European Commission
Horizon 2020
European Union funding
for Research & Innovation

Report on the Technical Energy Analysis (TEA)

D10.2

EU-SysFlex

© Copyright 2018 The EU-SYSFLEX Consortium

This project has received funding from the European
Union's Horizon 2020 research and
innovation programme under grant agreement No 773505.

PROGRAMME	H2020 COMPETITIVE LOW CARBON ENERGY 2017-2-SMART-GRIDS
GRANT AGREEMENT NUMBER	773505
PROJECT ACRONYM	EU-SYSFLEX
DOCUMENT	**D10.2**
TYPE (DISTRIBUTION LEVEL)	☒ Public ☐ Confidential ☐ Restricted
DATE OF DELIVERY	19 April 2022
STATUS AND VERSION	V1
NUMBER OF PAGES	121
Work Package / TASK RELATED	WP10 / T10.1
Work Package / TASK RESPONSIBLE	Robert SOLER (EDF R&D)
AUTHOR (S)	Robert Soler (EDF, WP Leader and Task Leader), Carmen Calpe (e.on), Maik Staudt (MITNETZ STROM), Pirjo Heine (Helen Electricity Network), Oliver Ojala (Helen), Simone Tegas (EDIS), Carla Marino (Enel Global Infrastructure & Networks), Daniele Clerici (RSE), Giacomo Viganò (RSE) Miguel Jorje Marques (EDP), José Villar (Inesctec), Bernardo Silva (Inesctec), Ye Wang (EDF), Ismet Zenuni (EDF), Alan Ribière (EDF), Guillaume Lehmann (EDF), Kalle Kukk (Elering).

DOCUMENT HISTORY

VERS	ISSUE DATE	CONTENT AND CHANGES
1	08/04/2022	First version
2	19/04/2022	Second version, including proposed changes from WP10 partners and PMB members

DOCUMENT APPROVERS

PARTNER	APPROVER
EIRGRID	Shane O'Keeffe, Project Coordinator, with PMB review
EDF	Marie-Ann Evans (Technical Manager)

TABLE OF CONTENTS

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

aFRR	Automatic Frequency Restoration Reserve
AMR	Automated Meter Reading
BESS	Battery Energy Storage System
BUC	Business Use Case
CIM	Common Information Model
DER	Distributed Energy Resources
DSO	Distribution System Operator
EV	Electric Vehicle
EU-SYSFLEX	Pan-European System with an efficient coordinated use of flexibilities for the integration of a large share of Renewable Energy Sources (RES)
FCR	Frequency Containment Reserve
FCR-D	Frequency Containment Reserve for Disturbances (in Finland)
FCR-N	Frequency Containment Reserve for Normal Operation (in Finland)
ICT	Information and Communications Technology
KPI	Key Performance Indicator
mFRR	Manual Frequency Restoration Reserve
MOPF	Multi-Temporal Optimal Power Flow
nRMSE	Root Mean Square Error (RMSE) normalised with the specified nominal power of the wind farm
O&M	Operation and Maintenance
OLTC	On Load Tap Changer
p.u.	Per Unit
RES	Renewable Energy Sources
RMSE	Root Mean Square Error
SCADA	Supervisory control and data acquisition
SO	System Operator
SoC	State of Charge
STATCOM	Static Synchronous Compensator
SUC	System Use Case
RR	Replacement Reserve
TLQ	Traffic light qualification
TSO	Transmission System Operator
VRES	Variable renewable energy resources
WP	Work Package

1. EXECUTIVE SUMMARY

The H2020 European project EU-SysFlex aims at demonstrating innovative flexible solutions for the power system and at studying the large-scale deployment of flexibility considering the integration of more than 50% RES at the horizon 2030. These flexibility solutions include technical options, system control and data transfer enhancement. The Work Package 10 of the European project EU-SysFlex has several main objectives, the main one being the elaboration of a roadmap of flexibility for Europe (D10.5). The roadmap is fed by all results of the project and in particular by other studies carried out in WP10 such as the definition of Key Performance Indicators (D10.1) for the demonstrations, and a Technical Energy Analysis assessing the KPI results (D10.2) which is the aim of this very report.

A tentative use of the ETIP-SNET framework for defining the KPIs was done at the beginning of the EU-SysFlex project and helped producing a preliminary list of KPIs after 6 months. However, this approach turned out to be too general and difficult to use by the demonstration leaders. Therefore, decision was made to adopt a bottom-up approach and to define demo-related KPIs that are specific to each demonstration and are aiming at proving the success of the services trialled, qualify their performance and reliability . The consequence is that the defined KPIs necessarily vary from one demonstration to another even within a same group of demonstrations (VPP, TSO-DSO coordination, Data Exchange) and, for some demonstrations, do not cover the full scope of the trials but only specific aspects that demo leaders could quantify (e.g. France where KPIs only cover experiments related to FCR provision and energy arbitrage whereas over aspects were covered by the demonstration such as FFR and aFRR provision and ramp-rate limitation). This made it rather difficult to carry out a cross-analysis of the results. In the following sections, the results are merely presented per group of demonstrations and according to KPIs categories as defined at the beginning of the project in D10.1.

1.1 VIRTUAL POWER PLANTS (VPP) OPERATION

Three demonstrations (Finland, France, Portugal) were aiming at aggregating assets in order to provide flexibility services. These 'Virtual Power Plants' were connected to different voltage levels, used different types of assets, and provided different types of services to the TSO and/or the DSO.

1.1.1 LOCAL ECONOMIC IMPACTS OF THE SOLUTIONS

The demonstrations dealing with VPP analysed economic impacts such as the increase in revenue for the flexibility provider or the decrease in possible penalties for not complying with the requirements (Finland). In the case of large-scale VPPs located on the transmission grid or MV grid, the analysis shows a moderate increase in revenue for the flexibility provider (as compared to the operation of uncoordinated single assets) but a strong interest for reducing imbalance costs. The aggregation of small assets on the LV grid for frequency regulation services (tested in Finland) turned out to be technically feasible but not economically viable at that stage. Neither was the reactive power market proof of concept for the DSO (Finland).

1.1.2 ABILITY OF THE SOLUTION IN MEETING SO' TECHNICAL NEEDS WITH RESPECT TO FLEXIBILITY SERVICE PROVISION

The compliance to the TSO's requirements of existing services provision with existing or new assets was studied in the French and in the Finnish demo for frequency regulation services provision. In the Finnish demo, the compliance of FCR-N, FCR-D and mFRR provision by aggregated LV and MV assets was studied whereas the French demo focused on the compliance of the FCR provision by the VPP to the TSO requirements. In both cases, some results were either not compliant (FCR-D and mFRR provision in Finland) or not as good as expected initially (FCR in France).

1.1.3 AVAILABILITY AND ACCURACY OF SUB-SYSTEMS (FORECAST, COMMUNICATION INFRASTRUCTURE).

Some KPIs dealt with the sub-systems and were addressing the accuracy of forecast (in the Portuguese VPP) and the availability of the communication infrastructure (in France). No specific problem was identified although results would always benefit for ever improved forecasting or reliability of ICT.

1.1.4 RELIABILITY AND AVAILABILITY OF THE FLEXIBILITY SERVICES PROVIDED.

The reliability of the flexibility services provided was measured by calculating the Root Mean Square Error (RMSE) in Finland for FCR-N and FCR-D provision and for the reactive power market and in France in the case of FCR provision. The availability of the assets was evaluated in Finland. Gobally, the frequency regulation services and the provision of reactive power services (Finnish demonstrator only) had a good reliability at a demonstration stage. In some cases, high RMSE values highlighted some specific faulty periods in which failures or malfunctions occurred. When these periods were removed from the calculations, the service provision was found to be reliable. The availability of the assets was found to be higher than 95%.

1.1.5 CUSTOMERS' ACCEPTANCE

The Finnish demo was the only one dealing with distributed assets belonging to end-use customers. For all assets owned by end-use customers, the stakeholders'acceptance is very critical. Scaling-up or replicating the experiment can not be reached without these customers. Accessing data requires agreements. Besides, the smaller the customer the smaller are the profits. Therefore, the technology, equipment, control systems should be simple enough to install and use and economical. Currently the customer-scale BESS owners are forerunners and so far only a few customers have purchased a BESS with their PV system. Helen's customers in Finland were contacted and discussed a possibility to participate in the demonstration. All of them agreed to participate.

1.2 TSO-DSO COORDINATION

Three demonstrations (Germany, Italy, Portugal) were aiming at accessing and operating flexibilities embedded in the distribution grid in order to deliver flexibility services such as congestion management and voltage support both to the TSO and the DSO, thereby improving coordination between both system operators. In all cases, the demonstration has been done taking into account transmission grid and distribution network mutual needs and constraints and thus improving data exchanges between the two System Operators.

1.2.1 LOCAL ECONOMIC IMPACTS OF THE SOLUTIONS

Some economic aspects were analysed in the Portuguese FlexHub demonstration only with respect to reactive power provision and to active power provision. The costs of reactive power provision depend on the assets and were found to be low. The observed bidding prices ranged approximately between 1.2 and 2.7 €/ Mvar (over a year of observation). In the specific case of this demonstrator, results show a larger usage of reactive power flexibility by the DSO to balance its grid than by the TSOs to operate its own. Considering the low marginal cost of providing the services and the values obtained for this particular demonstrator grid, a low impact on the whole systems costs can be expected.

With respect to the provision of active power, the bidding price estimation of assets has been done qualitatively. Only renewable generation, demand response and storage were considered.

1.2.2 ABILITY OF THE SOLUTION IN MEETING SYSTEM OPERATORS' TECHNICAL NEEDS WITH RESPECT TO FLEXIBILITY SERVICE PROVISION

The compliance to the TSO's requirements of flexibility services provision was studied in all three demonstrations. Different aspects were analysed such as i) the accuracy of the state estimation and the reduction of curtailment in the German demo, ii) the tracking error and the increase in flexibility service provision capability in the Italian demo, and iii) the tracking error and the increment of active or reactive power flexibility for the network operators in the FlexHub demonstration. The system operators'needs were met with a good accuracy in all cases and no specific problem was highlighted by these KPIs.

1.2.3 IMPACTS ON THE POWER SYSTEM AND IN PARTICULAR ON THE DISTRIBUTION GRID WHERE CONGESTION MUST BE AVOIDED WHEN PROVIDING FLEXIBILITY SERVICES FROM DISTRIBUTED RESOURCES

Some impacts on the power system have been assessed, in particular on the distribution grid where congestion must be avoided when providing flexibility services from distributed resources. Various indicators were calculated depending on the demo: i) the grid losses reduction (Germany); ii) the hosting capacity increase (Italy); iii) the network secure operation margins while delivering active or reactive power (Italy, Portuguese FlexHub, Germany). It was found that the network secure operation margins (voltage profiles) were respected while delivering active or reactive power. The German demo achieved a significant grid losses reduction compensating the incurred costs.

1.2.4 ACCURACY OF THE FLEXIBILITY SERVICES PROVIDED AT THE TSO/DSO INTERFACE.

This aspect was addressed in the German demo only. Two different tools have been developed (IEE.NetOpt and PQ-Maps) to help scheduling preventive and corrective measures in congestion management and voltage control. Both approaches show good results in accuracy. The IEE.NetOpt tool is currently in line with the requirements of today's regulatory framework in Germany whereas, the PQ-Maps tool cannot be used in daily operation because the German regulation requires for schedule-based congestion management (redispatch) the segregated lists of available active and reactive power flexibilities at the DSO-TSO interface. This needed function is not integrated in PQ-Maps yet.

1.2.5 RELIABILITY AND AVAILABILITY OF THE SERVICES PROVIDED OR OF SUB-SYSTEMS (FORECAST, COMMUNICATION INFRASTRUCTURE).

The reliability and the availability of the sub-systems (forecast, communication infrastructure) have been studied in Germany with respect to the forecast quality and in Portugal with respect to execution times observed for the Q-Market clearing process and the TLQ process.

No specific problem was highlighted by the demo results. However, in the case of Portugal, the grid-size dependence of execution times would need further attention.

1.3 DATA EXCHANGE DEMONSTRATION

The KPIs of the Data Exchange demonstrations are of a different nature than those of the other EU-SysFlex demonstrations. The latter are generally oriented towards the flexibility providers or the System operators whereas the fomer are IT-related. The development and implementation of the BUCs and SUCs were successful and no specific problem was highlighted by the KPIs.

2. INTRODUCTION

The H2020 European project EU-SysFlex aims at demonstrating innovative flexible solutions for the electrical system and at studying the large-scale deployment of flexibility considering the integration of more than 50% RES at the horizon 2030. These flexibility solutions include technical options, system control and data transfer enhancement.

The Work Package 10 of the European project EU-SysFlex has several main objectives, the main one being the elaboration of a roadmap of flexibility for Europe (D10.5). The roadmap is fed by all results of the project and in particular by other studies carried out in WP10 such as the definition of Key Performance Indicators (D10.1) for the demonstrations, and a Technical Energy Analysis assessing the KPI results (D10.2) which is the aim of this very report. Within this Work Package, Task T10.1.1 dealt with the identification of the Key Performance Indicators for the demonstrations. Its main output is deliverable D10.1 – *Report on the selection of KPIs for the demonstrations* which contained KPI definitions and formulas that enabled their evaluation in Task T10.1.2 – *Technical Energy Analysis*. Based on these KPIs, data have been collected during the course of each demonstration and assessments have been done to highlight the successes, identify potential improvements and the lessons learned of the developed innovation.

A tentative use of the ETIP-SNET framework for defining the KPIs was done at the beginning of the EU-SysFlex project and helped produce a preliminary list of KPIs after 6 months. However, this approach turned out to be too general and difficult to use by the demonstration leaders. Therefore, decision was made to adopt a bottom-up approach and to define demo-related KPIs that are specific to each demonstration and were are aiming at proving the success of the services trialled, qualify their performance and reliability and were defined using a bottom-up approach. The approach followed several steps. First of all, a structured template was created for defining each KPI and providing a calculation methodology. A typology of KPIs was then proposed in order to classify the KPIs into main categories and identify those common to several demos:

1. Local economic impacts of the solutions. These are impacts such as the increase in revenue for the flexibility provider, the decrease in cost for flexibility service provision;
2. Ability of the solution in meeting system operators' technical needs with respect to flexibility service provision (frequency regulation, voltage control, congestion management, …);
3. Impacts on the power system and in particular on the distribution grid where congestion must be avoided when providing flexibility services from distributed resources:
4. Market aspects;
5. Reliability and the availability of the services provided;
6. Reliability and the availability of sub-systems (forecast, communication infrastructure);
7. Customers' acceptance in the Finnish demo;
8. Data exchange KPIs.

The entire list of KPIs is give in Annexes 1 to 7 along with their descriptions and formulas.

In section 3, the KPI results are presented in detail, demonstration per demonstration. Conclusions are given in section 4 demo per demo and then per KPI category.

3. EVALUATION OF EU-SYSFLEX DEMO-RELATED KPIS

The detailed evaluation of all proposed EU-SysFlex KPIs is described in this section. As mentioned previously, these indicators are specific to each demonstration. They have been defined in Deliverable D10.1 *Report on selection of KPIs for the demonstrations* and sometimes have evolved during the course of the project to make them more relevant to the actual trials.

The final reports of the demonstration (see §12.1) give an exhaustive view of the field tests, off-line simulations, and KPIs assessment. The following sub-sections give a detailed synthesis of the results, demonstration per demonstration, and KPI per KPI.

3.1 FINLAND: AGGREGATION OF DISTRIBUTED ASSETS

3.1.1 DESCRIPTION OF THE DEMONSTRATION

In the Finnish demonstration, located in Helsinki, small distributed assets in LV and MV networks were aggregated and operated to the TSO's reserve markets (FCR-N, FCR-D, mFRR) and for the DSO's reactive power compensation needs to stay within the limits of the PQ-window. The TSO's reserve market operations included forming forecasting and optimization of the assets, constructing communication channels as well as control logics from the aggregation platform to the different flexibility assets and similarly communication from the aggregation platform to TSO's markets. The proof-of-concept reactive power market included constructing communication and control logics to reactive power assets.

The demonstrator was composed of six sub-demonstrations (Figure 1):

- five active power demonstration:
  - one industrial-scale BESS operated on the FCR-N market,
  - one medium-scale BESS operated on the FCR-N market,
  - aggregation of small-scale residential batteries for the FCR-N market
  - aggregation of EV-chargers aiming at participating to the TSO's FCR-D market,
  - aggregation of electric heating loads via AMR control in order to offer bids to the mFRR market
- one reactive power demonstration comprising an industrial-scale BESS, a PV plant and its inverters

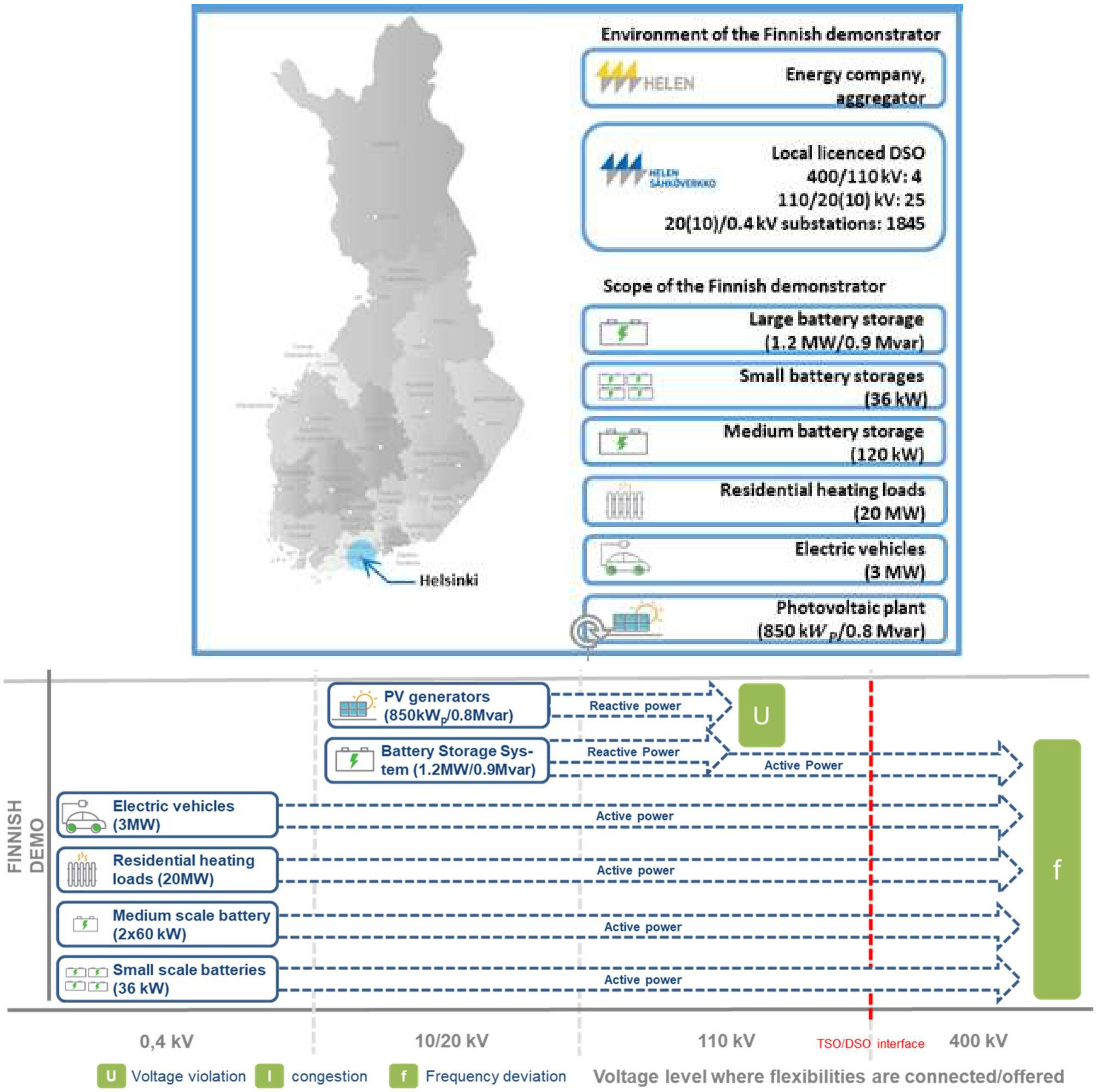


FIGURE 1: ENVIRONMENT AND SCOPE OF THE FINNISH DEMONSTRATION

In the demonstration, four different commercial aggregation platforms were tested (Figure 2). One of the platforms (DEMS) was already in use prior to EU-SysFlex and one of them (Virta Energy platform) was in use by Virta Ltd. The two other platforms (DES and IoT platform) were pre-existing prior to the project and taken into further development during the project.

