating and cooling using electricity. In the EU, **heat pump** (HP) is recognized as a renewable energy technology [15], paving the way for decarbonizing heating and cooling systems. If all current fossil-fuelled heat generation technologies were replaced by heat pumps overnight, the combined emissions of the heat and power sector would be reduced by 16% in the EU [14].

Furthermore, heat pumps can be integrated within existing **district heating** (DH) systems on an industrial scale[17] and combined with thermal energy storage (TES). By 2050, heat pumps could power approximately 25–30% of European DH systems [15]. The DH companies are eager to diversify their source of energy due to several reasons, such as carbon emission reduction, accommodation of a higher share of renewables, minimization of market risks (e.g., high fuel and electricity prices), and increase of the production profitability through arbitrage with variable electricity prices [16]. As concerns, the utilization of TES, the heat storage of up to 1% of annual

[16] Cooling was excluded from the study by DNV due to lack of sufficient data, even though its flexibility potential is generally considered large.

[17] One successful HP project in Mäntsälä, Finland, is to extract heat from the Yandex data center and reduce carbon emissions (i.e., COP= 3.7) [15].

DH energy, increases the DH company's profitability [17]. Moreover, TES, equivalent to around 1% of annual heat demand, is sufficient to minimize operating costs and enables flexibility beyond four days [18]. On the other hand, it is worth mentioning that if a long-term type of optimization is intended, the size of the TES has to be larger than it is for operational optimization, for example, to store energy for a more extended period (e.g., seasonal). Therefore, depending on the DH's objective (operational vs. long-term) and intended use of TES (e.g., energy arbitrage, balancing market, reserve market, congestion management, etc.), the required TES capacity might differ.

The share of heating in the total energy balance and hence the importance of heating electrification towards decarbonisation of the energy sector is even more significant in Northern Europe, where the heating demand is the highest and the heating season is the longest compared to the rest of the EU. Indeed, the heat pump potential has also been recognized in the Finnish-Baltic region (as relevant for the SFP), especially in Finland and Estonia, where large amounts of heat pumps have already been installed.

**Heat pump** sales in **Finland** have experienced steady growth within the last ten years. In 2020, according to the Finnish heat pump association (SULPU), over 600 million euros were invested in the installed more than 100 thousand HPs, an increase of 4% compared to 2019 [19]. The interest in air-source HPs was the highest, with more than 80 thousand installations, followed by ground-source HPs and exhaust-air HPs, with 9 and 3.5 thousand units, respectively. It is worth mentioning that a growing number of housing companies have decided to install ground-source HP in conjunction with an exhaust-air HP and to switch entirely from district heating to a heat-pump-based heating and cooling solution. In Finland, about 120–150 thousand houses are heated by oil [6], which means there is still plenty of potential for HP deployment in the residential sector. According to SULPU, there will be about 2 million HPs in Finland by 2030, providing 22 TWh of energy equivalent to 3–4 GW of controllable load[18] [19].

According to statistics collected by the European Heat Pump Association (EHPA), the number of **heat pump** installations in **Estonia** has been steadily growing during the last years, reaching a stock of 196.1 thousand units in 2020 [20] (compared to 179.4 thousand in 2019 [20]). Overall, there has been a 74% increase over five years. Thus, it has been estimated that there were 34.3 heat pump units per 100 households in Estonia in 2020, which is the 4$^{th}$ largest penetration in Europe (preceded by Norway, Sweden, and Finland with 60.4, 42.7, and 40.8 units per 100 households, respectively) [21].

In contrast, the number of **heat pumps** installed in **Latvia** is very low, and only limited statistical data is available. According to the official statistics, 0.9% of households (~7.5 thousand) had a heat pump installed in 2020, which is more than twice that in 2015 (0.4%, ~3.2 thousand) [22]. Since EHPA does not collect data on the heat pump market in Latvia in contrast to Estonia and Finland, only data from official/general household surveys are available, which could be an underestimation of the total penetration of heat pumps given their suitability to a specific type of households and dwellings. In contrast, the official survey is supposed to equally cover all types of dwellings, including multi-apartment buildings with district heating where individual heat pumps would not usually be deployed. Furthermore, during 2022 a significant growth in heat pump sales has been seen as a result of the energy crisis and also thanks to the available state support for renewable heating technologies.

Overall, HPs are expected to play a **significant role in the future energy systems** in the Finnish-Baltic region by counterbalancing the high share of renewables as a relevant power-to-heat technology. That would bring several benefits, such as "avoiding the curtailment of renewable energy production, providing flexibility on the demand side, utilizing existing thermal storage capacities, providing ancillary grid services, and increasing self-consumption via local renewable generation" [23]. Grid services could be provided by large-scale heat pumps, incl. the ones used for district heating, but also aggregated individual heat pumps. It should be stressed that the

[18] All the controllable loads should not be assumed to be available at a specific point in time because the primary use of HP is to provide heating/cooling and flexibility is the secondary usage of HPs. Therefore, the commercial potential of HP flexibility might be much less than the controllable load amount.

mentioned benefits can be more prominent when HP and TES capacity is designed not only based on the heating demand of the consumer but also from a flexibility provision perspective. In other words, in the design stage, both heating demand and flexibility should be taken into account to maximize the benefits for the end user and the grid.

On the European level, a record growth of heat pump sales by 34% was seen in 2021, according to EHPA [24]. The increase is expected to continue due to the introduction of new plans on the EU level aimed at damping the recent energy price spikes and reducing carbon emissions. The REPowerEU plan[19] [25] prepared by EC puts forward an additional set of actions to assure the energy supply's security that accelerates the deployment of HP technology even further. To facilitate a clean energy transition, the EU aims to **double** the current **heat pump deployment rate**, resulting in a cumulative 10 million units over the next five years. By the end of 2020, 40.1 and 1.8 million aerothermal and ground source HPs were already under operation in the EU [26]. Hence, if the REPowerEU goal is realized, about 50 million HPs will be in operation by 2027. According to EHPA, significant heat pump penetration growth is expected in 2023 and onwards as "the REPowerEU plan to get off Russian gas and its ambitious targets for heat pumps kick in" [27].

**Transport electrification** and advances in smart charging and vehicle-to-grid technologies will also serve as a source of distributed flexibility to the power system. While electrification inevitably increases the total electricity demand, smart control of electrical equipment accommodates it to power system needs. For example, the market of **EVs** has been expanding in recent years. In 2021, about 5.5 million electric cars were in Europe [28]. However, of all new car sales in 2021, light-duty electric vehicles[20] accounted for 17%, and the increase of newly registered EVs (2.3 million) amounted to more than 65% compared to 2020[28].