- The industrial-scale 1.2 MW/0.6 MWh BESS was connected to the MV grid and controlled with a single aggregation platform (DEMS).
- One set of EV-charging stations were controlled by the Virta Energy Platform and a single charge point by an IoT platform as a proof of concept.
- The customer-scale battery was controlled with a DES aggregation platform which required several integrations to a vendor cloud.

- The office-scale BESS as well as the PV power plant were controlled by the IoT platform

The main objectives of aggregation platforms were the ability to add new assets to the platform and to control the attached assets according to the use cases. The IoT platform turned out to be the most successful and the aggregated assets connected to the platform could be operated as a virtual power plant (VPP).

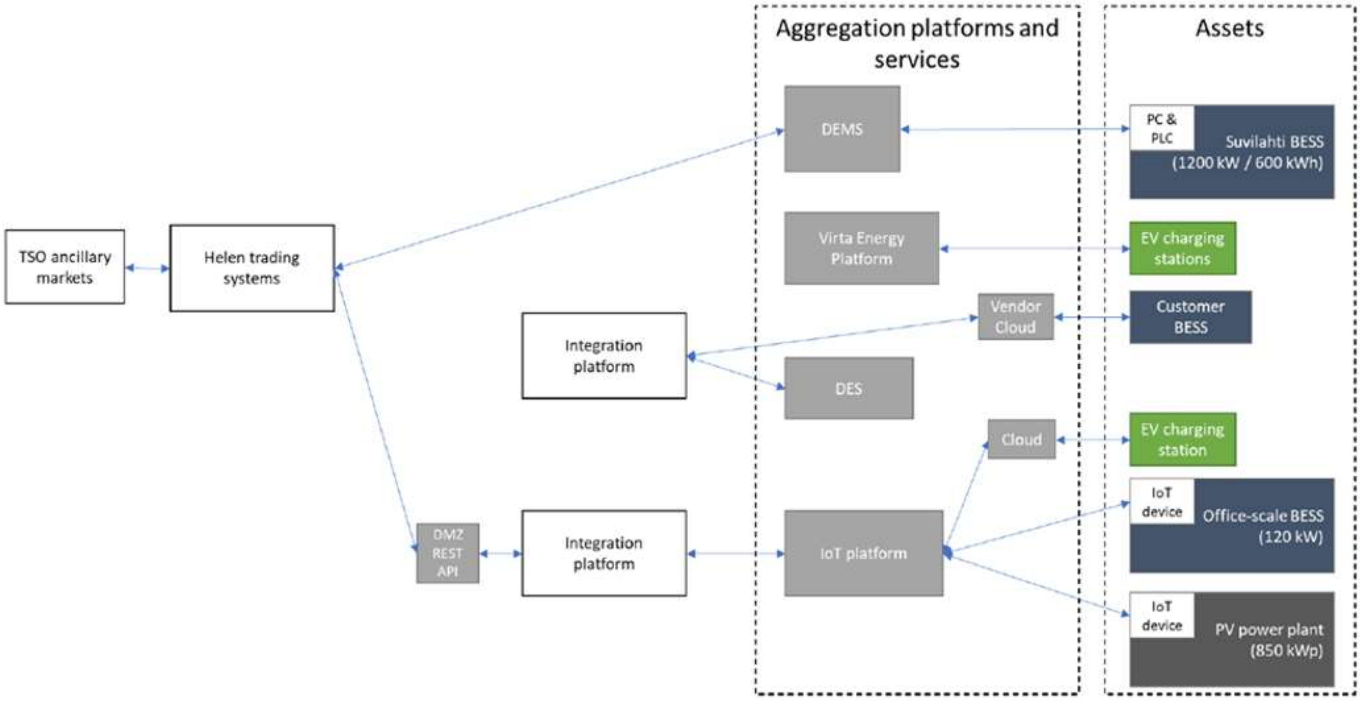


FIGURE 2: OVERVIEW OF THE DEVELOPMENT AND INTERFACES IN THE FINNISH DEMONSTRATION

The initial KPIs of the Finnish demonstrator were described in Deliverable D10.1 Report on selection of KPIs for the demonstrations. They have been slightly updated during the EU-SysFlex project by adding two additional KPIs: Usability of the asset (KPI #5b) and Profits of service provision (KPI #7). All KPIs are described in Annex 1:

- KPI #1: Increase in revenue of the flexibility service provider
- KPI #2: Decrease in penalties for going out of the PQ window
- KPI #3: Reactive power market utilization factor
- KPI #4: Flexibility service reliability
- KPI #5a: Reliability of the aggregation platform
- KPI #5b: Usability of the asset
- KPI #6: Customer acceptance
- KPI #7: Profits of service provision (revenues of service provision-costs of service provision)

The estimation of the KPIs is detailed in the final report of the demo (D6.9). The following sections summarize the main conclusions.

3.1.2 INDUSTRIAL-SCALE BESS - ACTIVE POWER (KPI #1, #4, #5B, #7)

An industrial-scale 1.2 MW / 0.6 MWh BESS (Figure 3) was connected to the MV grid. During the project, a set of forecasting/optimization tools were developed to estimate the available flexibility of the LV/MV assets for providing ancillary services to the TSO. At the beginning of 2019, Helen started to operate successfully this BESS in the Finnish FCR-N market. In terms of KPIs, the key results are the following:

- The increase in revenue for the service provider is rather good. It is about 45184 €/year when providing 0.5 MW to the FCR-N market,
- The earned net profit was 22259 €/year (2023 €/month) and could even have been greater had the aggregation platform not failed in the end of the year.
- The availability of the asset was 94,8% which was not as high as expected as the BESS had several failures due to poor design and programming. However, the downtime did not significantly affect the revenues and profits gained except when the BESS malfunctioned at the end of December.

FIGURE 3: INDUSTRIAL-SCALE 1.2 MW/0.6 MWH BESS USED IN THE FINNISH DEMO

3.1.3 MEDIUM-SCALE BESS - ACTIVE POWER (KPI #1 #5B, #7)

A medium-scale 120 kW / 136 kWh BESS (Figure 4) was located at an office building (LV). During the project, communication systems, control and optimization logics were successfully developed for multi-use of the BESS. There was also the need to develop a trading integrating system from the IoT platform to Helen's trading systems in order to operate in the FCR markets. The BESS was successfully operated in the FCR-N market where it followed accurately the frequency changes (FIGURE 5). It was also used for shaving the demand peak of the local office and for reactive power compensation.

Key Results:

- the aggregation (IoT) platform proved to be very reliable (99,32 %)
- The usability of the asset was excellent (99,47 %)
- the increase in revenue was rather small (7609 €/year) due to the BESS size.

As regards the reliability of the service, the RMSE for the test period was 0.0239 MW which represents approximately 24 % of the offered capacity. This is significantly better than with the industrial scale BESS and can be explained by several factors. First the power to energy capacity ratio is smaller and thus the BESS can deliver nominal power for a longer time and in addition a smart state of charge optimization function is enabled with the office scale BESS. The SOC optimization can be implemented to the industrial scale BESS with some system changes.

FIGURE 4: MEDIUM-SCALE 120 KW / 136 KWH BESS LOCATED IN AN OFFICE BUIDING

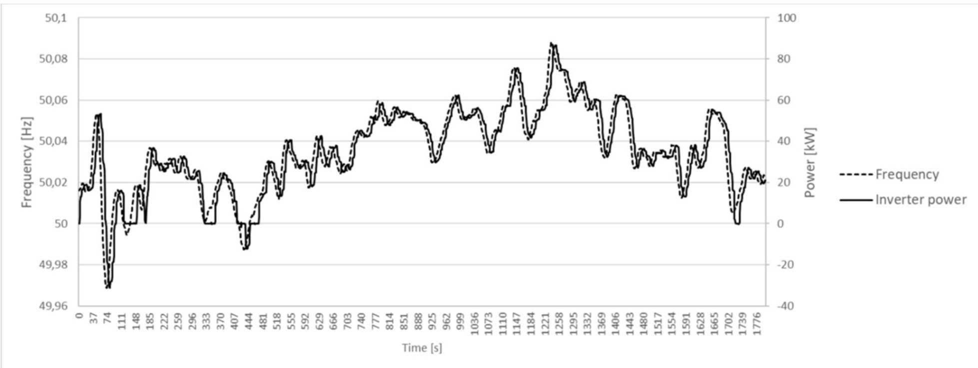


FIGURE 5: MEDIUM-SCAL BESS PERFORMANCE IN THE FCR-N MARKET

In the Finnish demonstration, the office scale BESS was used for FCR-N, peak shaving and also reactive power compensation. In real-life solutions, this multi-use also means agreements between the stakeholders. The agreements were not in the scope of this research.

3.1.4 SMALL-SCALE BESS - ACTIVE POWER (KPI #1, #5A, #6, #7)

This sub-demonstration was about the aggregation of residential small-scale batteries ranging from 1.5 kW to 5.5 kW with an average of 3 kW and owned by thirteen residential customers.

Controlling individual small assets was technically hard because it involved many steps as the BESSs were controlled via a vendor cloud and through an integration platform. As a result, the aggregation platform used with customer scale BESS had major issues as it was at an early development stage and the demo failed the requirements for the FCR-N market (Reliability of the aggregation platform was only 39,7%).

In addition, the demonstration was not profitable for customers (maximum customer profits amounted to 62 €/year) and the flexibility service provider since the main use of the batteries was peak shaving of a PV system production and therefore they could only be used in winter, when the PV output was low. The total operating hours was only 2160 h.

Customer-scale BESSs could nevetheless provide ancillary services in the future as more robust control systems and greater value for service is realised.

Currently the customer scale BESSs owners are forerunners as the BESS prices have been high and financial benefits are unclear. So far only a few customers have purchased a BESS with their PV system. Helen's customers were contacted and discussed a possibility to participate in the demonstration. However, the contracts made with the customers already had a term where Helen could use the BESS for demonstrating distributed assets. All of the customers accepted to participate and thus the acceptance of customer scale battery demo was 100 %.

Key Results

- Reliability of the aggregation platform: 39,7%
- Customer profits max: 62 €/year

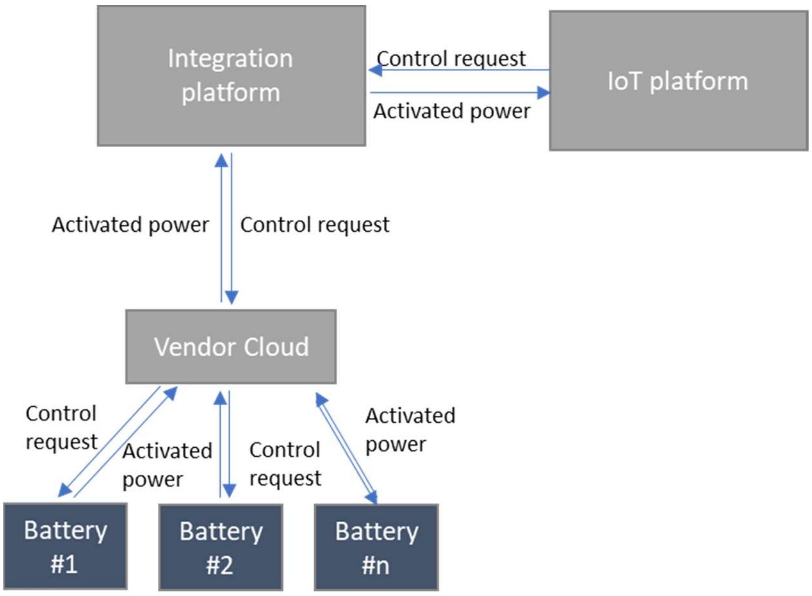


FIGURE 6: CONTROL OF SMALL-SCALE BESS FOR PARTICIPATION TO THE FCR-N MARKET

3.1.5 EV CHARGING - ACTIVE POWER (KPI #1 #5B, #7)

Another active power demonstration comprised eight AC EV-chargers 22 kW each and one 50 kW DC fast charger that were to participate to the Finnish FCR-D market. However, in 2019, the average charging power of Helen's public chargers was 70 kW (peak 200 kW) and that was not enough to comply with the 1 MW minimum bid to the FCR-D market. Therefore, the participation was only simulated.

The results show that using the EV-chargers for reducing power load can be done efficiently and precisely. Combining the power reduction capabilities and the forecast showed that excess power with the charges is required to fullfill the forecast errors. In addition, the results show that the current system that is in use is not capable enough to meet the strict requirements of the FCR-D market (requirement < 5 s from frequency change). While the communication delays from the controller platform were found to be too long in the existing system, in the different EV charging controlling tests these delays were found to be negligeable (< 2 s) between charge point and EV.

As of 2019, the calculated increase in revenue corresponding to the 70-kW capacity of EV-chargers was 3066 €/year (i.e. 43800 €/year for a 1-MW capacity)

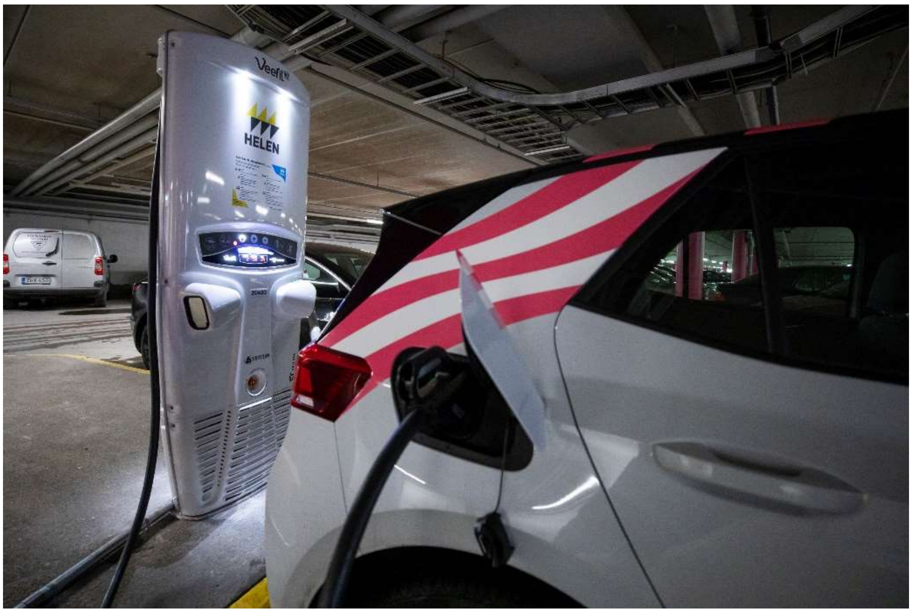


FIGURE 7: EV-CHARGERS PARTICIPATING THE THE FCR-D MARKET

As regards the reliability of the service, the RMSE for the test period was 1.151MW which underlines the problems faced with the system during the tests.

3.1.6 ELECTRIC HEATING LOADS VIA AMR CONTROL - ACTIVE POWER (KPI #1 #4, #5A)

The last active power sub-demontration was about aggregating electric storage heating loads (i.e. hot water tank as a storage) of residential single houses controlled by DSO’s owned AMR meters (Automatic Meter Reading) in order for the aggregator to offer bids to the TSO’s mFRR market. The demonstration’s main contribution was the further developed forecast of the controllable electricity storage heating load via AMR meters.

A simulation of the potential benefits from the mFRR market has been performed for 727 customers.

The tests were performed with the first generation AMR meters and systems revealed that the time limits of the mFRR market were not reachable for a high amount of simultaneously operated AMR meters. The second generation AMR meters and systems could bring a solution for this requirement.

Moreover, the economic benefits for aggregators (increase in revenue of ~77.5 €/year/load) and customers (profits of ~32 €/year/customer) were simulated showing only modest benefits from the mFRR market which may compromise future developments. The costs for the DSO were not included in those calculations.

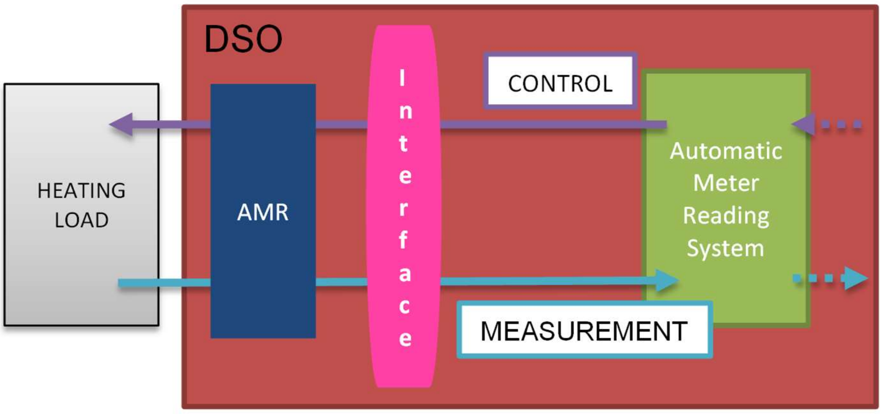


FIGURE 8: AGGREGATION OF RESIDENTIAL HEATING LOADS

3.1.7 REACTIVE POWER MARKET DEMONSTRATION (KPI #2, #3, #4, #5B)

A reactive power market was demonstrated as a technical proof-of-concept. In the demonstration, the reactive power assets were : a 0.8 Mvar solar PV inverter and an industrial-scale 0.9 Mvar BESS.

- In the demonstration, the distributed assets of BESS and PV plant were operated according to the reactive power market needs and this operational part was successful. During the demonstration, the availability of the assets was 99.75 %, however the reactive power market utilization factor was only 27 %. As a matter of fact, the demonstration revealed that in the specific Helsinki case and the demonstration period, the amount of additional reactive power from the market depends strongly on the time (season, weekday, hour). For example, in Helsinki, the market would have been in operation during a few months of the year hence the low utilization factor.
- Regarding the reliability of the service provided, in the calculation of RMSE, the realized compensation is compared to the targeted compensation value. This RMSE value does not take into account whether the realized compensation was above or below the target value knowing that whenever the realized reactive power compensation is smaller than the target value, then penalties would occur for the aggregator and asset owner. The penalties would then be calculated according to the amount of the failure of delivery and the aggregator/asset owner would pay that amount. Therefore, the RMSE as such does not tell about the success of the service provision. An additional KPI (hours of full delivery) is defined in order to show the amount of hours that were 100 % successfully delivered. When removing the effect of an error caused by a fault situation of the BESS on 31st May, the compensation service provision of both assets was found to be reliable (RMSE =6.28 kvar, Hours of full delivery=93.5%).
- For the demonstrated simulation period, the DSO reached some savings. Compared to the operation of the assets in the established TSO's markets with business opportunities the economic benefits from the reactive power markets were unrealistic. At this stage creating a totally new market is not seen economically viable.
- One of the aims was for the DSO to respect its PQ parameters at the TSO/DSO connection point without penalties when utilizing via the market the aggregator's operated, aggregated, distributed, small reactive power assets. The operation of such a reactive power market could – in the specific Helsinki case and the

demonstration period - allow a decrease in possible penalties for going out of local PQ-window as high as 16 %.

It was seen that the excessive high amount of assets could create a market saturation thus creating uncertainty to the future prospects of such a market. At least, for the near future, in the case of Helsinki, partly arisen from the characteristics of the local city distribution network, a local reactive power market is not realistic.

3.2 PORTUGAL: VPP

3.2.1 DESCRIPTION OF THE DEMONSTRATION

The Virtual Power Plant (VPP) is a concept of joint operation control of multiple power production units. The demonstration was located in the north of Portugal and consisted in a VPP coordinated by a market agent to provide flexibility from centralized resources, including pump storage plants (PSP) and wind power plants connected to the transmission level, and providing frequency regulation (aFRR) and balancing reserves (mFRR/RR).
The resources used for the VPP demo comprised of a Variable Speed Hydro Power Plant 756 MW (2 x 378 MW), Venda Nova III, and two nearby Wind Farms (115 MW from 57 turbines & 50 MW from 25 turbines), the Alto da Coutada WF and the Falperra WF, as shown in Figure 9.

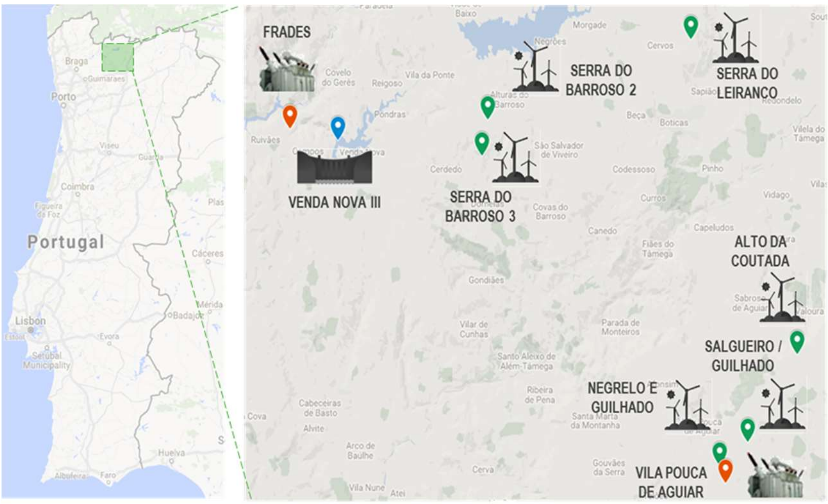


FIGURE 9: DEMO SITE 1 – RESOURCE LOCATION

The demonstration aimed at developing a power dispatch optimizer that would support a new balancing area concept, help decrease the imbalances via the participation of RES in energy markets, maximize the profit in Wind Parks operation by reducing O&M expenses and therefore increase the revenue brought about by using a VPP, as opposed to the individual operation of the units. To reach these objectives, the forecasts accuracy of price and resource availability had to be increased.
Two business cases have been defined for the VPP, corresponding to the provision of the following services:

- **Provision of aFRR**
    - The VPP can offer its generation bandwidth on the aFRR day-ahead market;
    - This service is currently done by the hydro power plant, Venda Nova III.
- **Provision of mFRR/RR**

- VPP offers the resources on the RR day-ahead and intra-day market;
- It will be a combined offer done for the VPP owned resources;
- TSO requests the activation of the resource.

The VPP core provides support for the bidding decisions on the wholesale market (day-ahead/intraday), ancillary services market (aFRR and mFRR/RR) as well as on the continuous trading (XBID).

Six KPIs had been defined at the beginning of the EU-SysFlex project (see D10.1) in order to analyse the behaviour of the Portuguese VPP demonstration. This list has evolved during the project. Only four KPIs have been considered and three of them have assessed. These KPIs are listed here-after and are described in more detail in Annex 5:

- KPI #1: Increase in revenue of the flexibility service provider (Overall economic performance of delivery via a VPP)
- KPI #3: Variation in the imbalances in participation of RES in energy markets
- KPI #4: Market price forecasts quality
- KPI #5: Quality of forecasts of available Renewable Energy Sources (RES) power and water level of pumped storage plants

To analyze and visualize the results, a KPI dashboard has been created so that the user can get an overview of the indicators (Figure 10): Traded Energy per market, Traded Reserve, Revenue, Imbalances, Imbalance Costs, Fractions of traded capacity per market (bid/bought/sold) and Produced energy per plant in VPP.
All KPIs can be calculated on user-chosen dynamic time buckets: year/month/week/day/hour.

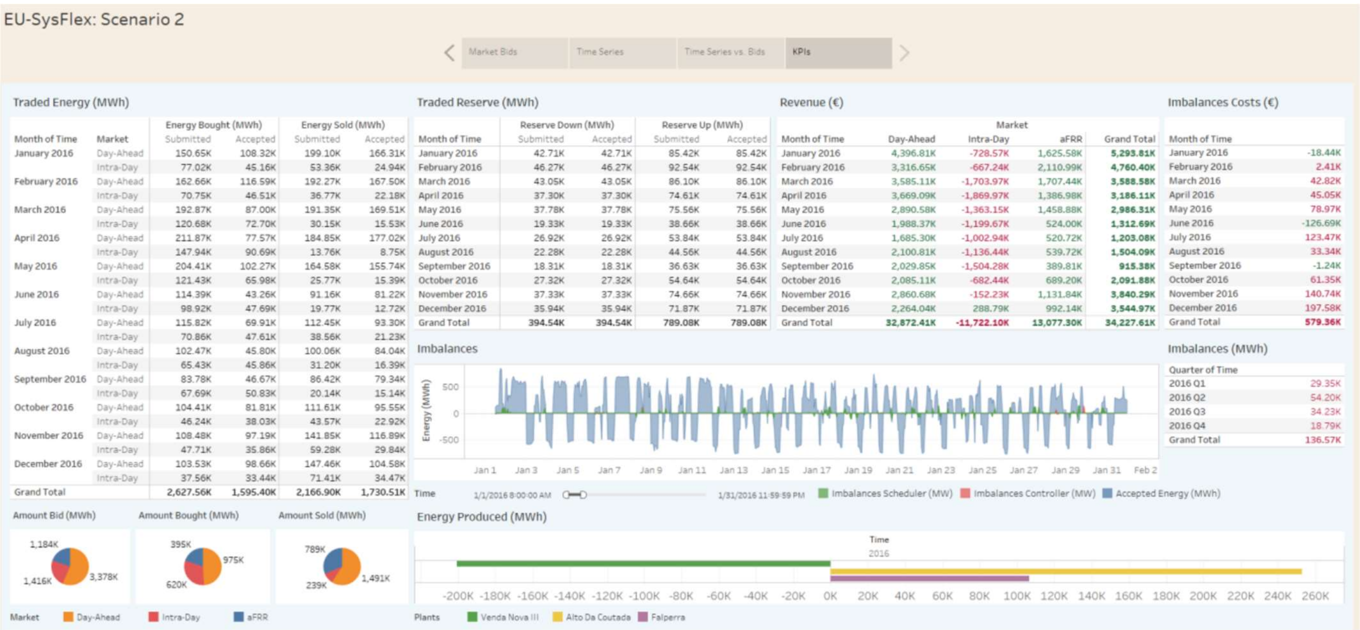


FIGURE 10: KPIS DASHBOARD

The KPIs' results are described in detail in the final report of the demonstration (D7.6). What follows is a summary of the main conclusions.

3.2.2 ECONOMIC EVALUATION (KPI 1 AND KPI 3)

Offline testing have been carried out in order to prepare the online demonstration and evaluate all economic KPIs (KPI #1, #3). The offline set-up gave the possibility to explore several different components, forecast and market situations, for selected offline scenarios as specified in the following Table 1 and which mainly differ in two aspects: the components which form the virtual power plant and the underlying predictions.

TABLE 1: OFFLINE DEMONSTRATION - SCENARIOS OVERVIEW

Name	Number	Components	Predictions	Comments
Single Assets	**1**	Venda Nova III (PHS), Falperra (WF) and Alto da Coutada (WF)	Expert Model	Individual bidding of PHS and WFs. PHS in Scenario 1a, WFs in 1b.
VPP Approach	**2**	Venda Nova III (PHS), Falperra (WF) and Alto da Coutada (WF)	Expert Model	Aggregated offer with realistic forecasts. VPP consists of PHS and WFs
Perfect Forecast	**10**	Venda Nova III (PHS), Falperra (WF) and Alto da Coutada (WF)	Perfect	Aggregated offer with ideal forecasts only for Wind and market prices in Scenario 10a and ideal forecast only for Wind in Scenario 10b. VPP consists of PHS and WFs.

The results of the economic KPIs are summarized in Table 2 for single assets and VPP biddings on the wholesale market (day-ahead, intraday) and the aFRR reserve market:

TABLE 2: OFFLINE SCENARIOS – KPIS

Scenario	Scenario Description	Net Profit Energy [M€]	Net Profit Reserve [M€]	Profit Sum [M€]	Imbalances [GWh]	Imbalance Penalties [k€]
1a	VNIII	11.79	1.75	13.54	55.7	429.9
1b	WPs	11.42	0	11.42	39.1	396.9
1	Sum of VNIII + WPs	23.21	1.75	**24.96**	**84.8**	**826.8**
2	VPP	23.49	1.88	**25.37**	**69.4**	**515.1**
10a	Perfect forecast only RES	23.61	1.86	**25.47**	**52.1**	**360.3**
10b	Perfect forecast	31.69	2.21	**33.9**	**10.8**	**90.8**

The VPP approach (scenario 2) showed a ~2% overall profit sum increase compared to the sum of revenues from the single assets (scenarios 1a/1b which correspond to individual bidding of the PHS for 1a, and the wind parks for 1b). It should be emphasized, that in Scenario 1a, VNIII PHS has already been handled with optimization for market participation and power dispatching. Therefore, in a combined VPP scenario the only lever is reduction of

imbalances from renewable generation (which also requires some capacity reserve of the pumped hydro storage that immediately affects revenue from market participation of standalone VNIII).
The simulation showed that in the VPP approach the imbalances could be reduced by ~18% and imbalance costs even by ~38% by intelligent forecast.
Scenario 10 was executed to get some baseline of how well the market participation and dispatch optimization algorithms of the VPP prototype performed for this use case and to evaluate the impact of forecast quality.

- For Scenario 10a with perfect forecast for wind power, there is only a marginal increase of overall profit sum of ~0.5% compared to Scenario 2. The imbalances could be further reduced by another ~20% from Scenario 1 in comparison to Scenario 2 (with further imbalance penalty decrease of ~19%).
- For Scenario 10b with perfect forecast for both wind power generation and market prices, there is a significant overall profit increase of ~35%. This shows that improvements in market price forecasts and market bidding optimization (handling of uncertainties and market bidding strategies) could be the biggest levers to further improve performance of the presented VPP control prototype.

3.2.3 MARKET PRICE FORECASTS QUALITY (KPI 4)

Several algorithms have been developed concerning market buying and selling price forecasts (day-ahead, intraday and aFRR). Four different methods, as collected in Table 3, have been considered:

TABLE 3: MARKET PRICE FORECASTING METHODS

Number	Name	Comment
1	Perfect	Exact prices from the future
2	Expert Model	Linear regression models of Ziel and Weron (2018)
3	Similar Day	Same values as known values of previous day
4	Hour of Week	Repeated average weekly values of years 2014 - 2017

- “Perfect” forecasts refer to the hypothetical and ideal situation, where the forecasts could exactly predict the future,
- “Expert Model” forecasts predict future price values by a linear combination of selected passed values,
- “Similar Day” forecasts are obtained by repeating the values obtained 24 hours ago if predictions more than 24 hours into the future are needed,
- “Hour of Week” forecasts are obtained by dividing the historical time series in the years 2014 to 2017 into weeks, averaging these partial time series and using them as forecast for a value in a future time t, by looking up the corresponding average values for the given hour of the week to which it belongs.

An assessment of KPI 4 (Market price forecast quality) is given in Figure 11 for day-ahead market prices and in Figure 12 for aFRR reserve market prices. Both figures deal with the forecast quality in the concerned bidding period, which are the hours of the following day.

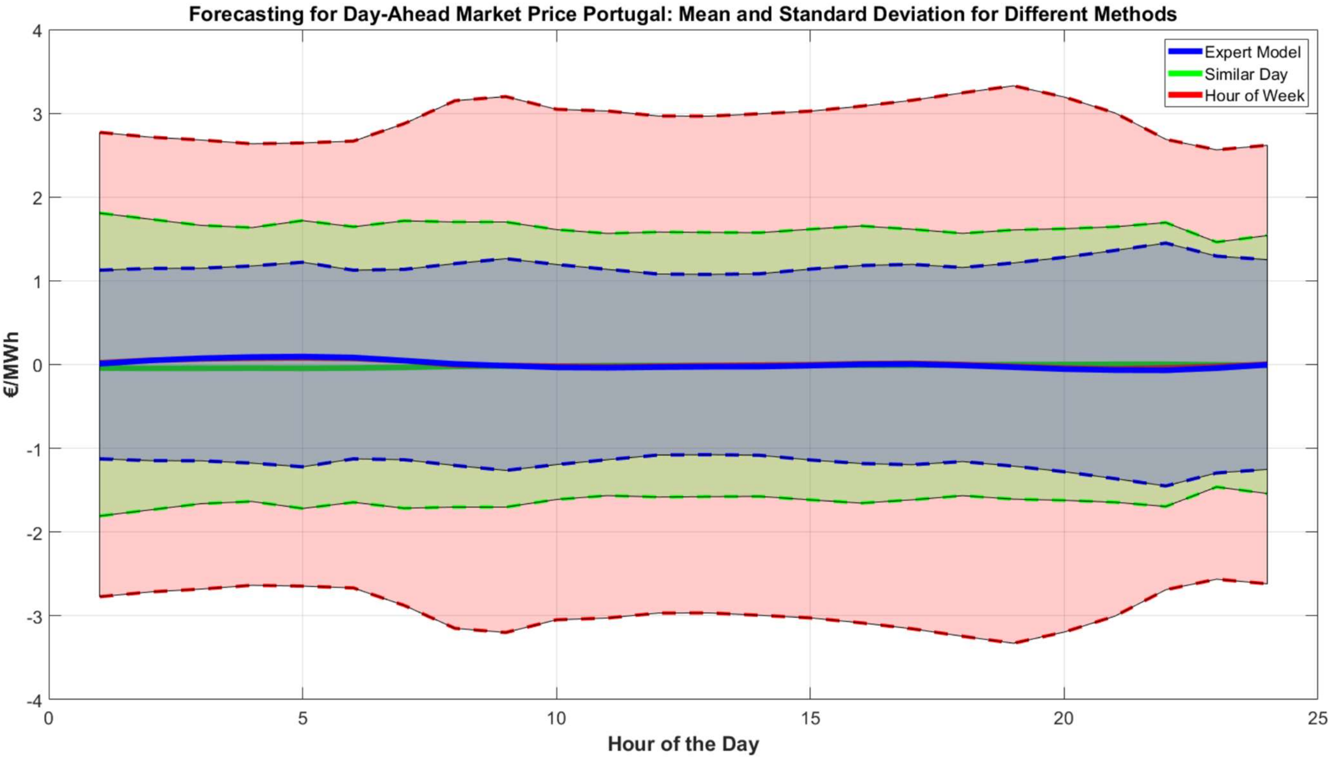


FIGURE 11: FORECAST DAY-AHEAD ENERGY PRICE PORTUGAL

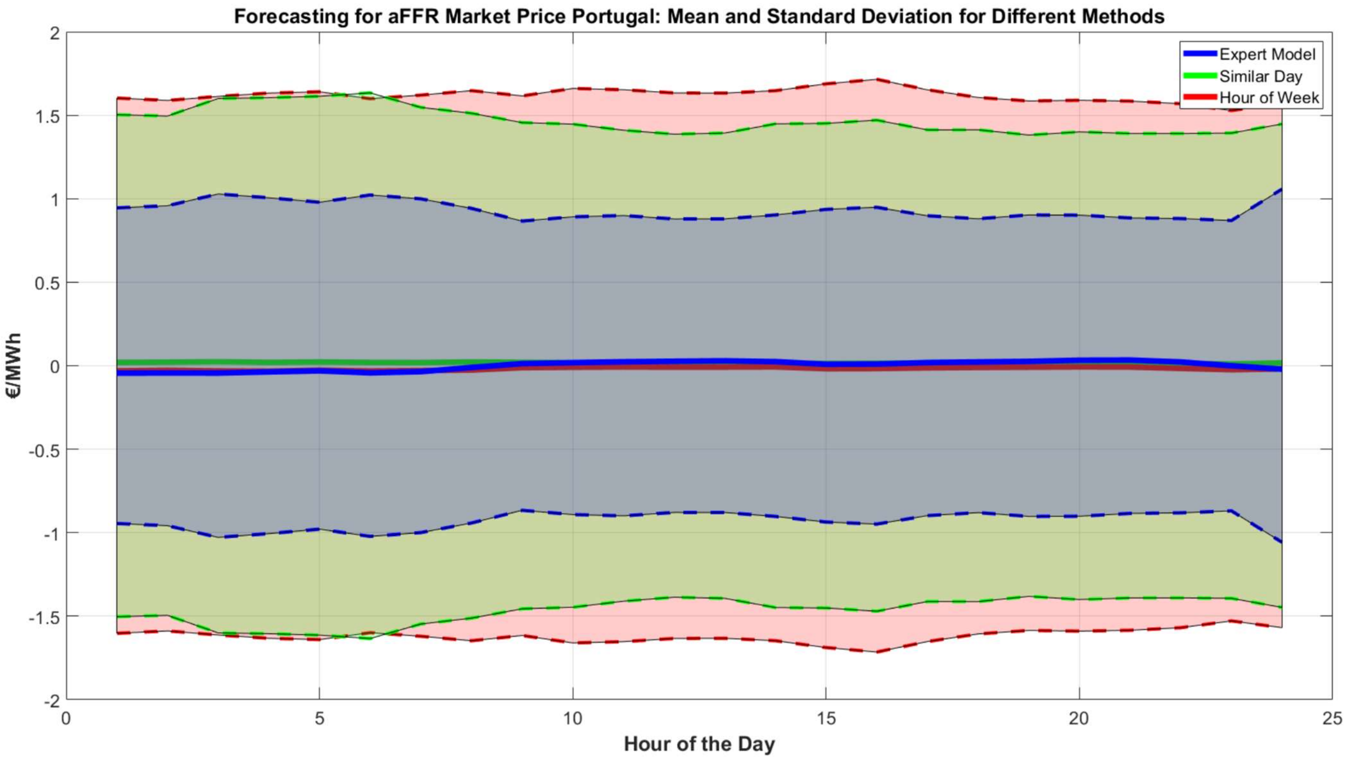


FIGURE 12: FORECAST AFRR PRICE PORTUGAL

- The middle lines in these figures represent the average deviation from the true value (= “Perfect” forecast) over the bidding periods in the simulated year 2016. This shows that **averaged over an entire year all forecast methods are unbiased**.
- The dotted lines and colored areas depict the standard deviation. Here we see clear differences: **The “Expert Model” has a much smaller variance than the other two in both considered markets**.