In June 2022, EU member states agreed to strengthen CO2 emission performance standards for new passenger cars and light commercial vehicles [29]. The proposal introduces increased EU-wide reduction targets for 2030 and sets a new target of 100% for 2035, which means that as of **2035,** the sale of combustion engine cars would be stopped in the EU market, and **all new cars and vans** sold in the EU should be **zero emission** [30]. Hence, despite the coming economic slowdown, electrification of transport will only continue in Europe. On the EU level, 2021 saw a significant uptake of electric vehicles and vans. The share of new car registrations grew from 10.7% in 2020 to 17.8% in 2021. Moreover, in the third quarter of 2022, the market share of battery and plug-in EVs accounted for 20.4% of total EU passenger car registrations [31].

The share of newly registered electric vehicles in **Finland** stood at 31.8% in 2021 and 3.2% and 3.9% in **Estonia** and **Latvia,** respectively [32]. Lately, the growth trend of EV share has been exponential in Latvia, reaching 3.5 thousand registered EVs by Oct. 01, 2022 [33]. Moreover, in all three countries, state support has been available for EV buyers and is also planned onward; hence a continuous steady increase in EV penetration is expected to continue. While the growing number of electric vehicles is also contributing to the rise in electricity demand, extracting flexibility from EVs can enhance power system flexibility and facilitate further integration of intermittent renewables into the energy system.

#### 4.4.2.2 ENABLING REGULATION

While the IEGSA developed by the INTERRFACE project and employed within the SFP demonstration facilitates the provision of different novel grid services by DSF and coordination between the TSOs and DSOs, the overall maturity of legislation facilitating the utilization of DSF in various markets is still varied among different Member States. Of the three countries piloting the SFP, Finland is the most advanced in the legislative framework, followed by Estonia and Latvia, as can be seen by analysing their level of compliance with the relevant EU-level initiatives

[19] REPowerEU: A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition, released on 18 May 2022, https://ec.europa.eu/commission/presscorner/detail/en/IP_22_3131
[20] Includes battery-only and plug-in hybrid EVs.

and legal acts. Moreover, Finland is considered a benchmark for best practices among the EU Member States [34].

The EU-level **legislative framework** has been set by the EU Electricity Regulation 2019/943 [35] and Electricity Directive 2019/944 [36] to eliminate various existing barriers to the utilization of demand-side flexibility in all markets provided by a diverse range of resources. Even though their provisions became applicable in 2020 and 2021, respectively, there is still limited progress toward transposing key provisions into national legislation of the EU Member States as of 2022 [37]. E.g., a comprehensive demand response aggregation framework is mostly missing, except in France and Slovenia (however, Finland is currently revising its framework for DR aggregation [38]). Thus, much of the demand-side flexibility potential remains untapped, and markets where DSF can participate are fragmented.

Nevertheless, according to SmartEn DSF Monitoring Report [38], **Finland** is one of the most advanced countries in transposing the respective EU legislation. E.g., in terms of markets, there are clear rules for market-based procurement of ancillary services by the TSO. However, independent aggregation in Finland is allowed "with certain limitations in the reserve markets" [38]. There are around 20 aggregators (both independent and integrated (i.e., suppliers)) active in Finland, which bring together both generation and flexible loads where clients receive a payment in exchange for the services provided [34]. In addition to other DSF enabling measures, Finland considers DER an alternative to system expansion in the transmission network development plans.

An additional provision of the EU legislation is the move from regulated to market-based electricity prices and time-differentiated grid tariffs for end-users [38]. The deployment of **smart meters** is a prerequisite that can help optimize electricity use and empower consumers while increasing comfort and efficiency. Smart meters, in fact, have already been rolled-out in all three SFP demonstrator countries (Finland, Estonia, and Latvia), thus enabling implicit demand response whereby the end-users adjust their consumption according to the price variation in the spot markets and/or time-of-use grid tariffs (if existent) while reducing the cost.

In contrast to Finland, explicit demand-side flexibility is slowly starting in **Estonia** and **Latvia,** even though the Baltic TSOs have been exploring the potential of demand response in enhancing power system flexibility for more than five years. A dedicated study commissioned by the Estonian TSO on demand-side response was published in 2015 [39], followed later by a joint position paper aiming to harmonize the principles for introducing DR in the balancing market by the Baltic TSOs in 2017 [40]. Even though the article focused on independent aggregation until now, independent aggregation per se has not been introduced in Latvia. However, at least one independent aggregator is already active and successfully operating for a few years in Estonia. According to the Electricity Market Act [41], no consent from the electricity retailer is required for a customer to conclude an aggregation contract in Estonia. However, to compensate for the energy transfer between the aggregator and the existing retailer/balance responsible party (BRP), the regulator has a temporary solution whereby the reference price equals the day-ahead price. The regulator aims to create detailed market rules with a more specific market model for independent aggregation [42]. Independent aggregators can now access the balancing market, but the framework for day-ahead and intraday markets is under development [34].

While there are general rules for aggregators in place in Latvia, an aggregator first needs to agree with the retailer or BRP of the demand response providing customer [43], and there is no standardized process or compensation mechanism in place between the BRP/retailer and the aggregator. Consequently, entry of a new aggregator into the market can be significantly encumbered or prohibited by the existing retailer/BRP, and essentially only integrated aggregation is feasible, whereby the retailer/BRP or its affiliated party acts as an aggregator.

Currently, the activities of aggregators in Estonia and Latvia are limited to the wholesale market (e.g., by optimizing consumption schedule according to the hourly prices), and it is also possible to provide balancing services in the form of mFRR energy by participating in the common Baltic balancing market. Although, since the introduction of the common balancing market in 2018, the

Baltic TSOs now rely much more on local balancing resources (previously provided mainly through the Russian power system), there is still an insufficient amount of reserves offered in the market. The demand for balancing resources will only grow as more renewable resources are integrated into the power system and as the Baltic countries prepare for synchronization with the Continental Europe grid by 2025 and disconnection from the BRELL ring[21]. To that end, new reserve products (FCR, aFRR) and markets (incl. capacity market) are going to be introduced in the Baltic power system during the next few years [44]. These developments could provide additional opportunities for aggregated DR participation in the provision of ancillary services as it will be possible to select among different reserve products to better suit the specific DR asset characteristics. Furthermore, demand-side flexibility providers might also explore value-stacking options by providing different balancing products in various markets.

### 4.4.3 Impact on flexibility asset owners and aggregators

Among all the DSF technologies, HP is a very relevant asset for which the Single Flexibility Platform (SFP) or a similar market participation-facilitating tool could be beneficial. Importantly, in addition to the arguments presented in section 4.4.2.1, actual HP flexibility activations took place in the piloting stage of the SFP demo; therefore, an impact analysis of flexibility extraction of HP using the SFP will be provided in this section. To roughly calculate the monetary benefits HP owners could get from participation in the flexibility provision, the estimation of benefits made by the T5.3 external piloting partner (kapacity.io [45]) is used. The analysis starts with a discussion about the influential factors affecting the end customer gains from flexibility provision, and afterwards, two real-world examples already realized in Finland are presented.