The results are similar for the intraday market.

3.2.4 QUALITY OF FORECASTS OF AVAILABLE RENEWABLE ENERGY SOURCES (RES) POWER AND WATER LEVEL OF PUMPED STORAGE PLANTS (KPI 5)

Forecasts of available renewable power (wind farms and photovoltaic systems) rely on weather forecasts particularly concerning wind speeds (and to a lesser extend directions) and solar irradiation. Unfortunately, it was not possible to obtain the needed historic forecasts for the relevant components considered in the offline scenarios. In absence of such forecasts, precise statements could not be made about KPI 5 (Quality of forecasts of available Renewable Energy Sources (RES) power). In general, these forecast heavily rely on the input weather forecast quality. Due to missing input data for water inflows into reservoirs, forecasting of water level of pumped storage plants was not done either.

3.3 FRANCE: VPP

3.3.1 DESCRIPTION OF THE DEMONSTRATION

The purpose of the French demonstration of the EU-SysFlex project was to test the concept of multi-resources aggregation for multi-services provision. A decentralized multi-resources VPP containing wind and PV generation as well as a battery energy storage system (BESS) has been built at a scale of several MW and operated over a long period. The main objectives of this demonstration were:

- To demonstrate the technical feasibility to perform an optimal and coordinated control of wind turbines, PV panels and storage as a VPP to provide system services to the transmission system operator;
- To analyze the performance of the system services that can be provided by the VPP and to assess the contribution of the aggregator to the enhancement of system security and flexibility.

The main facilities and testing assets for the French demonstration are shown in Figure 13. This VPP was composed of a 12-MW wind farm, a 2-MW / 3-MWh battery storage and photovoltaic panels and is mainly implemented at EDF privately owned Concept Grid (CG), apart from the wind farm being at a remote location and connected to the French public distribution grid.

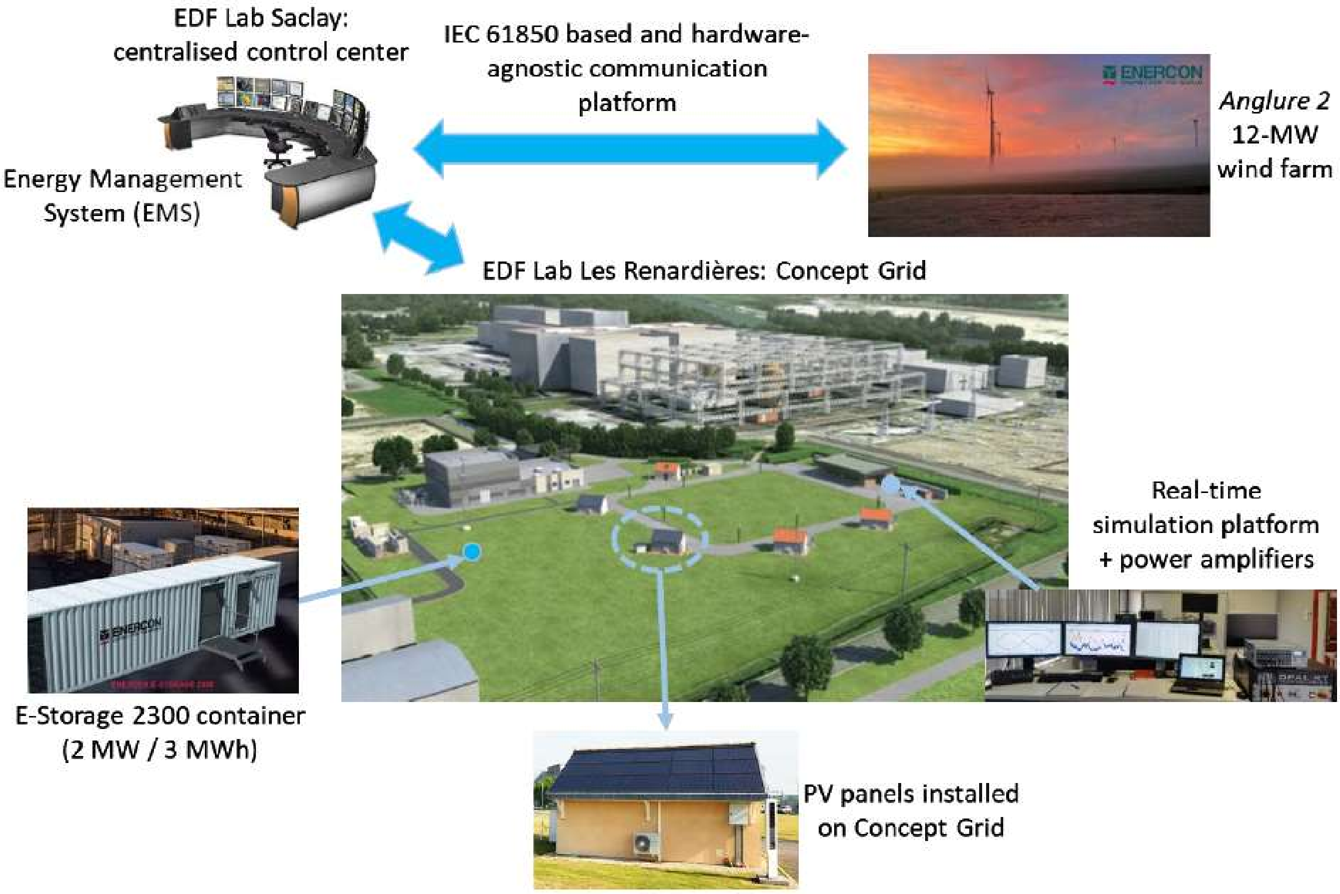


FIGURE 13: MEANS AND FACILITIES OF THE MULTI-RESOURCES MULTI-SERVICES DEMONSTRATION

Within the demonstration, the following flexibility services have been provided either simultaneously or consecutively depending on their compatibility:

- Manage VPP active power flexibility to support Fast Frequency Response (FFR), FCR and a-FRR at the TSO/DSO connection point;
- Manage VPP active power flexibility to perform ramp-rate control and peak shaving;
- Perform energy arbitrage.

The initial KPIs of the French demonstrator were described in Deliverable D10.1 *Report on selection of KPIs for the demonstrations*. Most of them have been adapted to the work progress and deal exclusively with the provision of FCR since the focus of the demonstration was on frequency services even if flexibility solutions such as ramp rate control (RRC) were successfully demonstrated. All evaluated KPIs are described in Annex 2.

- KPI #1: Increase in revenue of the VPP by providing multi-services
- KPI #2: Increase in revenue of the VPP by allocating reserve on multi-resources
- KPI #3: Reduction in power imbalances by application of stochastic optimization
- KPI #4: Compliance of the assessed FCR gain with the TSO’s requirement
- KPI #5: Availability of the reserved power capacity for FCR provision
- KPI #6: Reliability of the communication platform

These KPIs can be grouped in three main categories:

- Economic impacts of the demonstration (KPI #1 to #3),
- Compliance to System Operators (SO)' technical needs in terms of flexibility services provision (KPI #4 and #5),
- Reliability of the solutions implemented (KPI #6).

Economic KPIs measuring the global performance of the VPP in terms of revenues should normally be assessed over a sufficiently long operating period in order to be representative and conclusive. For the sake of cost and time savings, these KPIs were evaluated through offline simulations of the full VPP operation over 5 continuous weeks.

To further assess the dynamic behavior of the VPP when it was completely operated, three technical KPIs have been defined: two of them for measuring the compliance of the frequency service provided by the VPP with the requirements of the TSO; and one for evaluating the reliability of the IEC-61850-based communication platform. These KPIs were assessed by post-processing the experimental results of all 7 full-chain tests (with a total duration of 31 hours).

The evaluation of the KPIs is detailed in the final report of the demo (D8.4). The following sections summarize the main conclusions.

3.3.2 INCREASE IN REVENUE OF THE VPP BY PROVIDING MULTI-SERVICES (KPI 1)

The first economic KPI aims to assess whether the participation of the VPP in the FCR market could bring an additional gain, compared with the traditional management strategy of performing energy arbitrage only in the Spot market. The offline simulations showed that the provision of FCR in addition to energy arbitrage makes the VPP revenue increase by 7% on average. Indeed, while performing energy arbitrage, the BESS is used mainly when prices are at the lowest (for charging from renewable energies) or the highest (for discharging). For the remaining period, the battery is only a bit charged to counter the effect of loss of energy for FCR provision or discharged to reduce the impact of forecast errors and imbalance penalties. Therefore, it is economically interesting for the VPP to provide the FCR service when energy prices are not extreme, as the BESS is largely available during this period of time. Although its charging and discharging capacities cannot be fully mobilized while participating in FCR , it still turns out to be a good compromise.

One arguable issue is that the participation in FCR leads to an additional uncertainty on the SoC level, which could sometimes prevent the VPP from respecting its commitment in the Spot market. However, the simulation results tend to show that the gain from the FCR provision is higher than the penalties generated by this uncertainty. Note that in any case, larger uncertainties related to forecast errors are always present in the VPP management.

3.3.3 INCREASE IN REVENUE OF THE VPP BY ALLOCATING RESERVE ON MULTI-RESOURCES (KPI 2)

The second KPI aims at assessing whether the participation of both the wind farm and the storage in FCR would help increase the global revenue of the VPP, compared to the case where only a single unit is used to provide this service. Two cases have been considered:

- **The frequency containment reserve is allocated on the wind farm only (the storage is just used for energy arbitrage)**. In this case, there is the same increase in revenue as that for KPI°1. Indeed, when a symmetric reserve should be procured totally from the wind farm, the VPP is almost never positioned in the FCR market, as if the only service activated were the energy arbitrage. This is because the provision of upward reserve by the wind farm implies significant curtailment of its generation, leading to important shortfalls for energy sales in the Spot market, which can almost never be compensated by the FCR participation. Generally, to find an economic interest for the VPP to provide the FCR in this case, the price of the service should be at least at the same level as the daily peak-to-valley height of the Spot price.

- **Both the wind farm and the storage provide FCR and all the reserve is allocated on the storage only**. It has been found that there is a slight decrease in revenue (-0.35%) in this case. This decrease does not seem intuitively understandable – one of the possible explanations could be the inaccuracy of the BESS model considered by the VPP scheduling. Indeed, this simplified model was initially built based on the assumption that the FCR response is always symmetrical and could not precisely describe the evolution of the SoC while the BESS is providing asymmetric reserves.

In conclusion, the assessment of the second KPI reveal that it is beneficial to have a joint participation of the wind farm and the storage in FCR provision when they are available. Along with the result of the first KPI, the economic interest of the French demonstration, based on the approach of “multi-services provision by multi-resources”, has been proven.

3.3.4 REDUCTION IN POWER IMBALANCES BY APPLICATION OF STOCHASTIC OPTIMIZATION (KPI 3)

This KPI aims to analyse the interest of a program scheduling based on stochastic optimization for the VPP management, with a focus on the mitigation of power imbalances. It has been assessed by simulating energy arbitrage of the VPP over 5 weeks with different scheduling approaches. It has been revealed that more than 4% of negative power imbalances can be mitigated when the stochastic optimization is applied (IMB = -4.5%). As a consequence, it also helps increase slightly the VPP actual revenue of 0.25% in the end.
From the VPP operation point of view, a VPP operating program scheduling based on stochastic optimization has been proven effective to reduce costly power imbalances with respect to the commitments and entails higher overall revenues.

3.3.5 COMPLIANCE OF THE ASSESSED FCR GAIN WITH THE TSO’S REQUIREMENT (KPI 4)

This KPI is dedicated to verifying whether the actual gain of the VPP while offering the FCR service is compliant with the requirement of the TSO. To obtain the FCR certification, the full reserve must be activated in less than 30 seconds (full activation time criterion) and held for at least 15 minutes if the frequency deviation remains at 200 mHz. For the French VPP, these criterion have been partially verified through the local tests focusing on the FCR provided by individual resources. It should be noted that the holding time of 15 minutes, which can be easily assured by conventional power plants and well-sized batteries, seems complicated to be guaranteed for the reserve provided by renewables.
Table 4 gives on overview of the percentage of time during which the assessed FCR gain of the VPP conformed to the required quality level (CSP), evaluated for each test. The overall CSP for the total duration of all tests is about 53%, lower than the expected performance (90%).

TABLE 4: ASSESSED PERCENTAGE OF TIME OF "COMPLIANT FCR" (IN TERMS OF FCR GAIN)

Test n°	*Date*	*Duration*	*CSP*
1	Oct. 20, 2021	5h	59%
2	Oct. 21, 2021	1h45	10%
3	Oct. 22, 2021	8h	69%
4	Oct. 28, 2021	7h	43%
5	Oct. 29, 2021	2h15	69%
6	Dec. 9, 2021	4h30	44%
7	Dec. 9, 2021	2h30	50%
Assessed CSP for the total duration of the tests			53%

One has to keep in mind in analysing this KPI that the assessment has been performed by analysing the experimental results of a VPP demonstration carried out at a reduced scale. The precision of the forecasts and the available active power (AAP) estimation will be considerably improved for an up-scaled VPP and the performance of the FCR response procured from such a VPP will be largely enhanced at the power system perimeter.

Another point regards the impact of the symmetry of wind reserve on the performance of the FCR service. The demonstration has shown that the FCR performance of a wind farm in terms of the regulation gain seems to be higher when it provides symmetric reserve rather than only downward reserve. However, this results inevitably in more energy losses for reserve constitution.

Moreover, it is important to point out that due to its variable (and unpredictable) nature, the frequency reserve provided by renewable generation could not be as "accurate" as that offered by a battery storage. The actual FCR response of the VPP as a function of the grid frequency, for the test performed on Oct. 22, is illustrated in Figure 14. The underfrequency responses (corresponding to the delivery of upward reserve mainly allocated on the BESS) complied more precisely with the expected regulation than the overfrequency responses (corresponding to the delivery of downward reserve mainly provided by the wind farm). Hence, it can be concluded that the use of the storage capacity enhances the overall technical performance of the frequency service procured from the VPP.

Finally, note also that the method applied to assess the actual gain of the FCR response was originally designed and employed by the TSO for measuring the compliance of conventional power plants. It is therefore questionable whether this method is appropriate to assess the effectiveness of the FCR provided by variable resources.

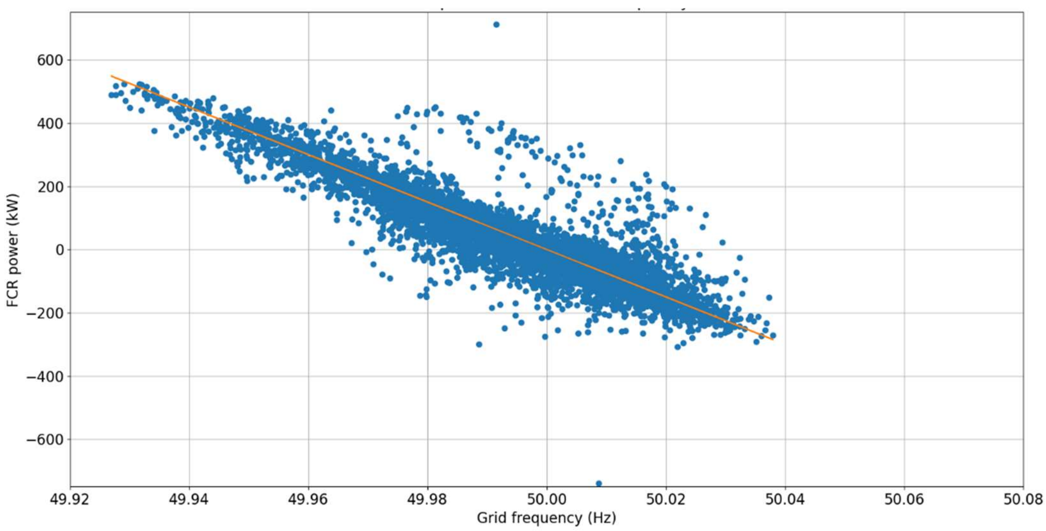


FIGURE 14: FCR RESPONSE OF THE VPP AS A FUNCTION OF GRID FREQUENCY (TEST ON OCT. 22)

3.3.6 AVAILABILITY OF THE RESERVED POWER CAPACITY FOR FCR PROVISION (KPI 5)

This KPI aims at assessing whether the committed FCR of the VPP is fully available when the extreme values of the grid frequency are reached during the frequency regulation.

Table 5 lists the assessed FCR availability for each full-chain experiment performed. It was found that on average, the FCR procured from the VPP was fully available during 64% of the total test time.

The availability of the FCR is quite dependent on the quality of the forecasts as well as on the wind generation level. Note that this availability can be improved, as the wind minimum operating point was not modelled in the Operational Planning Scheduler (OPS) for real tests. This parameter should have been considered in the scheduling phase, which would help increase the overall availability to at least 74% by post-processing the experimental data.

TABLE 5: ASSESSED PERCENTAGE OF TIME OF "FULL AVAILABLE FCR"

Test n°	*Date*	*Duration*	*ARP*
1	Oct. 20, 2021	5h	100%
2	Oct. 21, 2021	1h45	100%
3	Oct. 22, 2021	8h	34%
4	Oct. 28, 2021	7h	17%
5	Oct. 29, 2021	2h15	100%
6	Dec. 9, 2021	4h30	100%
7	Dec. 9, 2021	2h30	99.6%
Assessed ARP (availability of Reserve Power)			64%

As previously mentioned, one possible way to avoid the lack of FCR due to forecast errors is to take an additional power margin while scheduling (which will also result in additional costs). Another solution consists in reallocating a part of the committed wind reserve on the BESS, within the limits of available stocks, by activating the corresponding function of the STC control layer.