The benefits of HP's flexibility to the end customer are dependent on several factors such as market structure and rules (e.g., FCR-D, LFM, etc.), end customer's type of electricity contract (e.g., spot market, fixed fee, etc.) with a retailer, grid tariff structure (e.g., fixed fee, power-based tariff or time-of-use tariff) and FSP's ability to utilize flexibility in different markets and the technical readiness level (TRL) of the available tools, etc.

From the market structure perspective, the more markets where FSPs can participate, the more the end customers and FSPs are encouraged to cooperate because the business model is more supported by numerous revenue channels. For example, when flexibility can not only be used by a TSO to meet the balancing needs, but the market allows a DSO to use the same bid for congestion management (as was piloted in the SFP demo), the revenues can be higher. In line with that, market regulation plays an essential role by allowing demand-side flexibility to participate in markets. The Finnish case of allowing DSF to join the FCR-D market is one example that will be discussed in detail in section 4.4.4.

The end customer's electricity contract with the retailer may vary greatly depending on the type of customer (residential, business, etc.), the retailer's business model, and portfolio. For example, if a residential customer takes a tariff based on spot market prices, then utilizing HP flexibility can make a difference in minimizing the energy bills to shift the consumption hours to a time with a cheaper electricity price (i.e., spot market optimization). In addition, with an additional automation investment for load shifting of spot market optimization, flexibility can also be used in flexibility markets, such as balancing as a second revenue channel for the end customer and retailer/aggregator. On the other hand, if the end customer wants to be decoupled from the dynamics of the electricity price variations, then a fixed electricity price contract type might be selected. In that case, the customer would not be interested in utilizing the demand response for spot market optimization, but the participation in the flexibility markets may remain attractive because a low level of energy shifting is needed in those markets, but the automation investment must be fully covered with flexibility markets.

[21] Historically, the Baltic states electricity grid operates synchronously with the IPS/UPS system, which connects the energy systems of Belarus, Russia, Estonia, Latvia, and Lithuania in the so-called BRELL ring. The BRELL Ring is based on the BRELL agreement between these 5 countries, which was signed in 1998.

Another motivation of the customers to use their flexibility is to avoid the expensive grid tariffs introduced by grid operators (e.g., DSOs). For example, the time of use (TOU) type of grid tariff encourages the customers to shift their consumption to the off-peak hours. Similarly, some DSOs have introduced a power term to their grid tariff in Finland to encourage customers to reduce their peak power [46]. Introducing such a grid tariff would create one more use case for the end customer to utilize its flexibility. However, it is important to realize that the peak demand of a customer, a grid section of DSO, and a national grid may not appear at the same time, and therefore the synergies of DSO grid tariff load shifting are less than the synergies of spot price-based control. Power-based grid tariffs may also create an obstacle to utilizing flexibility on symmetrical markets like FCR-N or balancing power markets, where there is also a need to increase the load demand.

Another factor affecting end customers' benefit from the flexibility is the FSP's level of expertise and experience in the field and the TRL of the available tools. Although theoretically, utilizing flexibility for spot market optimization, energy optimization, and flexibility markets is not new, it is yet to be developed and commercialized in a widespread manner, especially for small-scale customers. Many energy companies, industries, and office buildings with a large energy portfolio have already utilized their flexibility to their favour; however, the potential of distributed flexibility has not yet been fully unleashed as it is a relatively new concept, and economic gains have not been strong enough compared to required investments or monthly service fees of retailer/aggregator. Therefore, customers (e.g., detached houses, small apartment buildings, etc.) have not thoroughly enjoyed the benefits due to business and technical immaturity. In this regard, IEGSA developed in INTERRFACE could be an instance of a tool that tackles technical immaturity and increases visibility to market participants, especially grid operators, about the existing flexibility resources connected to their grid. With that, a DSO can have access to the small-scale resources data that previously was inaccessible and, therefore, make use of them to alleviate congestions at the low voltage grid.

#### 4.4.3.1 REAL-WORLD EXAMPLES OF END CUSTOMER BENEFITS

In order to understand the scale of monetary benefits for different end customers, three customer groups were selected for analysis. Table 13 gives the sector and the size of the controllable load. Fig. 5 illustrates the earnings due to flexibility utilization provided by Kapacity.io. The air handling units (AHU) in all three cases were used as a flexibility resource to maximize energy saving, optimize against the spot market, and participate in reserve and balancing markets. The savings are an estimation done by the piloting partner Kapacity.io [47], and they are based on the Finnish market prices from January to July 2022, extrapolated to the whole year. The earnings for an office building with 330 MWh of annual energy consumption could reach 35000 €, followed by 21000 and 19000 € in logistics and a residential multi-family building, respectively. As shown in Figure 5, a large portion of the benefits comes from participation in the balancing market (i.e., mFRR market).

For smaller customers like a single-family house in Finland, the earnings are provided in the following Table 14 provided by the piloting partner Kapacity.io [47]. A detached house could gain about 500 € per year, which can motivate an end customer to be actively involved in flexibility provision. In addition, if the DSO uses a dynamic grid tariff (e.g., TOU, peak power, etc.), the residential customer could achieve up to 5% cost reductions by flexibility utilization, according to kapacity.io. The cost reductions depend on the grid tariff type and structure and the building's ability to store energy.

Table 13. Types and sizes of customers involved in flexibility provision

| Type of the building | Office | Residential multi-family | Logistics |
|---|---|---|---|
| Size of the controllable load (MWh/annual) | 330 | 140 | 180 |