3.3.7 RELIABILITY OF THE COMMUNICATION PLATFORM (KPI 6)

The last KPI of the demonstration is dedicated to measuring the reliability of the applied communication and IT platform, which is one of the most important subsystems of the VPP, especially for the control and monitoring of the remote distributed assets. This KPI has been assessed by calculating the percentage of time during which all the necessary data exchanges for VPP operation were correctly ensured by the platform for all tests performed.

The calculated overall availability of the whole ICT (Information and Communication Technology) infrastructure and interface (*AVC)* equals to 99.7%, meaning that **the implemented VPP communication platform, based on *GeneSys* solution developed by EDF R&D, is highly reliable most of the time during normal operation**. As a reminder, from the perspective of replicability and scalability of the demonstration, *GeneSys* solution also allows a simple and standardized integration of new components in the management portfolio of the VPP. However, note that there were still some software instabilities which required sometimes to restart *GeneSys* before a test to ensure its proper functioning during the test. This can be further improved in the next versions of the solution for industrial applications.

3.4 GERMANY

3.4.1 DESCRIPTION OF THE DEMONSTRATION

The German demonstration aimed at demonstrating the provision of active and reactive power flexibility range to the TSO (50Hertz) from decentralized resources connected to the HV distribution grid of MITNETZ STROM to support congestion management and voltage control at the interface grid node with the transmission system in a system with a high share of RES. It also included functionalities to make this distributed flexibility available for the TSO without putting the DSO grid operation at risk.

The portion of distribution grid considered in the demo includes over 30 retailers with more than 1.500 generation units and comprises 17 TSO/DSO interfaces with 46 transformers and around 400 HV/MV substations, thereof over 100 infeed of RES only. The main innovations of the demonstration consisted in:

- co-optimising the grid in active and reactive power management using scheduled grid asset utilisation, and forecasted infeed and load data;
- automating the conversion of the optimisation result into a control signal sent to generation sites for reactive power management purposes;
- integrating RES in a schedule-based congestion management process.

This implied:

- **Forecasting P and Q** by providing specific load profiles for each grid node: For a precise forecast, specific grid information will be needed (geographic coordination of generation sites, weather forecast, installed capacity of generation, historical measurements of load and generation).
- **Improving data management and transfer between DSO and TSO** to increase observability. This means dealing with the process of receiving data, translating data formats and sending data to calculation modules.

- **Performing losses optimization for congestion management and local voltage control in the distribution grid**: The tasks of congestion management and voltage control in the distribution grid is executed even when no demand of TSO is received. This optimization becomes a subordinated condition if the TSO sends a demand for active or reactive power. The executed optimisation always considers n-1 cases to ensure reliability of supply.
- **Enabling Provision of Active Power by the DSO to the TSO for congestion management**. The coordination process starts day ahead and ends intraday 2 hours before activation of flexibility.
- **Enabling Provision of Reactive Power by the DSO to the TSO**. In this case, a coordination is needed to prevent voltage failure in the DSO-grid due to the activation of the flexibility. The coordination process starts day ahead and ends with the activation of flexibility via sending an operation signal by DSO.

Eleven KPIs had been defined at the beginning of the EU-SysFlex project (see D10.1) in order to analyse the successes and failures of the German demonstration. These KPIs have been significantly modified along the project (some have been added, some of the them have not been assessed. The original KPIs are given in Annex 4. The updated KPIs are listed here-after:

- KPI #1: Active power flow forecast quality
- KPI #2: Processing duration of the forecast chain
- KPI #3: Accuracy of the state estimation
- KPI #4: Reduction of curtailment
- KPI #5: Active and reactive power flexibilities at the TSO/DSO interface
- KPI #6: Increase in efficiency of grid operation

The estimation of the KPIs is detailed in the final report of the demo (D6.7). They have evolved during the project and not all of the initial KPIs have been quantified. The following sections summarize the main conclusions. The German demonstration has not only have proven the feasibility of the concept, but has also shown the benefits of DSO-TSO coordination and combined optimisation of active and reactive power flexibilities.

3.4.2 QUALITY OF THE INTRADAY AND DAY-AHEAD FORECAST (KPI #1)

A forecasting system was implemented which forecasts the individual generators and loads on the busbars or transformers at the MV/HV level for a period of up to a maximum of 48 hours into the following days. For that purpose, it takes into account the configuration of the underlying MV grid. A detailed description of the complete forecasting system can be found in Deliverable 6.2 of the EU-SysFlex project.
Two KPIs can be seen as relevant to qualify the forecast quality:

- Quality of Forecast – Intraday: Evaluation of the forecast quality (KPI 11).
- Quality of Forecast - Day Ahead: Evaluation of the forecast quality (KPI 10).

Because it is a direct input into the schedule-based congestion management and voltage control, the accuracy of forecast determines the accuracy of the optimisation results. To produce trustable results, a trustable forecast is key:

- The PV forecast was significantly improved by post-processing. This can be seen very well in the reduction of nRMSE, as well as a massive reduction of the bias.
- The wind forecast already showed a respectable quality at the beginning and could experience a slight improvement of the nRMSE in the intraday area with an adjusted power curve. In the wind forecast, the mean bias was almost completely eliminated with the adjusted power curve.

The results are summarised in Table 6 for the nRMSE and in Table 7 for the bias.

TABLE 6: OVERVIEW OF THE ACHIEVED NRMSE VALUES WITH THE BASELINE AND THE IMPROVED FORECAST

nRMSE	Intra-Day		Day-Ahead	
	Base	Improved	Base	Improved
PV	20.3%	15.4%	20.6%	16.3%
Wind	15.8%	15.2%	16.1%	16.3%

TABLE 7: OVERVIEW OF THE ACHIEVED BIAS VALUES WITH THE BASELINE AND THE IMPROVED FORECAST

Bias	Intra-Day		Day-Ahead	
	Base	Improved	Base	Improved
PV	-13.3%	-3.8%	-13.0 %	-3.4%
Wind	-4.2%	0.8%	-3.7%	-0.2%

3.4.3 PROCESSING DURATION OF THE FORECAST (KPI #2)

This KPI deals with the processing time of the forecast chain, e.g. the time span of wall clock time and the delivery time of the forecast to the DSO. The forecast chain consists of several individual modules, which are responsible for converting data, generating forecasts for wind and PV, combining forecasts from different forecast runs, exporting and uploading them to the target server. The PV and wind lines can be executed in parallel, which can be seen in the following flow chart (see Figure 15).

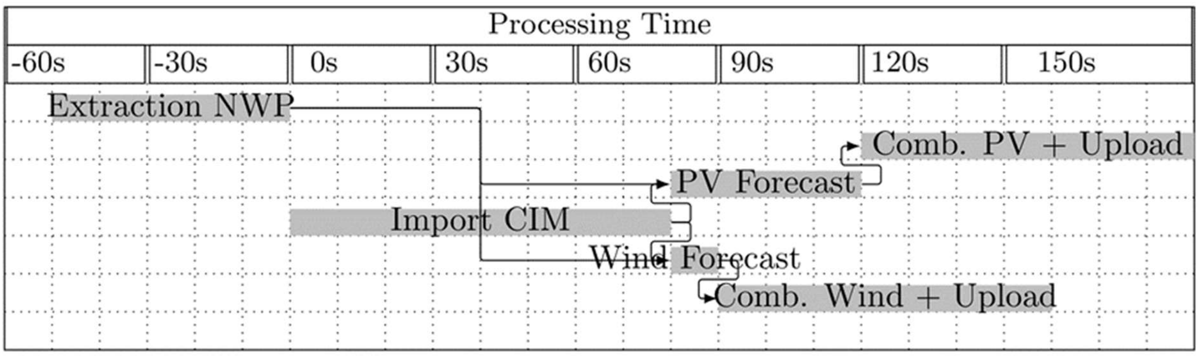


FIGURE 15: TIME DIAGRAM OF THE PROCESSES AND CALLS OF THE INDIVIDUAL MODULES IN THE WIND AND PV FORECAST CHAIN. EACH GRID CELL CORRESPONDS TO 10 SECONDS. THE START TIME IS RELATED TO THE WALL CLOCK TIME WHEN THE FORECASTING SYSTEM STARTS CALCULATING

According to the time diagram, the processing duration of the forecast for the entire chain was 3 minutes 10 seconds which is a very good result slightly above the targeted three minutes: The processing for the PV forecast needed 1 minute and 50 seconds whereas the processing for the wind forecast branch needed 1 minute and 20 seconds. Unfortunately, much of the valuable time was used for retrieving and importing the CIM data. Here, at the moment, no potential for any optimisation can be seen. The processing time of the forecast chain could easily be optimised so that it lies within the specified limits.

3.4.4 ACCURACY OF THE STATE ESTIMATION (KPIS #3)

The accuracy of the state estimation is key. The demonstration showed that the accuracy of active power estimation is higher than of reactive power estimation (see Figure 16 in the case of Pulgar).

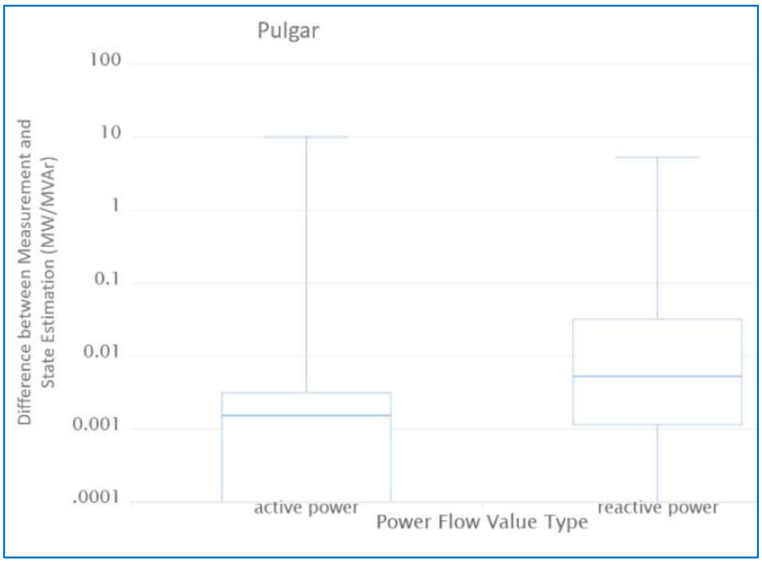


FIGURE 16: ACTIVE AND REACTIVE POWER DEVIATIONS OF MEASURED AND ESTIMATED VALUES IN ONE OF THE FOUR GRID REGIONS OF MITNETZ STROM

As a matter of fact, the stronger non-linearity of reactive power results in higher deviation. Overall, the achieved accuracy is at the same level as the measurement error. Therefore, the developed state estimation tool meets the requirements. Together with deviation from forecasting, the horizon of schedule-based voltage control has to be chosen carefully. It also influences the achievable efficiency of preventive redispatch. Because of the interdependencies of active and reactive power management, grid operation needs to consider these uncertainties.

3.4.5 REDUCTION OF CURTAILMENT (KPI #4)

The maximum of needed capacity to be activated as flexibility is reduced by the German demonstration. Curtailment has been reduced in all investigated cases. Figure 17 shows that, for maximum capacity, the reduction varies from 0 % (close to the benchmark) to 90 % (open dot as extreme value in the box-plot). On the figure, the benchmark of 100% represents the old curtailment regime. However, in some cases the period of flexibility need could be longer. Since settlement is out of scope of the German demonstration, the precise quantification of curtailed energy is not feasible. This indicates further need of investigation. It was not foreseen in project planning.

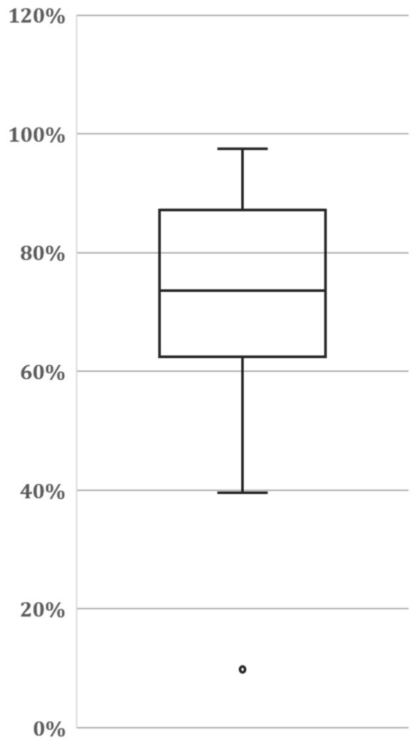


FIGURE 17: REDUCTION IN CURTAILMENT (100% REPRESENTS THE OLD CURTAILMENT REGIME)

3.4.6 ACTIVE AND REACTIVE POWER FLEXIBILITIES AT THE TSO/DSO INTERFACE (KPI #5)

Within the German demonstration, two different tools have been developed to help scheduling preventive and corrective measures in congestion management and voltage control:

- One tool, the IEE.NetOpt, was developed by Fraunhofer IEE and tested under operational conditions in the grid control centre of the DSO MITNETZ STROM. This tool supports the decision-making process of the operator in preventing congestions and voltage issues via a security constrained optimal power flow calculation. The tool is in line with the requirements of today's regulatory framework. That means a function is integrated that computes and generates segregated lists of available active and reactive power flexibilities at the DSO-TSO interface (see Figure 18) as well as the values that aggregated set points can handle at these interfaces (see Figure 19). With this, the TSO has all the data needed as input for its own congestion management to calculate the best option to prevent contingencies with the activation of flexibility in the distribution grid without putting at risk the distribution grid stability.

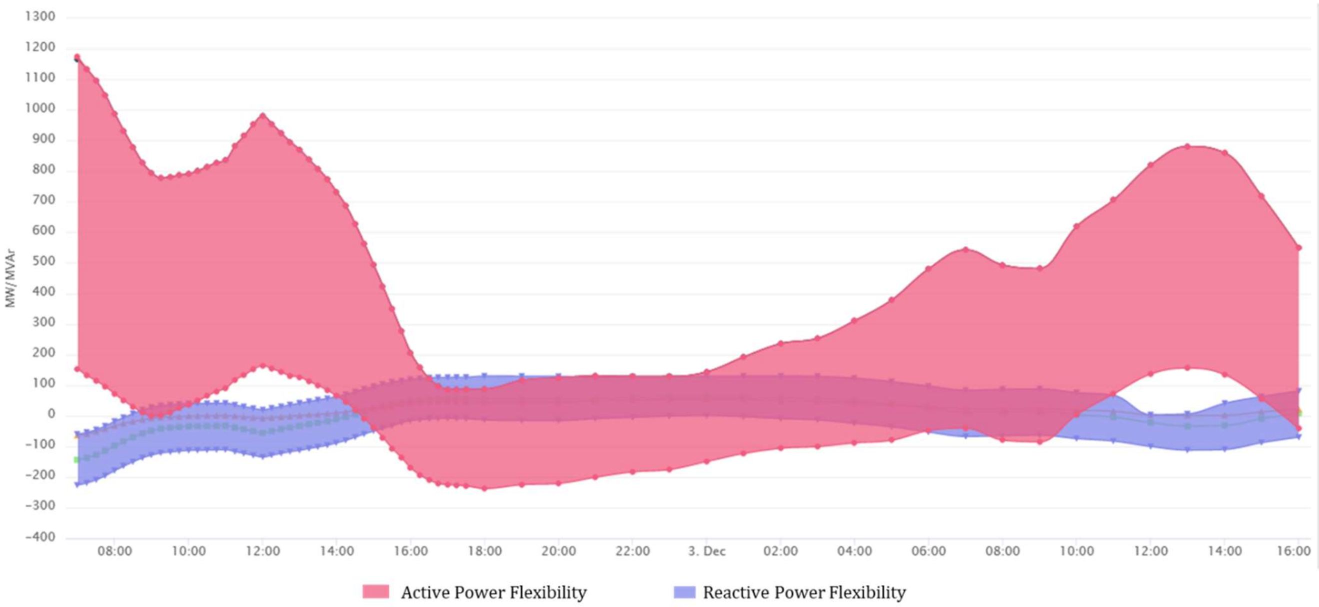


FIGURE 18: ACTIVE AND REACTIVE POWER FLEXIBILITIES AT THE DSO-TSO INTERFACE (IEE.NETOPT OUTPUT)

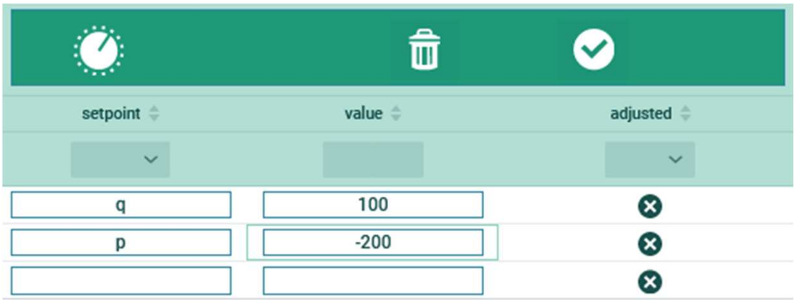


FIGURE 19: USER INTERFACE TO INSERT SET POINTS (IEE.NETOPT)

- The second tool of the German demonstration focuses even stronger on the interdependencies of active and reactive power management at the DSO-TSO interfaces. The PQ-Maps tool was developed by INESC TEC and tested with a partial grid of MITNETZ STROM. This tool predicts the joint active and reactive power ranges that can be exchanged at the DSO-TSO interfaces while using the available flexibility resources connected to the distribution network without compromising its operation (see Figure 20). PQ-Maps enhances the accuracy in the definition of contractual values of electrical energy exchange between transmission and distribution systems. Furthermore, PQ-Maps helps the DSO to avoid penalizations due to possible violations of power exchange defined by the TSO. Moreover, if the TSO has several DSO grid interconnection substations the tool performs the PQ-Maps for each interconnection enabling redistribution of the active and reactive power throughout the DSO-TSO interconnections. Currently, the tool cannot be used in daily operation because the German regulation requires for schedule-based congestion management (redispatch) the segregated lists of available active and reactive power flexibilities at the DSO-TSO interface. This needed function is not integrated in PQ-Maps yet.

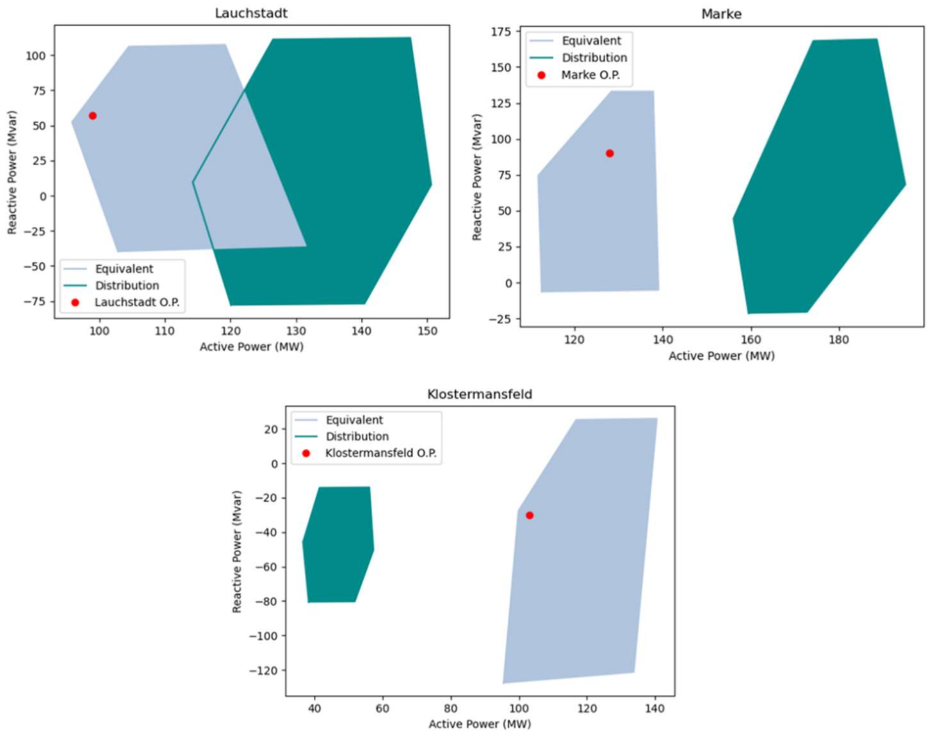


FIGURE 20: PQ-MAPS RESULTS

The PQ-Maps approach uses historical data instead of the transmission grid topology data as in IEE.NetOpt. If the DSO gets the data of the observability area of the transmission grid, IEE.NetOpt works with high accuracy. However, the disclosing information of the transmission grid data to DSO could give rise to confidentiality issues. If this data is not available, PQ-Maps can use equivalents of the transmission grid created from historical data. With this approach, the data from the observability area of the transmission grid is not needed, but the risk of low accuracy is higher if the historical data does not represent the transmission behaviour. If not enough historical data is available from the transmission grid, the resulting ranges of active and reactive powers at the DSO-TSO boundaries are not reliable. Taking this into account, the advantage of IEE.NetOpt in this case is that congestion management and voltage control in distribution grid are still manageable.

Both approaches show good results in accuracy. It is shown that the higher the input accuracy the better the results. These tools contribute to improve the observability in the high voltage distribution grid and partly in the underlying voltage levels.

3.4.7 INCREASE IN EFFICIENCY OF GRID OPERATION (KPI #6)

Since the optimisation algorithm needs a target and in the case where the external flexibility request is missing, the overall target of the optimisation of the German demonstration therefore is to reduce the grid losses. Yearly grid losses can be reduced with the developed IEE.NetOpt tool. Today's energy losses in the grid amount to approximately 155 GWh. When introducing the IEE.NetOpt tool into grid operation, not only the flexibility potential could be provided for TSO, but also grid losses could be reduced. The potential of reduction depends on available flexibility. Because the flexibility is provided by RES, the reduction potential is limited in times of bad weather conditions and therefore low infeed.

Depending on the available flexibility, German demonstration has shown (Figure 21) an average of 5 % grid losses reduction (up to 9 %).

Due to these reduced grid losses, costs for operating the innovative tools of the German demonstration are compensated. Therefore, grid users could participate in enhanced efficiency of grid by minimised grid connection fees. The savings, based on an electricity price of 50.79 €/MWh and approximately 5 % of grid losses, have been estimated in average at 410 000 € (Figure 21).

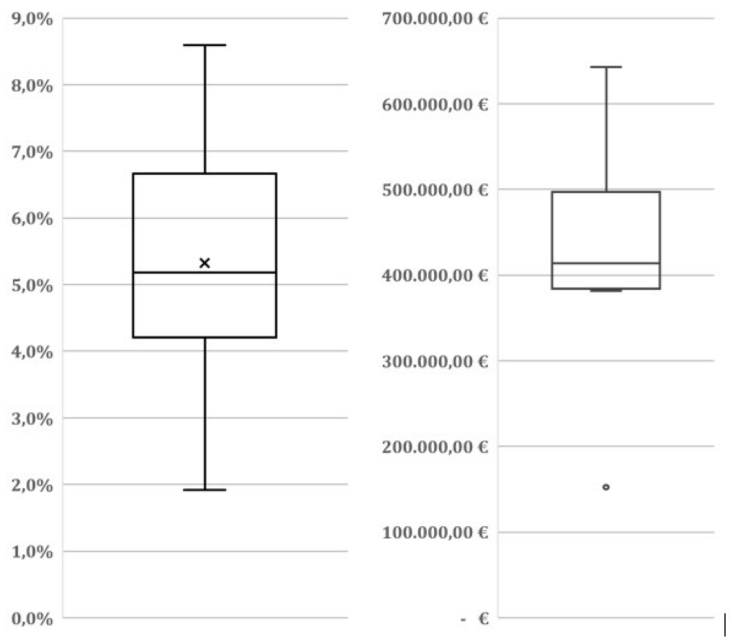


FIGURE 21: REDUCTION OF LOSSES AND RESULTING SAVINGS

3.5 ITALY

3.5.1 DESCRIPTION OF THE DEMONSTRATION

The Italian demonstration site was located in the area of Forlì-Cesena (Emilia Romagna) in an area which is characterized by a strong penetration of renewable generation (mainly PV) along with a low consumption (back-feeding phenomena from MV to HV observed several times). The aim of the demonstrator itself was to prove that e-distribuzione is able to implement an efficient solution in order to provide an aggregated information of network capability at its interface with the TSO (Primary Substation of the MW network) taking into account transmission grid and distribution network mutual needs and constraints. In addition to the previous benefits, the DSO can provide the TSO with a better observability of DERs making use of forecasting tools for an enhanced network state estimation and computation of reactive power capability, thus improving data exchanges between the two System Operators to guarantee safety in the operation of the electrical system.

The demonstration aimed at establishing the proof of concept for the provision of:

- active power flexibilities from the distribution grid to the Transmission Network Operator in real-time to support mFRR/RR and congestion management.

- reactive power flexibilities at Primary Substation interface for voltage control and congestion management in real-time (performed by the Distribution System Operator through suitable optimization processes, exploiting reactive power flexibilities connected to its network).

The main features of the demonstration included i) the improvement of data exchange between the DSO and TSO and of the forecasting system in order to increase the observability, ii) the modulation of active and reactive power at the Primary Substation in order to allow the TSO to guarantee the secure operation of the electrical system. Reactive power will be modulated by the DSO by means of different types of resources (STATCOM, inverters of PV plants) whereas the modulation of the Active Power will be simulated.

Prior to the beginning of the EU-SysFlex project, e-distribuzione implemented an advanced MV network control system onsite, which is used for local voltage and current control. The system carries out network state estimation automatically, optimisation calculations and sends control commands to the available resources, comprising the OLTC of the HV/MV transformer. The distributed resources that were used for the demonstration are composed of a 1 MVA/1 MWh storage system, 4 PV generators (which can be regulated in reactive power), an on-Load Tap Changer (OLTC) at the HV/MV substation, 2 STATCOMs (1 for each busbar). All are interfaced to the DSO SCADA, which includes a tool of state estimation that collects forecast data and network state information (Figure 22).

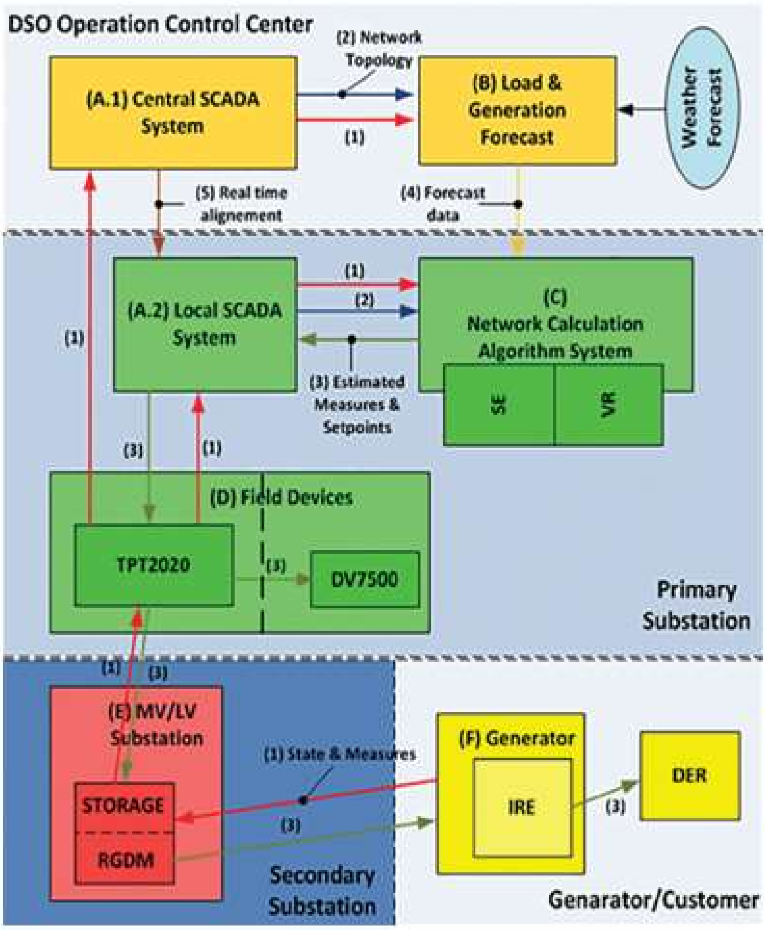


FIGURE 22: ARCHITECTURE OF THE ITALIAN DEMONSTRATION

The specific indicators that have been considered for evaluating the Italian Demonstrator efficient performance are related to the following parameters:

- **Analysis of the tracking error**, that is the resulting error between the requested Reactive Power Set-point and the measured one, at TSO-DSO interface as well as in relation to each employed resource, thus proving the effective implementation of the required set point;
- **Evaluation of the PV Forecast performances** which is mainly processed by taking into account the error of PV plants, expressed in kW, as the difference between the exchanged active power and the forecast of generated power based on weather forecast.
- **Estimate of the increase in reactive power capability at primary substation**.

The initial list of KPIs is given in Annex 3 (See D10.1: "The report on the selection of KPIs for the demonstrations"). This list has evolved during the project and not all KPIs have been kept. After the execution of the real field Demonstration tests, the following five KPIs have been evaluated:

- KPI #1: **Tracking error measured at TSO/DSO interface** [%]:

$$e_{TSO/DSO}(t) = \frac{|Q(t) - Q^*(t)|}{Q^*(t)}$$

- KPI #2: **Tracking error measured at DER interface** [%]:

$$e_{DER}(t) = \frac{|Q(t) - Q^*(t)|}{Q^*(t)}$$

- KPI #8: **Increase of Hosting Capacity at primary substation** [%]:

$$\Delta HC\% = \frac{HC_{SG} - HC_{base}}{HC_{base}} * 100\%$$

- KPI #6: **Increase of reactive power capability at primary substation** [%]:

$$\Delta C_{RP}\% = \frac{\sum_t (\Delta Q_{SG} - \Delta Q_{base})}{\sum_t \Delta Q_{SG}} * 100\%$$

- KPI #7: **Line Voltage profile** [%]:

$$\Delta V(t) = |V^*(t) - 1|$$

Where:

$$V^*(t) = \frac{V(t)}{V_n}$$

A detailed description of the KPIs results obtained by the Italian demonstration is given in deliverable D6.8. A summary of the results is given here-after.

3.5.2 TRACKING ERROR MEASURED AT TSO/DSO INTERFACE (KPI #1)

The tracking error (resulting error between the requested Reactive Power Set-point and the measured one) measured at the TSO/DSO interface should be calculated assuming to receive a command from the TSO in order to support the HV side voltage regulation. The field tests have been performed by setting on a certain request in terms of Reactive Power at the TSO/DSO interface to a TSO simulator and subsequently trying to verify the satisfaction of the specific setpoint through the measurement of Reactive Power at the HV/MV Substation.

In this context, it can be pointed out that the activity has been carried out successfully from a communication protocol side, with the correct implementation of the setpoint in the Local Scada as an absolute Q setpoint referred to the HV/MV Green Transformer. However, since the actual weather and climate conditions of the specific day when the field test was performed did not allow a significant production from the PV plants, the measurements collected from the field devices, even if they demonstrate that the TSO request has been received (and the system has been triggered), can not be used to prove the full achievement of the requested setpoint at Quarto Primary Substation.

3.5.3 TRACKING ERROR MEASURED AT DER INTERFACE (KPI #2)

The tracking error measured at the DER interface has been simulated by using the Central Scada System. In particular a simulation regarding the implementation of different specified reactive power setpoints has been carried out on the IRE of Quarto FTV PV generator and the resulting reactive power measurements have been acquired. The error in the implementation of each set point level has been calculated, as shown in Table 8. In detail, the calculation has been performed considering 1 MVA power plant and assuming an actual power active supply of 100 kW. The % setpoint - sent to the resource - represents a defined request in terms of Reactive Power which the power plant has to exchange with the MV network.

TABLE 8: CALCULATED ERROR AT DER INTERFACE FOR DISCRETE REACTIVE POWER SETPOINTS

Setpoint (%)	Pmeas (kW)	Power Factor	Q setpoint (kVAr)	Qmeas (kVAr)	Error
-5	-100	-0,89	-49,92	-50,5	0,01
-4	-100	-0,93	-39,936	-37	0,07
-3	-100	-0,96	-29,952	-25	0,17
-2	-100	-0,98	-19,968	-15	0,25
-1	-100	-1,00	-9,984	-10	0,00
0	-100	±1	0	0	0,00
1	-100	1,00	9,984	10	0,00
2	-100	0,98	19,968	17	0,15
3	-100	0,96	29,952	26,4	0,12
4	-100	0,93	39,936	38	0,05
5	-100	0,89	49,92	51	0,02

In particular, Figure 23 shows the trend of the percentage error referred to the requested Q setpoint, in which it can be highlighted how the calculated error decreases as the requested Q value increases.

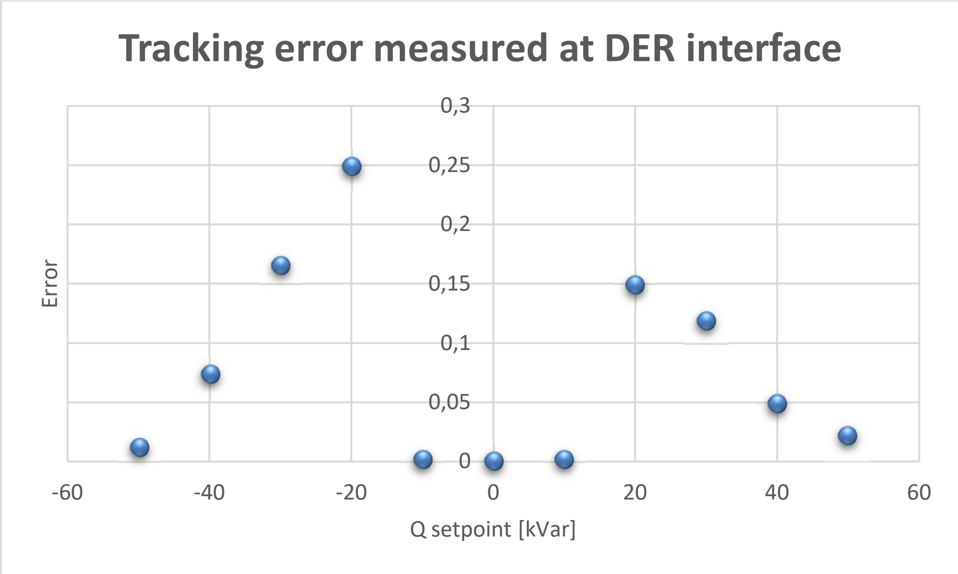


FIGURE 23: TRACKING ERROR TREND MEASURED AT DER INTERFACE

Figure 24 shows the laboratory implemented limit for power factor values related to the required Q setpoints.

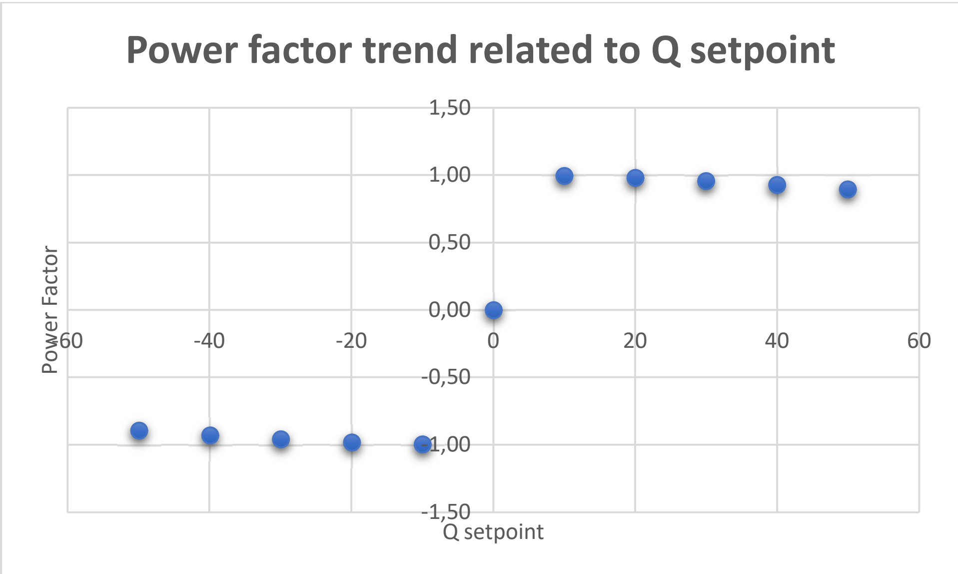


FIGURE 24: POWER FACTOR TREND FOR THE CORRESPONDING Q SETPOINT AT DER INTERFACE

3.5.4 INCREASE IN HOSTING CAPACITY AT THE PRIMARY SUBSTATION (KPI #8)

The Hosting Capacity increase at Quarto Primary Substation has been calculated to estimate the rise in the potential connectable power to the distribution network as part of the improvement enabled by the EU-SysFlex Project. One of the most important constrains to be considered for the connection of new Distributed Generators to the MV grid is the network voltage quality, which depends on the fact that the connection of DERs causes a change in the voltage profiles along the network itself. Since the voltage must always be between 90% and 110% of Vn (in accordance with standard CEI 0-16) and in order to keep the voltage in all network nodes within the previous limits during all operating conditions, one of the main interventions is the voltage regulation that allows an increase in the connectable DG, suitably regulating the voltage on the MV side of the HV/MV transformer and the reactive power on DER. Therefore, a simulated computation has been developed thanks to the Advance Distribution Management System software (ADMS), where the ***"Base Scenario"*** is characterized by the absence of automatic voltage regulation, while the ***"Smart Grid Scenario"*** refers to the state where the voltage regulation is activated. Considering the MV node with the most relevant level of criticality from the voltage rise point of view - Sanna FTV under the SARSI MV feeder - in the day of year 2021 when maximum production and minimum load can be noticed (06/06/2021), a calculation was carried out.

- In the ***"Base Scenario"*** (absence of automatic voltage regulation), the results show that it is not possible to connect further DERs on the considered MV node (where the two PV generators are connected) as the voltage level is already at the higher limit. Then the initial Hosting Capacity is assumed equal to the one currently installed under the whole feeder.
- In the "***Smart Grid Scenario***" (voltage regulation is activated), the demonstration proves that operating the network at a lower voltage level allows to connect further Distributed Generators on that specific Secondary Substation and, in this context, the connectable DG value is no more limited by the voltage level.