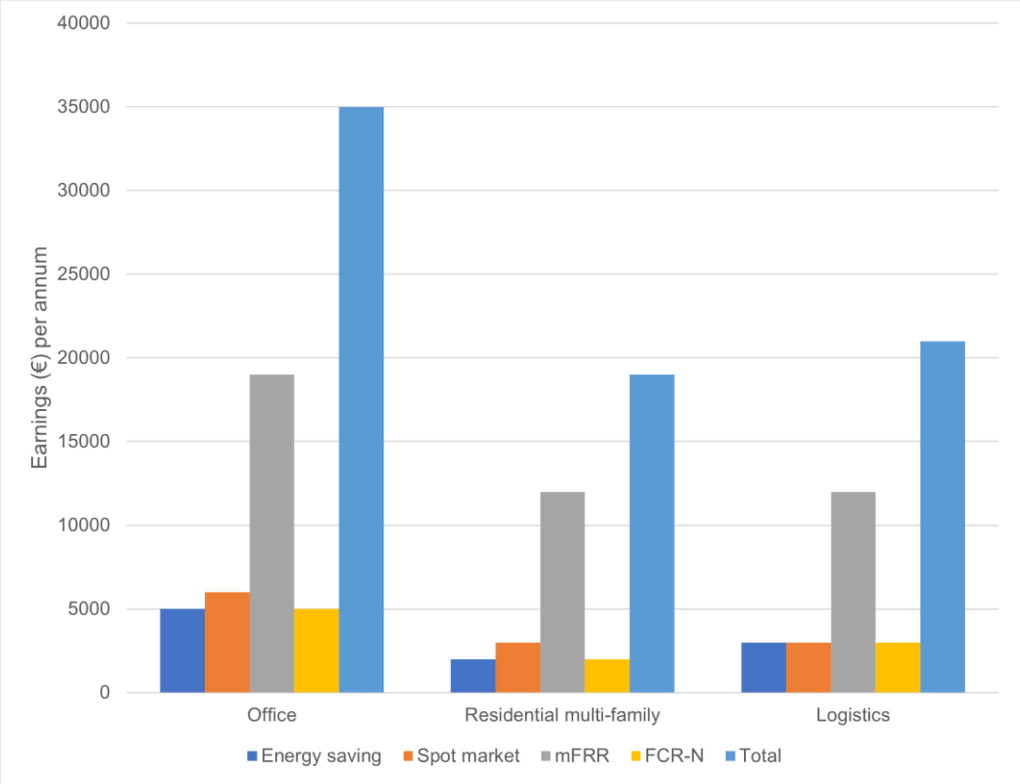


Fig. 5. Flexibility utilization-related earning for end customers

Table 14. Single-family house earnings in Finland

| Type of the house | Residential single family |
|---|---|
| Size of the plot | 200 m2 |
| Size of the HP | 12 kW |
| Energy saving (€) per annum[22] | 180 |
| Spot market (€) per annum[23] | 320 |
| Total (€) per annum | 500 |

Another benefit that extracting HP flexibility could create is to be EU taxonomy [48] compatible. One of the cornerstones of the EU Sustainable Finance Action Plan is to bring clarity to the market regarding which economic activities can be considered sustainable. The EU Taxonomy is an ambitious attempt to define these activities and the related technical standards for six environmental objectives. Sustainalytics' EU Taxonomy Solution assesses companies' eligibility and alignment with climate change mitigation objectives. Companies with EU taxonomy compliancy can benefit from a range of mechanisms. Leveraging EU taxonomy solution to meet regulatory reporting requirements under the EU Action Plan or other regulations is one use case of benefits [48]. In addition, EU taxonomy compliance enables investors to credibly quantify and report on the real-world contributions of their investments through this framework [48]; therefore, financing such projects is facilitated. As the companies' stakeholders are citizens, the benefits of EU taxonomy compliancy are relayed to end customers.

[22] Assuming that the total energy price (0.25 €/kWh) includes tariffs, and taxes.

[23] Calculated based on fall 2022 of the Finnish electricity prices.

It is worth mentioning that the benefits of flexibility provision are not only used by the end customers since FSPs are often the mediator between the end customer and the market. Therefore, a portion of the end customer benefits from market participation is shared with the FSP. FSPs with access to end customers' HP flexibility would have a more diversified portfolio in terms of flexibility location, size, technology, availability, etc., which could result in higher profits for them.

#### 4.4.3.2 COSTS TO THE END CUSTOMERS

Some hardware and software-related costs are imposed on the end customer when enabling and utilizing HP flexibility. The expenses depend on how capable the current infrastructure is and what functionality is missing. For example, most of the recently produced HPs that have third-party external control enabled can already accommodate energy and spot market optimization. Nevertheless, for balancing market participation like the FCR-D market, where a fast response time is required, a frequency measurement device has to be installed on the premises worth approximately 250 € for a detached house in Finland, according to Kapacity.io [47]. In addition, FSP (e.g., kapacity.io) provides software as a service, and its monthly charge is fixed based on the generated value from HP flexibility. Furthermore, load shifting often causes losses in the heating and cooling systems that can be seen as a cost to the end customer.

#### 4.4.3.3 EXTRAPOLATION OF END CUSTOMER IMPACTS

The benefits from HP flexibility for the asset owners depend on several factors, as mentioned earlier in section 4.4.3. As a result, extrapolating the benefits of HP flexibility utilization at the EU level is very difficult because each country has its peculiarities, and a huge amount of effort is required to perform the task properly. Therefore, to stay on the safe side and avoid unsupported claims, examples of Table 13 and 14 were provided to glimpse the potential of HP flexibility and their monetary benefits for the end customers without providing an extrapolation of financial benefits to the end customer at the EU scale. Although the benefits, to the best of the authors' knowledge, particularly from HP flexibility to the end-customer on the EU level, is not available, a study by DNV gives the benefits of DSF in total, including HP at the EU level. It showed that full deployment of DSF could lead to a potential cost reduction for those consumers of more than 71 billion EUR (64%) per year on electric consumption by 2030 [11].

### 4.4.4 Impact on the power system and the society at large

In general, DSF is believed to improve the security of supply and reduce related costs. Recently, DNV has quantified that the savings DSF could potentially bring to balancing markets by 2030 are between 262 to 690 million EUR in total for the EU [11]. In relative terms, this amounts to a balancing energy cost saving of 43…66%. Here, balancing includes aFRR, mFRR, and RR provision. Furthermore, DNV estimates that DSF could enable savings of the required investments in distribution grids amounting to 77.6 to 203.6 billion EUR (–27…–80% of today's forecasted investment needs) between 2023 and 2030 or 11.1 to 29.1 billion EUR per year at the EU [11].

However, the impacts of utilizing DSF on the power system could be not only positive but also negative in some aspects if not appropriately managed. One of the most important benefits to the power system is balance management improvement for the TSO if demand-side flexibility is available in balancing markets. Due to the growing penetration of intermittent power generation, TSO's flexibility needs are rising accordingly, and therefore, flexibility from DSF sources can meet the increasing demand. Consequently, the price of balance management that otherwise would be expensive could be kept in a reasonable range using flexibility from HPs and other DSF assets. **Finland** is a clear example of the reduced reserve cost whereby the TSO, Fingrid, has allowed DSF participation in the FCR-D (FCR for disturbances) market since 2017. Table 15 shows the decreased tender prices of the yearly FCR-D market after 2017 due to the participation of demand response in the market [49]. The hourly FCR-D market data in 2021 indicates that demand response constitutes 19% of the offers, compared to 78% coming from hydropower [50] while the majority of the procured bids, 49% are from demand response compared to 45% of hydropower

[51] due to a cheaper demand response offers. Both yearly and hourly FCR-D market data indicate the dampening effect of DSF on market prices.