In conclusion, it can be estimated an $\boldsymbol{HC_{base}}$ approximately about ***7,4 MVA*** and an $\boldsymbol{HC_{SG}} = \boldsymbol{HC_{base}} + \boldsymbol{HC_{V\_regulation}}$ equal to **8,7 MVA**, with a consequent $\Delta\boldsymbol{HC}\%$ **= 18%.** It should be noticed that in this computation a conservative approach has been adopted since the benefit in terms of HC increase is only referable to the contribution of the Primary Substation OLTC, not having considered the contribution to the voltage regulation of the two Statcoms, Storage and the variation of reactive power on the three PV dispatchable generators.

3.5.5 INCREASE IN REACTIVE POWER CAPABILITY AT PRIMARY SUBSTATION (KPI #6)

The expected increase of reactive power capability at primary substation level has been calculated thanks to the Q measurements acquired during the Demo operation.
In detail, the resulting lack of Reactive Power Capability increase ($\Delta C_{RP}\%$) must necessarily be analyzed by taking into account, on the one hand, the meteorological conditions of the season where the test has been executed - which do not support the production from PV plants – and, on the other hand, the limited dispatchable resources involved in the simulation itself which does not contemplate the two Statcom modules and the Storage.
Therefore, as the Q capability changed from **524 kVar** in the ***"Base Scenario"*** (absence of automatic voltage regulation) to **518 kVar** in the "***Smart Grid Scenario***", the calculated $\Delta C_{RP}\%$ is about **-1%.**

3.5.6 LINE VOLTAGE PROFILE (KPI #7)

In order to evaluate the KPI related to voltage quality, the voltage profile - function of time V(t) has been analyzed on the most critical involved secondary node from the voltage rise point of view, due to production of energy from distributed generation. The difference in the voltage values measured during the execution time of the demonstration - which took place on 08th February - and the comparable time window of the corresponding day of the previous week - 01st February – has been evaluated.
Figure 25 shows the difference between the nominal voltage value and the effective operational one on SANNA FTV MV node during the time window of the demonstration test and the corresponding interval of the comparable

day of the previous week. As expected, it is clear that the calculated $\Delta V(t)$ [%] decreases for each considered moment during the field test - for which measurements are available.

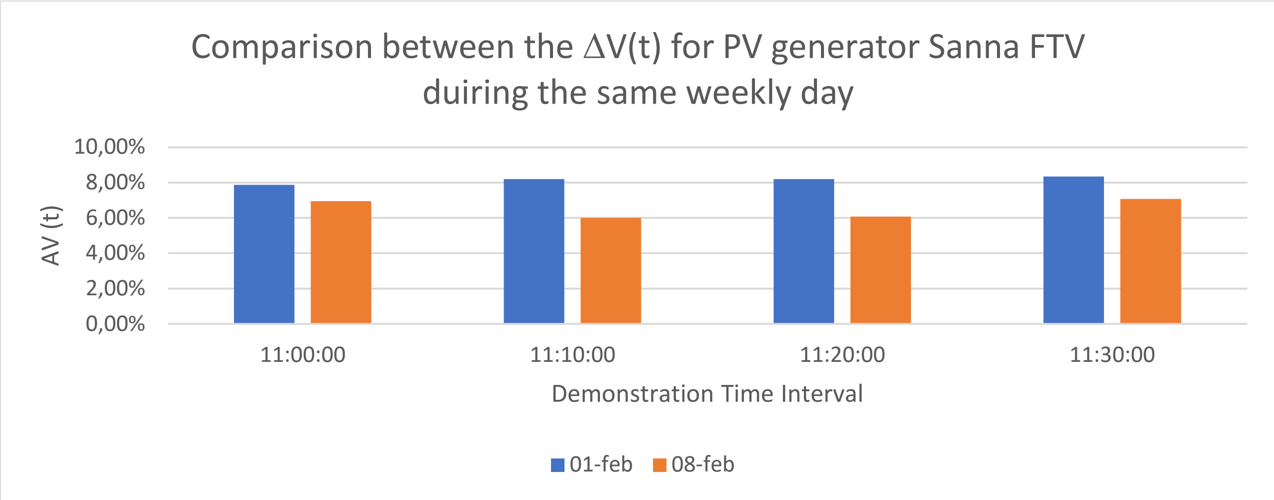


FIGURE 25: COMPARISON BETWEEN UPPER OPERTAING VOLTAGE LIMIT ON SANNA FTV REACHED DURING REAL FIELD TEST AND THE CORRESPONDING DAY OF THE PREVIOUS WEEK

3.6 PORTUGAL: FLEXHUB

3.6.1 DESCRIPTION OF THE DEMONSTRATION

The Flexibility Hub was conceived, as can be seen in Figure 26, as a TSO-DSO coordination platform for the provision of three different services organized into three different BUC:

- Short-term reactive (PT-FXH-RP BUC) and active (PT-FXH-AP BUC) power flexibility to the TSO from DSO grid connected resources, guaranteeing that the activation of these flexibilities does not violate the DSO grid constraints,
- Longer term relevant information to the TSO for its planning process, by sharing with the TSO a grid dynamic equivalent model which is a simplified model of the distribution grid of the DSO, designed to reproduce the distribution grid dynamics under voltage and frequency disturbances at the DSO-TSO connection point, based on a standardized structure, without involving the disclosure of sensitive distribution grid data (PT-FXH-DM BUC).

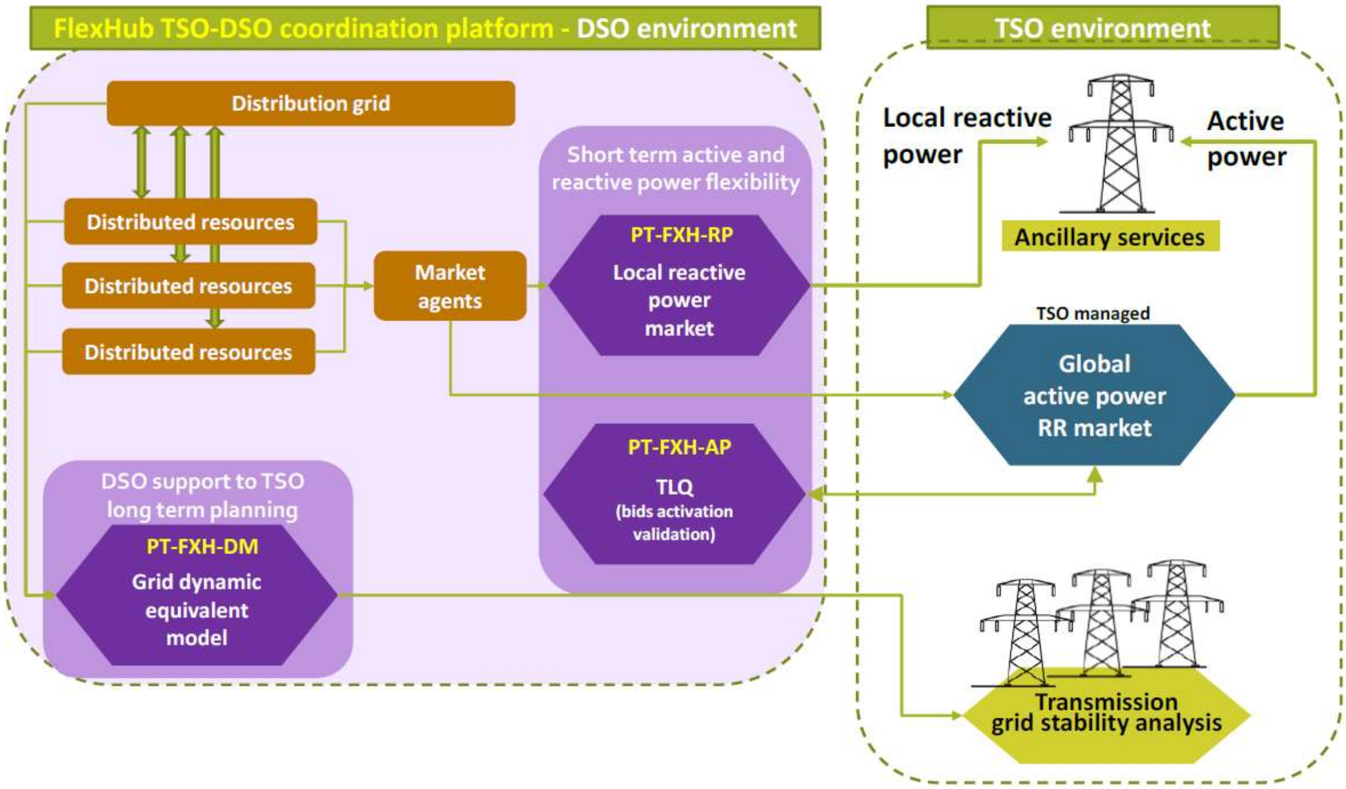


FIGURE 26: FLEXIBILITY HUB, A TSO-DSO COORDINATION PLATFORM

The demonstration has been developed at the distribution grids of two demonstration sites: 1) the HV level distribution grid connected at the TSO-DSO linking substation of Frades and the feeder associated with Évora substation (MV level – MV line EV15-46), see locations in Figure 27 (1- Frades, 2- Évora).

FIGURE 27: FLEXIBILITY HUB – DEMOSITE LOCATIONS

Frades is a 20 MW TSO/DSO substation located at the north of Portugal, with 40 transformers that provide service to about 8000 grid connection points, 90 MW of installed RES (larger than the grid consumption), and 2 distribution high/medium voltage (HV/MV) secondary substations (Vila da Ponte & Caniçada). Flexibilities come from 46 MW of wind active power, with reactive power ranging between 50 Mvar and +50 Mvar. On the other hand, Evora feeder grid was used due to the possibility of managing a storge facility located at this grid for provision of active power flexibility. The two demonstration sites, along with the assets involved, are detailed in Figure 28.

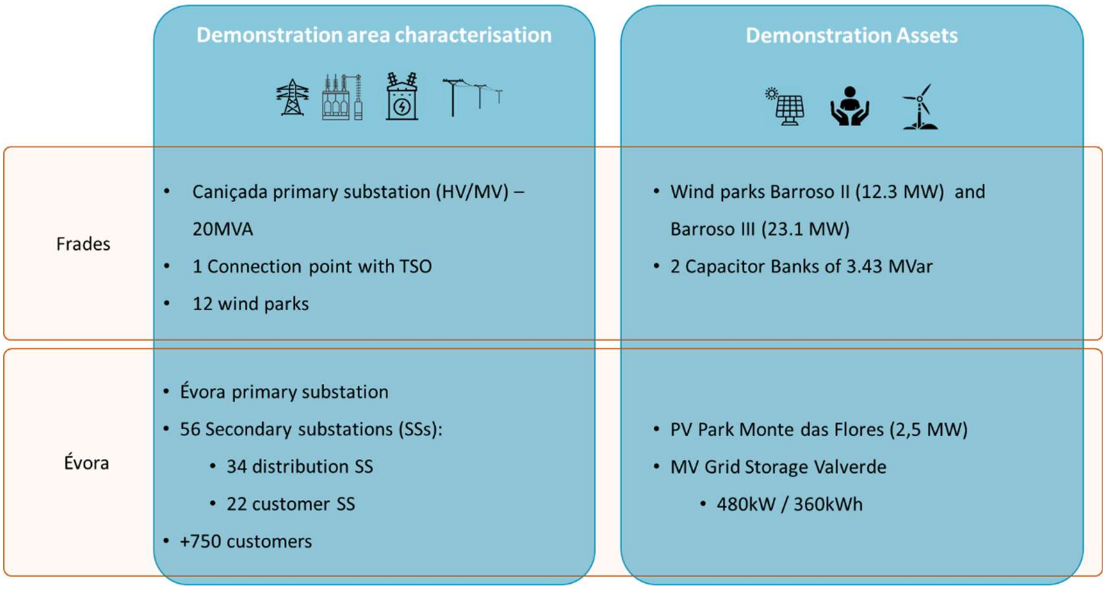


FIGURE 28: FLEXIBILITY HUB - EU-SYSFLEX DEMO SITES, ASSOCIATED CHARACTERISTICS AND ASSETS

The main contributions of the FlexHub are:

- A new innovative **local reactive power market design** to provide reactive power from resources connected to the distribution grid, to compensate for the decrease of the resources currently providing this service.
- A new **innovative active power market design** to provide active power from resources connected to both the transmission and distribution grids. This market is a redesign of the current restoration reserve (RR) market.
- A new simplified **equivalent dynamic model** of the whole distribution grid for frequency and voltage disturbances at the TSO/DSO connection point, to provide a more realistic dynamic behavior of the grid.
- A new platform that promotes the interaction and coordination between TSO and DSO for enhanced system operation.

Thirteen KPIs had been defined at the beginning of the EU-SysFlex project (see D10.1) in order to analyse the behaviour of the Portuguese FlexHub demonstration. These KPIs are listed here-after and are described in more detail in Annex 4:

- KPI #1: Bidding price estimation of providing reactive power
- KPI #2: System cost cost of providing reactive power
- KPI #3: Bidding price estimation of providing active power
- KPI #4: Estimation of the increment of reactive power flexibility for the network operators (TSO and DSO)

- KPI #5: Estimation of the increment of active power flexibility for the TSO
- KPI #6: Error in the reactive power provision service
- KPI #7: Error in the active power provision service
- KPI #8: Execution time of the Q market clearing process
- KPI #9: Execution time of TLQ process for the P market participation
- KPI #10: Network secure operation margins while delivering reactive power
- KPI #11: Network secure operation margins while delivering active power
- KPI #12: Modelling error of the dynamic model BUC
- KPI #13: Benefit of a dynamic model vs a static resistive model

The KPIs' results are described in detail in the final report of the demonstration (D7.6). What follows is a summary of the main results.

3.6.2 BIDDING PRICE ESTIMATION OF PROVIDING REACTIVE POWER (KPI 1)

The costs of providing reactive power depend on the assets, since different assets show different responses and regulation capability. According to the market mechanism proposed in the BUC PT-FXH-RP (Provision of reactive power flexibility with resources located at the distribution grid), ideally, the price should be equal to the marginal cost or marginal opportunity cost of providing reactive power. Therefore, the market players should bid their units in order to recover their marginal costs. Uniform pricing allows, for those units that are not marginal, to recover additional costs.

The bid concept used in the demo is based on a simplified marginal cost computed, for each hour, by approximating linearly the marginal cost curves of the assets. In addition, for simulations, small positive or negative increments (σ) with respect to a reference price ($Cref$) are added.

Figure 29 depicts the average weekday bid prices for each month. It can be observed that the marginal cost of providing the services is low. The bid price shows hourly variations but also depends on the month, as it is for the average monthly intraday market price used as reference price. In January, variations on day and hour leads to prices approximately between 1.5 and 2.5 €/ Mvar.

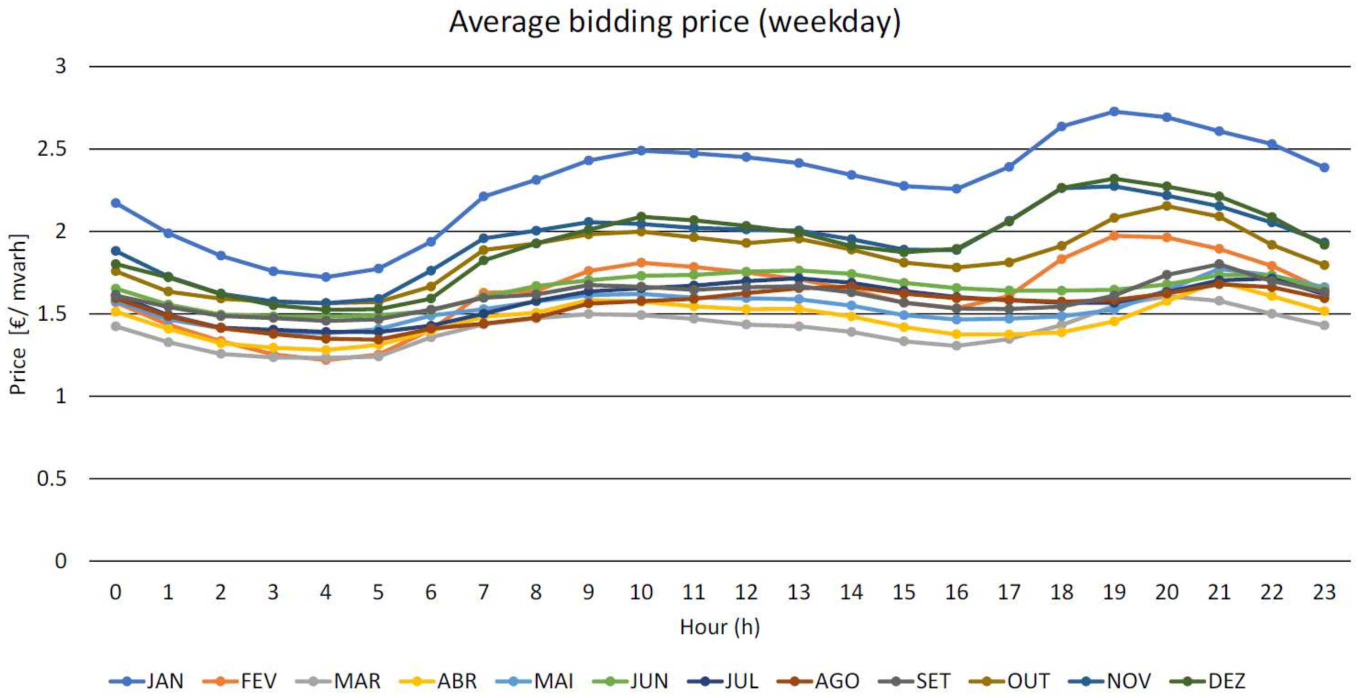


FIGURE 29: AVERAGE BIDDING PRICE FOR A WEEKDAY

3.6.3 SYSTEM COST COST OF PROVIDING REACTIVE POWER, SHARED BETWEEN TSO AND DSO (KPI 2)

The objective of this KPI was to assess the service cost and its allocation between TSO and DSO according to their respective resources' usage. In order to illustrate the share between DSO and TSO payment obligations, and since there is no information to determine when the TSO is demanding reactive power and when the reactive power exchanged is the result of small DSO grid reactive power imbalances, the reactive power market was cleared assuming five TSO-DSO reactive power exchanged profiles (Figure 30). These profiles include hours where the TSO is clearly demanding reactive power from the distribution grid (capacitive or inductive), and hours that may correspond to small reactive power imbalances of the distribution grid according to the regulation limits. However, no additional information allows to differentiate them.