Table 15. Yearly FCR-D tender prices in Finland

| Year | FCR-D upregulation price (€/MW/h) |
|---|---|
| 2015 | 4.13 |
| 2016 | 4.5 |
| 2017 | 4.7 |
| 2018 | 2.8 |
| 2019 | 2.4 |
| 2020 | 1.9 |
| 2021 | 1.8 |
| 2022 | 1.9 |

While for balancing the Finnish power system, there are several different market/product types DSF can contribute to, in **Estonia** and **Latvia**, there is only one mFRR market operated by the TSOs for balancing purposes, where DSF can also take part. Markets for other types of reserves, such as aFRR and FCR, including capacity products, are soon to be established so as to become fully functional before 2025 [44].

Since the opening of the currently operational common Baltic balancing market in 2018, where the balancing reserves are shared among three countries, there have been a number of efforts by the TSOs and regulatory authorities aiming to facilitate the participation of demand response in the balancing market and other potential venues. However, the framework for fully deploying DSF via aggregators as enabling market actors is still being developed in the Baltic countries.

The scale of prospective business opportunities for DSF participation in power system balancing can be deduced from the common Baltic balancing market size, e.g., in terms of the activated balancing energy. In 2021, there were more than 200 GWh of mFRR activations in each direction in total [24]. However, almost 33% of the activated reserves were provided from Sweden and Finland, indicating a potential lack and/or higher cost of reserves offered from Estonia, Latvia, and Lithuania instead. Furthermore, during 3% of the time in 2021, there were no downward regulating bids submitted in the Baltic balancing market at all. When looking only at the bids offered from each country, Estonia had 15% of hours without any downward bids, while in Latvia, during 41% of 2021, market liquidity for down-regulation reserves was zero. Hence, this market gap could be clearly filled by reserves offered from different DSF resources. For example, according to a study by Tallinn University of Technology (Taltech) conducted in 2014, it has been estimated that the theoretical capacity of demand response in Estonia could be, on average, 213–407 MW per hour [25] (households: 55–230 MW, business and public sector: 93–112 MW, industry: 65 MW). This can be contrasted to the volume of balancing bids submitted by all Estonian balancing market participants (so not only DR): 24 MW per hour for up-regulation and 46 MW for downregulation on average in 2021. Consequently, it is evident that more active DR participation could significantly improve the balancing market liquidity as well as facilitate cost reduction of balancing reserves incurred by the TSOs.

Additional venue of DSF benefits from a power system viewpoint lies in the fact that demand-side flexibility exploitation by the grid operator enables a higher utilization rate[26] of the existing grid infrastructure and, therefore, less need for expensive solutions like network reinforcement. A cheaper deployed solution would mean a cheaper grid tariff paid by end customers. For example, in Finland, a few hours of congestion in a distribution grid per week can be avoided in winter when

[24] https://www.ast.lv/lv/electricity-market-review?year=2021&month=13

[25] https://elering.ee/sites/default/files/attachments/Tarbimise_juhtimine_1.pdf

[26] A higher utilization rate of a grid component like a transformer means a duration curve closer to the maximum transformer capacity.

heating demand is high to utilize the existing infrastructure better if DSF can make its way to flexibility markets (e.g., LFM) and work as a viable solution to the grid operator. In that case, the grid operator does not need to invest heavily in the grid, so the grid service fees are not increased. At the same time, the DSF of heating loads, typically utilized only for TOU or power-based grid tariff optimization, would become available for other flexibility markets and enhance flexibility markets' liquidity. End customers would benefit from reduced grid cost due to reduced DSO's cost and earnings of flexibility provision on all flexibility markets.

Flexibility utilization generally facilitates a paradigm shift of the power system operation from load-following to production-following. If HPs and other demand-side assets play their role in power system operation daily as flexibility resources, the consequences on society will be multi-fold and interconnected. According to the fundamentals of electricity price formation, when the intersection of the electricity demand and production curves determines the electricity price, a shift of either of the curves could lead to a different equilibrium point resulting in a different electricity price. Higher flexibility would shift the demand curve towards the origin of the coordinates and, therefore, a cheaper electricity price for customers. Regardless of the mutual impact of electricity price and societal welfare, a cheaper average electricity price will eventually make fossil fuel-based generation infeasible or at least less competitive to operate due to their higher marginal cost compared to renewables. At the same time, the value of renewable generation is enhanced because their intermittency is managed more efficiently, and the balancing costs remain at a reasonable level thanks to the involvement of demand-side flexibility. The result would be more competitive renewable energy sources and a reduction of greenhouse gas emissions.

One additional benefit of DSF (to increase the demand) is that RES curtailment is reduced when the RES and must-run generation (e.g., run-of-the-river hydropower and heat-driven CHP) capacity is higher than the demand and export capacity together. The DSF would realize the production-following and would therefore reduce the RES curtailment during the excess generation hours. RES curtailment situation may also appear when the share of RES and nuclear power is larger than demand because both RES and nuclear power are close to zero marginal price production types. Therefore, the DSF would benefit both production types to gain reasonable profit from the market or at least to avoid negative spot market prices.

In addition, a higher flexibility presence in spot markets reduces the price volatility of electricity, which can lead to a reduced risk of high costs for all market participants. DNV has estimated that utilization of DSF would bring more than 300 billion EUR of indirect annual benefits to people, communities, and businesses in the whole EU by 2030, resulting from reductions in energy prices as a whole, generation capacity costs, investment needs for grid infrastructure, system balancing costs, and carbon emissions [11].

However, an important aspect to be taken into account when employing DSF for specific power system needs is the possibility of causing adverse impacts on an involved stakeholder. For example, customers using their flexibility may participate in a balancing market to fulfil TSO's needs which could lead to congestion issues for a local DSO. To avoid that, when the shift of customer consumption is due to a request from a grid operator as explicit flexibility[27], a coordination mechanism between TSO and DSO, like the one proposed in the INTERRFACE project, could be used. Nevertheless, coordination in the current form falls short when implicit flexibility[28] is used. For instance, price-sensitive customers could shift their consumption hours to a time when the electricity price is lower, and therefore, a considerable amount of load may cause a peak in distribution level that otherwise would be non-existent. In fact, the possibility of customers reacting to market signals (i.e., spot market) can be double-edged when the unification of customers' consumption behaviour coincides. Coordination seems a viable solution when

[27] Explicit demand side flexibility is committed, dispatchable flexibility that can be traded (similar to generation flexibility) on the different energy markets (wholesale, balancing, system support, and reserves markets). This is usually facilitated and managed by an aggregator, which can be an independent service provider or a supplier [54].

[28] Implicit demand-side flexibility is the consumer's reaction to price signals. Where consumers have the possibility to choose hourly or shorter-term market pricing, reflecting variability on the market and the network, they can adapt their behavior (through automation or personal choices) to save on energy expenses [54].

explicit flexibility is traded. In contrast, when flexibility is utilized in reaction to the spot market prices due to the will of the end customer outside the market as implicit flexibility, coordination is challenging, if not impossible, because often there is no information available about that.

Another negative impact of higher utilization of implicit demand-side flexibility from supplier and grid operator perspective is the higher uncertainty in load forecasts. Customers with flexibility could behave differently in response to an external factor like electricity market price. Therefore, TSO's and DSO's grid planning and operation, dependent on the accuracy of load forecasting, will be more challenging. In that case, the grid operators need to include spot market, balancing, and congestion management price forecasts in their existing load forecasts. A more complicated load forecast requires more resources and expertise from grid operators. Similarly, implicit DSF can cause additional imbalance for the supplier or the BRP if not forecast beforehand.

Despite the challenges of utilizing implicit and explicit demand-side flexibility, the benefits can outweigh the downsides if, for example, barriers (e.g., regulatory) on the way of independent aggregator participation in markets are removed, and the developed tools in research projects like INTERRFACE pave the way for the solutions to be commercialized. In that case, it can be assumed that a large share of, e.g., HPs' flexibility is represented in the markets by aggregators. Therefore, coordination between aggregators and flexibility buyers (grid operators) can happen more readily. On the market side, having access to the functionality of a single interface to markets proposed in IEGSA further eases the aggregators' efforts to bid into the flexibility markets because a bid can be exposed to a larger pool of potential buyers and less effort is required from the aggregators thus decreasing the market entry barriers.

### 4.4.5 Single Flexibility Platform socio-economic impact summary

During the SFP demonstration activities in Finland, actual HP activations took place via IEGSA. Indeed, a thorough assessment has shown that HPs are among the most prospective technologies for the utilization of distributed flexibility resources. Moreover, they are already quite widespread in Finland, rapidly growing in penetration in Estonia, and slowly rising in popularity also in the third SFP demo country – Latvia. International industry reports also confirm that this is generally the trend in most of Europe. Evidently, IEGSA could be an invaluable tool to provide HPs and other flexibility resources access to ancillary services markets to compete on fair grounds with other service providers, including the conventional ones.

The value potentially unlocked by IEGSA or a similar platform can be considered from several perspectives. Improved access to flexibility markets, including novel markets (as for congestion management or the upcoming FCR and aFRR market in Estonia and Latvia), can bring monetary value to end users. This concerns consumers who directly cooperate with FSPs and partake in flexibility markets and those who are passive. Passive consumers can benefit from reduced electricity of grid tariffs thanks to potentially cheaper ancillary services. Although, of course, the business case for active consumers strongly depends on the costs associated with unlocking their flexibility as well as on the actual demand (and thus prices) for their flexibility. This, however, is expected to grow in the future, especially due to rising intermittent generation, which needs to be balanced as well as due to a congestion management market increasingly being seen as a viable alternative to network reinforcement.

# 5 Conclusions

The three demonstrators within the INTERRFACE WP5, which were piloted in a total of five countries, allowed the evaluation of a diverse set of business use cases centred on the overall theme of congestion management. Moreover, additional streams to extract the value of flexibility while using IEGSA and other bespoke technologies and approaches developed within the project were explored.

While there were some technical issues encountered during the piloting activities within WP5, the business use case validation was deemed as successful. It was shown how congestion management could be provided efficiently and innovatively, combining it with other services (i.e., allowing the resources not to be locked in solely for one service provision, but enabling their participation in several). Moreover, a level of coordination between marketplaces was achieved, and an efficient pre-qualification algorithm was implemented for improved TSO and DSO coordination.

The most important technical innovations achieved during the project are related to IEGSA and its components, especially the Flexibility Register, TSO-DSO Coordination, and the Single Interface to Market. While the SFP demonstration was most closely integrated with IEGSA and consequently could provide the most thorough testing of its processes, there were also innovative solutions developed to address the specific needs of other demos, such as the Information Hub for the IDN or the SW platform for the DSO and Consumers Alliance demo.

When looking at the demo results individually, some of the most important outcomes are as follows:

- DSO and Consumers Alliance demo validated short-term congestion management using distributed generation; namely, a CHP plant (with a TES system), low-voltage power quality improvement using a battery aggregator and demand response as well as renewable energy-producing local energy community smart coordination to reduce the reverse power flows into the TSO network.
- The Intelligent Distribution Nodes demo validated the IDN concept, which enabled its users to achieve efficient energy use while minimizing its costs. Additionally, it demonstrated how the IDN could be used for the operational CM service in two different ways – automatically and manually. Similarly, it was shown how the same resources (IDN and the BESS within it) could also be exploited for TSO needs, i.e., for the balancing (frequency restoration) service. In general, the IDN management system developed allows for diverse flexibility value extraction and also provides valuable additional tools for its users.
- The Single Flexibility Platform demo validated the use of existing mFRR and intraday marketplaces to provide also bids for novel congestion management services, both within the short-term and operational framework. It was found that minimum additional technical developments are needed to enable such a functionality (mostly related to additional locational properties for bids and bid forwarding). The SFP also showed how IEGSA and its processes could be used to perform resource and bid grid qualification to ensure that, for instance, TSO balancing market bid activations from resources connected to the distribution grid does not cause infeasible conditions within the DSO network.

A common takeaway of the WP5 demos is that IEGSA can facilitate the uptake of flexibility resources. Moreover, flexibility utilization is enhanced when the same resource can be used for several services (e.g., for both congestion management and balancing).

While the current need for flexibility is varied across the regions, the future development trajectory of the European energy system does indicate that flexibility of all types will become increasingly required. To this end, the INTERRFACE project has provided an excellent starting point.

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# ANNEX I. KPI for network capacity utilization

Simulations and description by Antti Mutanen, Elenia

### Functionality

In smart grids, one of the main goals is to maximize the degree of network utilization while making sure that the network power flow and node voltage limits are not violated. This is also the goal of TSO-DSO coordination; allow network to operate close to the limits but block flexibility activations that would take the network beyond these limits.

### KPI

Performance indicator that describes what percentage of the network capacity is available for load and flexibility.

$$KPI = mean\left(\frac{actual\ load + estimated\ free\ capacity}{actual\ load + actual\ free\ capacity}\right) \cdot 100\ \%$$

The available free capacity can be estimated with different methods. This document uses power limit tables, PTDF, and nodal voltage sensibility factor (NVSF) matrices to estimate the free capacity. Because it is difficult to determine the actual free capacity from a real-life case, computer simulations are used here instead.

### Simulation setup

The 20-bus demonstration network from the Finnish demonstration is used as a basis for this simulation. The network is populated with 18 days of measured hourly loads, and next-day load forecasts are created based on historical load data. The network is studied in two switching states: the normal and backup state, where the second medium voltage (MV) feeder is supplied through the first MV feeder.

It is not an unambiguous task to determine the network's maximum capacity because the maximum capacity depends on how the load is distributed inside the network. For simplicity and consistency, it is assumed in this simulation that there is flexibility in every load node, and this flexibility is proportional to the existing base load. The network maximum capacity is determined by increasing all hourly loads, with the same factor, until either load flow or node voltage limits are violated. The actual maximum capacity is determined using load flow calculation, and this is later compared to the maximum capacity calculated using power limit tables, PTDF, and NVSF matrices. In the normal state, the capacity of the network is limited by a secondary transformer power flow. In the backup state, the capacity is limited by the node voltage limits.

It is assumed the power limit tables are updated once a month, and the monthly peak loads are used to determine how much free capacity there is under each critical component. For example, the most easily congested secondary transformer has a maximum capacity of 500 kVA, the forecasted peak load for the studied month is 343 kVA, and therefore the free capacity is 157 kVA.

The PTDF and NVSF matrices in this simulation are static, but the conducting equipment power flow and node voltage forecasts for the next day are updated daily.

### Simulation results

In a normal network state, the average network utilization rate using the power limit table (PLT) based grid qualification was 55.7 %,

$$KPI_{PLT} = 55.7\ \%.$$

In a normal network state, the average utilization rate using the PTDF matrix-based grid qualification was 87.7 %,

$$KPI_{PTDF} = 87.7\ \%.$$

Fig. 6 shows the available free capacities for the whole study period. The PLT-based method has a poor network utilization degree because it applies the worst-case situation for every hour of the month. The PTDF-based method is much more accurate because it can take into account the hourly load variations. The used simulation setup was susceptible to forecasting errors. The smallest, and thus most difficult to forecast, load dictated how much the load on the whole network could be increased. When ideal forecasts were tested, the utilization rate climbed up to 99.4 %. The last 0.6 % missing from the perfect score is due to the linearization errors inherent to the PTDF approach,

$$KPI_{PTDF\_ideal\_forecast} = 99.4\ \%.$$

During some hours, the PTDF-based grid qualification overestimated the free network capacity. This can be seen in Fig. 7. This was again due to forecasting errors. The forecasts were made so that there is a 95 % confidence that the forecasted load is not exceeded. In this case, the free capacity was overestimated on 8.6 % of the studied hours. This is a little bit higher than the expected 5 %. One possible reason is that normal distribution does not model loads accurately at the end of the distribution tails.

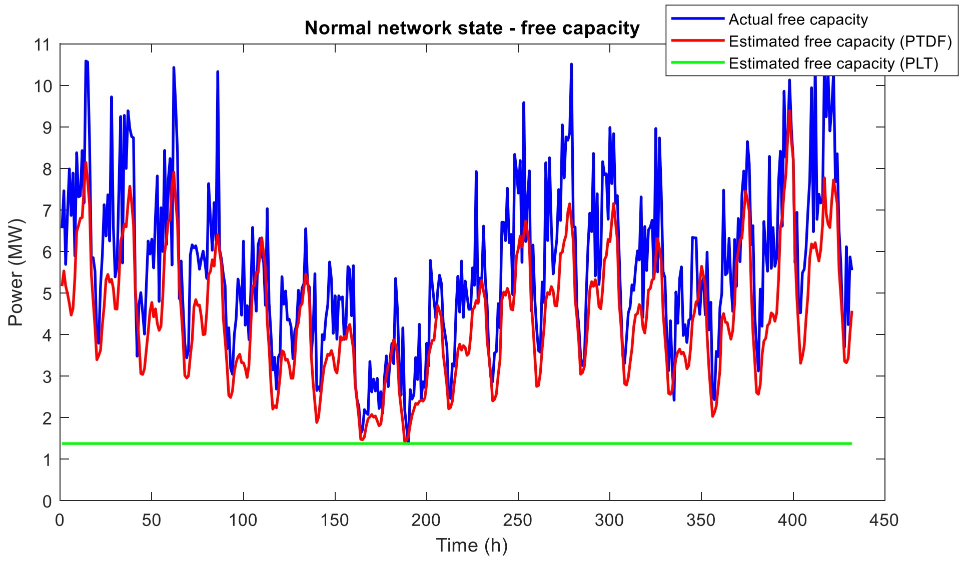


Fig. 6. Simulated free capacity for the whole network in a normal network state

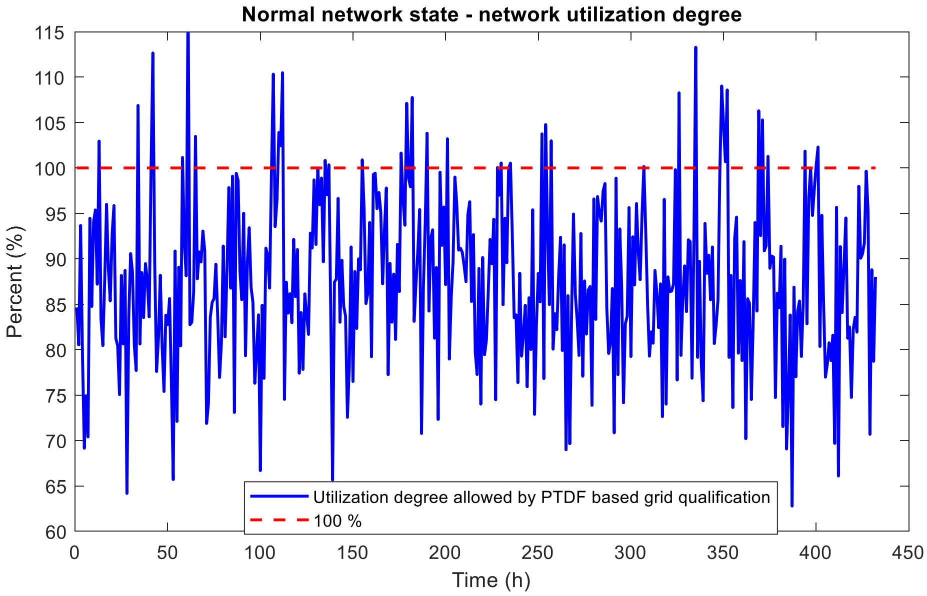


Fig. 7. Utilization degree allowed by the PTDF-based grid qualification in the normal network state

In the backup network state, the average network utilization rate using the PLT-based grid qualification was 67.8 %,

$$KPI_{PLT} = 67.8\ \%.$$

In the backup network state, the average utilization rate using the NVSF matrix-based grid qualification was 91.8 %,

$$KPI_{NVSF} = 91.8\ \%.$$

In the case of the backup network state, results based on the NVSF matrix-based grid qualification are shown because in this switching state, the maximum amount of flexibility that the network can host is limited by the network node voltage constraints. Figure 8 shows the available free capacities for the whole study period. The NVSF-based grid qualification gives much more stable results than the previously shown PTDF method because the network minimum voltage depends on several loads. The errors in load forecasts were once again the reason why the perfect score was not reached. When ideal forecasts were tested, the utilization rate climbed to 99.9 %.

As Fig. 9 shows, with the NVSF-based grid qualification, the network utilization degree remained below 100 % during all the hours in the simulation period.

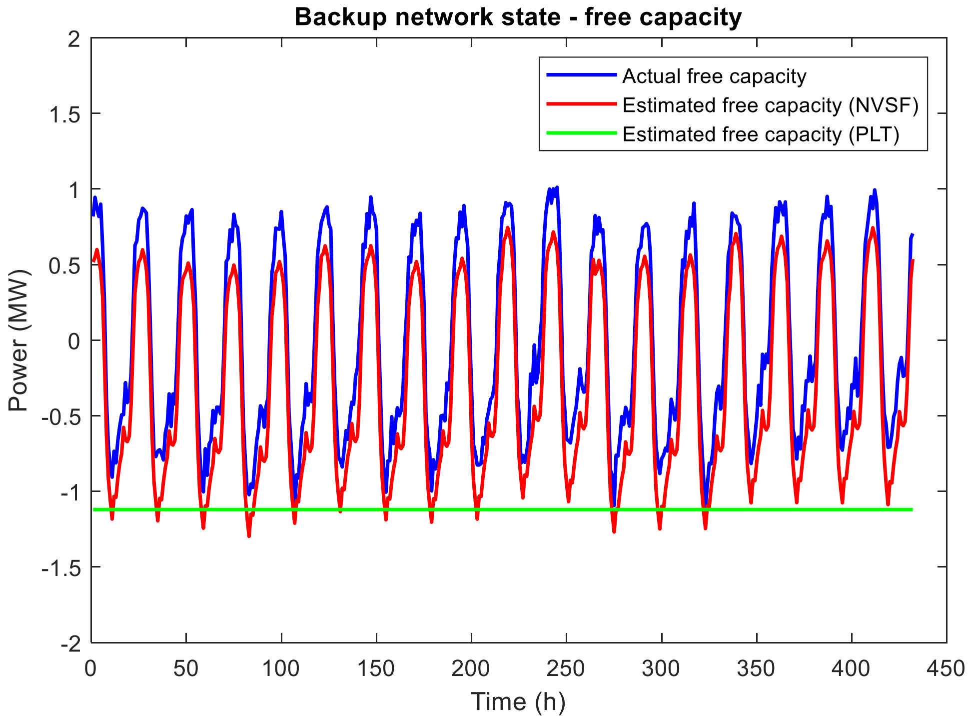


Fig. 8. Simulated free capacity for the whole network in a backup network state (negative values mean that the network is estimated to be congested).

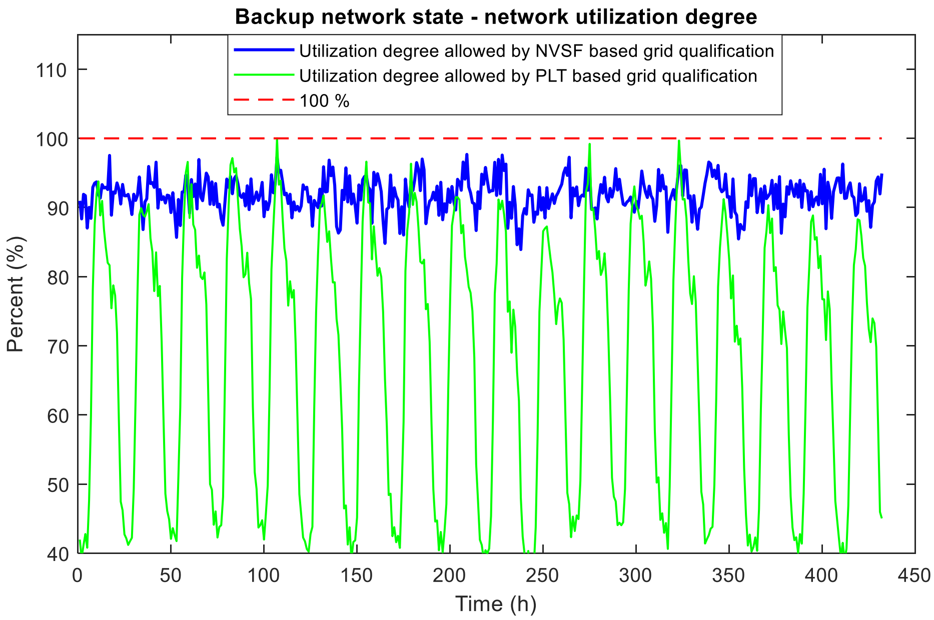


Fig. 9. Utilization degree allowed by the NVSF-based grid qualification in the backup network state.

### Final KPI values

Finally, we calculate the average from the above-shown normal and backup network state results and get the following:

$$KPI_{PLT} = 61.8\ \%,$$
$$KPI_{PTDF\&NVSF} = 89.8\ \%.$$

# ANNEX II. Principal of HP operation, efficiency, and types

The operation principle of HP is based on circulating refrigerant in a closed-loop system using a compressor [52]. HPs work based on the Carnot cycle to provide cooling, and they can be run in reversed Carnot cycle to provide heat. The feasibility of using HP is often justified by its high coefficient of efficiency (COP) [53].

$$COP = \frac{Q}{W} \quad (1)$$

where $Q$ is the thermal duty and $W$ is the required work of the compressor, which affects the electricity consumption. One way to classify the HP's COP is the division of HPs based on their distillation systems into narrow-boiling, medium wide-boiling, and too wide-boiling systems [53]. As provided in Table 16, in too wide-boiling, medium wide-boiling, and narrow-boiling systems, the COP is lower than 5, between 5 and 10, and larger than ten, respectively. Table 17 presents HP types and their source of heat [15].

Table 16. HP's distillation systems and their COP

| Distillation systems of HPs | Coefficient of performance (COP) |
|---|---|
| too wide-boiling | COP<5 |
| medium wide-boiling | 5<COP, COP<10 |
| narrow-boiling | COP>10 |

Table 17. HP types and sources of energy

| Type | Heat source |
|---|---|
| Air source heat pump (ASHP) | Ambient air |
| Water source heat pump (WSHP) | Water (lakes, ponds, wells, etc.) |
| Ground source heat pump (GSHP) | Ground |
| Other | Wastewater (i.e., sewage), industrial exhaust heat, etc |