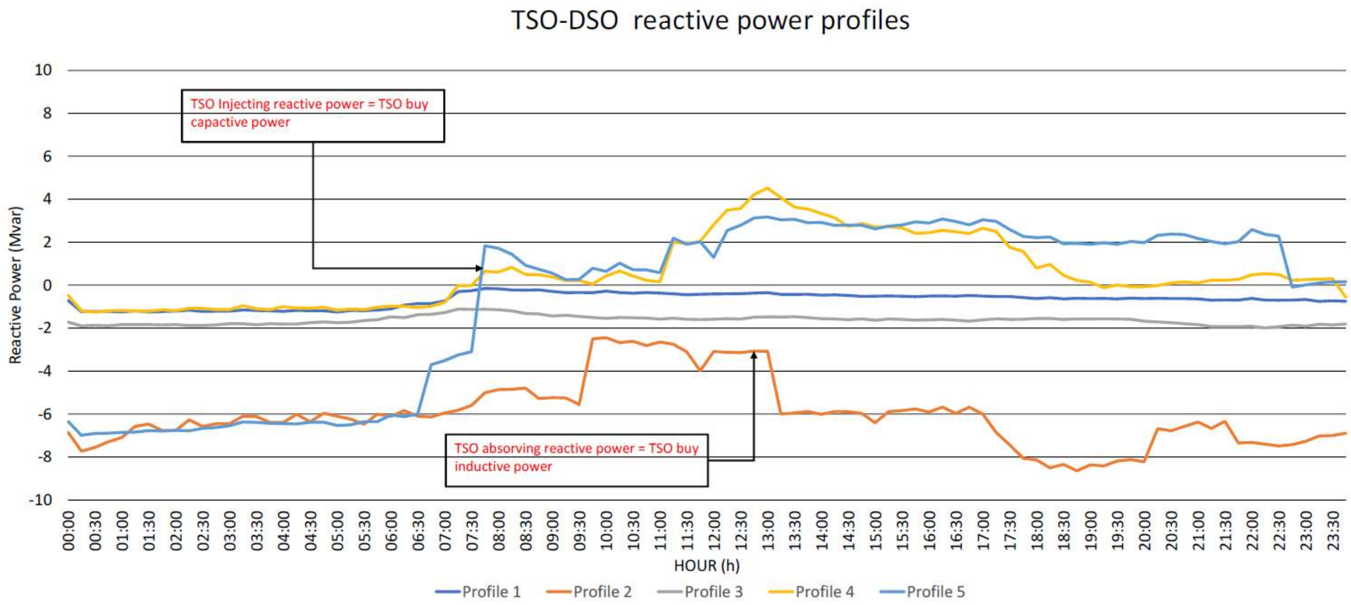


FIGURE 30: TSO-DSO REACTIVE POWER PROFILES

Results, for the specific case of this demonstrator, show a larger usage of reactive power flexibility by the DSO to balance its grid than by the TSOs to operate its own. The TSO sees payments obligations slightly higher than half those seen by the DSO to balance its grid.

TABLE 9: TSO AND DSO PAYMENT OBLIGATIONS ESTIMATED FOR A FULL YEAR

	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Total
TSO	16 305.57 €	3 499.40 €	22 253.78 €	1 926.96 €	3 189.65 €	**47 175.36 €**
DSO	42 360.18 €	1 085.27 €	24 376.11 €	3 561.86 €	1 114.93 €	**72 498.36 €**

The shared cost that has been calculated is a specific case for a specific grid and specific TSO needs, inferred from past data that do not represent properly a future scenario with high RES. In addition, reactive power is a local service whose cost, from the point of view of the TSO (or the system operation) should be assessed by considering other local provisions of reactive power that should be added. Therefore, the assessment of this cost remains totally out of the scope of this work. However, considering the low marginal cost of providing the services in (**KPI 1**: bidding price estimation of providing Q) and the values obtained for this particular demonstrator grid and the data available, it seems reasonable to expect a low impact on the whole systems costs.

If the service is needed to operate the grid, it should be properly remunerated directly (market-based or with some kind of regulated cost-based mechanism), or indirectly by recovering it from other revenues streams. Same considerations can be made for the DSO, which also profits from this local reactive power flexibility to balance its reactive power exchanges with the TSO.

3.6.4 BIDDING PRICE ESTIMATION OF PROVIDING ACTIVE POWER (KPI 3)

This KPI deals with the estimation of the variable costs and prices of providing active power flexibility from distributed resources that could guide the process of strategic bidding, out of the scope of this demonstration. Only renewable generation, demand response and storage were considered.

Renewable generation resources:

Usually renewable generation units commit, in the energy markets, their forecasted production, and do not benefit for a significant controllability of their production. This means that, in general, the possibility to provide positive active power flexibility, in the sense of increasing their production, is not possible since they cannot provide additional energy, unless some capacity payment makes them to remain below their maximum possible generation in the previous energy markets, something that has not been considered here.

For negative TSO needs (equivalent to downwards active energy or bids to sell) the clearing process of the TSO will first select all available bids with largest positive prices (since these will correspond to bids that accept to buy energy at larger prices), and only when no other options hold, the TSO will resort to renewable generation bids with null or negative prices.

Demand response resources (load shedding):

Only load shedding has been considered. If the demand provides a flexibility $Pflex$ and for the flexibility not to imply any additional cost to the consumers, or even to incentivize its provision, the flexibility will typically imply a consumption reduction which is equivalent to selling a positive $Pflex$ at a positive price. However, even if this flexibility $Pflex$ implies a bill reduction, it is in fact a utility loss of the consumer providing it, and therefore to compensate this utility loss with the flexibility provision the flexibility price should be strictly positive.

Storage resources:

For simplicity, arbitrage in energy markets and initial schedules have not been considered. In a very simplified approach, storage facilities will be willing to sell upwards flexibility (energy injection to the grid) when the price compensates (is larger than) the cost of previously buying this energy incremented with the storage losses due to the efficiency. Similarly, they will be willing to sell downwards flexibility (energy withdrawal from the grid) if the price of buying this energy is lower than the incomes at which this energy was or will be sold, including the efficiency losses.

3.6.5 ESTIMATION OF THE INCREMENT OF REACTIVE POWER FLEXIBILITY FOR THE NETWORK OPERATORS (TSO AND DSO) (KPI 4)

The increment of reactive power for the network operators will depend on the number of resources providing flexibility, the technical features of the flexible resources and the energy source availability (wind and sun). The available reactive power flexibility has been assessed for the particular case of Frades grid and is therefore difficult to extrapolate to other cases. For the Frades case, the participation of more resources increments significantly the amount of available reactive power at the TSO-DSO connection point, even if losses or grid constraints can be limiting. Indeed, it seems that, in general, voltages tend to be more limiting than lines capacity, since usually lines operate far from their maximum capacity, while voltages ranges are tighter. Relaxing voltage ranges can increase the flexibility that can be effectively provided. However, this increment is not always very significant. Finally, even if voltages are usually the more limiting constraints, in the context of smart grids this could change and the lines be operated closer to their maximum capacity, which could also limit the effective flexibility compared to the available one at the resources level.

3.6.6 ESTIMATION OF THE INCREMENT OF ACTIVE POWER FLEXIBILITY FOR THE TSO (KPI 5)

This KPI aimed at assessing the potential increment of active power flexibility for the TSO, given the available resources. The results obtained are very specific for the chosen Évora grid where the active power flexibility is mainly provided by two resources (Valverde storage and PV Mt. Flores), and cannot be generalized. For a better understanding of the conclusions, it's important to first clarify the technical capabilities and availability of each resource to provide ancillary services.

VRES: it was assumed that the PV Mt. Flores plants offer only downward flexibility.

Storage: It was assumed that the VALVERDE storage unit has no time dependency (can provide ancillary services all day). In this case, the storage device is available to ensure upward flexibility (discharge mode) and downward flexibility (charge mode), being only limited by its storage capacity.

Curtailable load: it was assumed that curtailed loads can provide upward flexibility only by decreasing in 10% their load consumption.

It was shown that the presence of curtailable loads does not increase the downward flexibility activated by the Traffic Light Qualification (TLQ) process. These resources also have a small impact on the increment of upwards flexibility. Although there's no energy restriction, the amount of flexibility provided is very limited

The available upward flexibility does not significantly change for the different scenarios studied. Since the upward flexibility is mostly ensured by the storage device capacity, the activated flexibility is significantly limited. For a forecast daily profile with more PV production it was possible to activate more downward flexibility.

3.6.7 ERROR IN THE REACTIVE POWER PROVISION SERVICE (KPI 6)

The actual amount of reactive power provided at the TSO-DSO connection point is guaranteed by the way the market is cleared in case there is enough flexibility available. This means that the flexibility activated is the flexibility needed to provide the service based on the availability and prices without expected error, and that, therefore, KPI 6 is null for the simulated scenarios unless there is a lack of flexibility.

During the demo, there were no significant amounts of reactive power requested meaning the wind farms and the capacitor banks were always able to answer those needs.

3.6.8 ERROR IN THE ACTIVE POWER PROVISION SERVICE (KPI 7)

Although this KPI was designed to be measured in the Évora demonstrator, an analysis of the error was conducted based on the results of simulated scenarios, which comes from the way the TLQ is applied.

In the case of PT-FXH-AP the TSO selects bids and the amount required, but this amount is at the flexibility provider connection point, which means that the final amount actually delivered will be in general lower.

In the PT-FXH-AP BUC (Provision of mFRR/RR type reserves), bids come from the apparent availability of the resource. However, grid losses can reduce the active power finally seen at the TSO-DSO connection point compared to the active power offered, even if no TLQ limitations due to grid constraints are identified.

In order to measure this KPI, the TSO-DSO connection point was compared within the following scenarios:

- Without TLQ (Business as usual (BAU) scenario)
- With TLQ, given 4 flexible resources (PV, Storage and 2 sheddable loads).

Table 10 shows the maximum absolute error value (in MW) for each scenario simulated. The difference of the TSO-DSO connection point before and after the TLQ is almost the same value of the activated flexibility. It can be observed that the error in the provision of the services was in general lower than 4% for the particular EVORA grid and that the losses do not significantly impact the real active power provided to the TSO. However, this error is very grid- and resource location dependent and should be assessed in each case. Large errors imply large energy losses whose costs should be assessed and shared properly, something not addressed in this demonstrator

TABLE 10: ABSOLUTE MAXIMUM ERROR PROVISION OF ACTIVE POWER FLEXIBILITY

	Downward flexibility (MW)	Upward Flexibility (MW)
January 7th	0.038	0.024
March 3rd	0.032	0.02
August 15th	0.042	0.007
October 10th	0.015	0.004

3.6.9 EXECUTION TIME OF THE Q MARKET CLEARING PROCESS (KPI 8)

This KPI deals with the Q market computational effort regarding each simulated scenario. It is important to refer that this KPI gives a performance indicator only of the multi-period OPF applied to the market clearing.

As can be seen in Table 11, the computational effort for all scenarios is less than 2 seconds. The impact of the network size on the the scalability feature of the market computational effort was also studied. It turns out that there is a linear increment with the grid side, and therefore, the potential scalability of the MOPF for larger grids without leading to computational issues, since MOPF execution times do not seem to be a potential issue.

TABLE 11: LOCAL REACTIVE POWER MARKET EXECUTION TIME

		MOPF TIME EXECUTION (Seconds)				
Scenario	**Resources**	**TSO needs Profile 1**	**TSO needs Profile 2**	**TSO needs profile 3**	**TSO needs profile 4**	**TSO needs profile 4**
1.1	2	1.07	1.71	1.4	1.02	1.04
1.2	2	1.08	1.46	1.46	1.03	1.03
2.1	3	1.25	1.72	1.41	1.11	1.03
2.2	3	1.21	1.47	1.47	1.18	1.04
3.1	7	1.43	1.87	1.78	1.46	1.39
3.2	7	1.37	1.93	1.72	1.59	1.39

3.6.10 EXECUTION TIME OF THE TRAFFIC LIGHT QUALIFICATION (TLQ) PROCESS FOR THE P MARKET PARTICIPATION (KPI 9)

This KPI tries to measure the effectiveness of the TLQ module to calculate a multi-period OPF (MOPF) for different distribution grid configurations and demand profiles. In order to evaluate the impact of the grid scalability in the execution time of TLQ, Évora grid was considered with its original size and also duplicated.

The computational effort for all scenarios considered reached a maximum of 10 seconds. As for the KPI 8 assessment (for the reactive power market BUC), this KPI gives a performance indicator of the TLQ.exe (the multi-period OPF applied to the traffic light qualification). All the other communication process are not accounted for here.

Considering a scaled Évora grid, it was shown that the TLQ process is able to perform for complex grids without leading to computational issues. It is important to refer that, when the amount of flexibility requested by the TSO cannot be fully activated, the TLQ must run a double MOPF to determine the least cost solution. Considering those results, the time effort is perfectly acceptable within the time process of 15 min.

3.6.11 NETWORK SECURE OPERATION MARGINS WHILE DELIVERING REACTIVE POWER (KPI 10)

This KPI tries to evaluate how the resources activation respect the secure operation margins of the DSO grid while delivering the expected reactive power.

The maximum and minimum voltage levels have been caclculated for the different TSO needs profile simulated. As expected, it can be verified that voltages remain between their acceptable limits.

In case of larger TSO needs, the evaluation of KPI 4 showed that voltage limits could be approached. However, the market clearing procedure guarantees that grid secure parameters remain in their acceptable intervals by limiting the maximum flexibility that can be activated. Therefore, in KPI 4 more extreme scenarios, the activated flexibility is lower than the theoretically available one considering the flexibility providers. In this sense, this KPI is also measuring indirectly the existence of a reduction of the effective availability compared to the one offered for those cases when grid constraints are reached.

3.6.12 NETWORK SECURE OPERATION MARGINS WHILE DELIVERING ACTIVE POWER (KPI 11)

The objective of this KPI is to assess how the activation of upward and downward flexibility impact the operation margins of the Évora Distribution grid. It has been verified that:

- The voltage and load capacity levels remain between their acceptable limits.
- Due the radial topology of Évora grid, the activation of downward flexibility (decrease of PV generation and Storage in charge mode) led to a constant maximum voltage level of 1 p.u. (at the reference bus).
- The upward flexibility activation of the storage unit (discharge mode) and the sheddable loads did not have significant impact on the voltage and loading levels.
- Within the range 08h00-17h30, the maximum voltage and loading percentage values report higher values due the PV production and is not as a consequence of the upward flexibility activation

3.6.13 MODELLING ERROR OF THE DYNAMIC MODEL (KPI 12) AND BENEFIT OF A DYNAMIC MODEL VS A STATIC RESISTIVE MODEL (KPI 13)

This section deals with the KPIs related to the Equivalent Dynamic Model of the distribution grid (PT-FXH-DM BUC):

- KPI #12 (Modelling error of the dynamic model)
- KPI #13 (Benefit of a dynamic model vs a static resistive model).

CASE 1 – VOLTAGE-SHORT-CIRCUIT SENSITIVITY

KPI 12: with respect to case 1 (voltage-short-circuit sensitivity), the equivalent model's capability of following the aggregated behaviour of active and reactive power upon the several short-circuits occurring on the transmission side was assessed. A baseline point of operation was kept common for all the cases, and the severity of the fault was changed, resulting in four different residual short-circuit voltages of 20, 40, 60 and 80% of the nominal voltage. Upon the disturbance, reactive power injection increase is required to the wind power units present in the distribution network, leading the overall reactive power to increase significantly during the faults. Due to power converter limits, active power of the converters is curtailed progressively as the severity of the disturbance increases. It was shown that the equivalent model has to a very good level of adherence to the detailed model with respect to voltage, active and reactive power for each disturbance considered. It should be noted that the equivalent model uses only one set of parameters to respond to the four disturbances, revealing robustness in the solution.

KPI 13: The previous result was compared with two classical models – Passive load and inverter-based generator (IBG)-only. These were parametrized accounting only with the balance of generation versus load installed capacity, for the point of operation under evaluation. The IGB-only model was parameterized using standard parameters. It was shown that the classical approaches are not very suitable to properly characterize the distribution network under these circumstances.
The method's resultant parametrization of the previous case was then applied to untrained conditions. The results at the transmission/distribution power substation for voltage, active and reactive power show that the equivalent model is able to follow the behavior of the detailed model, even for these untrained conditions. Although the level of adherence is not as high as in the trained cases, it confirms the robustness of the method.

CASE 2 – VOLTAGE-WIND POWER OPERATIONAL POINT SENSITIVITY
KPI 12: In case 2 (Voltage-Wind power operational point sensitivity), the capability of the equivalent model (and respective method) to follow several power injection scenarios from the wind units installed at Frades' distribution network was analyzed. For that matter, four cases were simulated in the detailed model, considering the units operating at 80, 70, 60 and 50% of its installed (maximum) capacity, for a severe, three-phase short-circuit occurring at the transmission side.
It was shown that the equivalent model is able to follow the aggregated active and reactive power dynamic response of the detailed model with a high level of success. A single parametrization enables a significant reduction of the dynamic model complexity, and a tight similarity of the overall behavior of the distribution network.

KPI 13: the solution was then compared with the classic approaches. As expected, the classic approaches are not able to successfully follow the behaviour of the detailed model. The same parametrization was also applied to four new untrained conditions, considering intermediary active power injection from wind power units present in the grid, for 75, 65, 55 and 45% of their nominal capacity. In line with the previous case, also for this case the equivalent model's untrained responses are highly satisfactory. The equivalent model reveals a high level of adherence to the detailed model, being able to capture its dynamic behavior during the transitory period under analysis and showing an ability to inter/extrapolate the accurate representation for cases not considered when deriving the proper parametrization.

The results provide the required level of confidence to assume the proposed method is able to fulfil a wide range of scenarios that the TSO may require the FlexHub platform, in terms of severe systemic voltage-related disturbances at the transmission network side.

3.7 DATA EXCHANGE (WP9)

3.7.1 DESCRIPTION OF THE DEMONSTRATION

The objective of WP9 was to test and demonstrate the data management solutions for flexibility services, developed in WP5. It focused on aspects of data management, including cross-border communication between different data exchange platforms and with different stakeholders in order to facilitate cross-border exchange of flexibility services. Two main joint demonstrations have been carried out:

- First, a joint demo, where a flexibility platform, a tool for flexibility aggregators allowing an affordable access to market by flexibility service providers (FSP), and a system operator simulator were interfaced through a data exchange platform. This allowed to define, investigate, test and demonstrate the data exchanges between different stakeholders participating in a flexibility market. The tool for flexibility aggregators (called Affordable Tool) enables an affordable access-to-market to small distributed flexibility sources. An interface between this tool and a data exchange platform has been developed.
    - The Flexibility platform allows flexibility trading market places to support TSO-DSO data exchanges for the effective supply of flexibility services from all sources connected to both the distribution grid and transmission grid. The application focusses on data exchanges between flexibility service providers (including aggregators) and flexibility users (system operators). An interface between this software and a data exchange platform has been developed.
- Second, cross-border and cross-sector communication between data exchange platforms and with different stakeholders in order to facilitate cross-border exchange of flexibility services. The aim was not to develop a single data exchange platform but ensure the interoperability of different solutions. This Cross-border exchange of data encompassed:
    - data exchange between a data exchange platform in Estonia (Elering), the ENTSO-E's platform in Brussels;
    - data exchange between Lithuanian customers located in the distribution grid of ESO and the Estonian data exchange platform Estfeed;
    - cross-sector Data Exchange between the Building sector (Building Registry: data on buidings) and the energy sector (Elering Data Hub: consumption and production data).

WP9 has tested recommendations from WP5 aiming at ensuring the scalability of data management solutions, including the requirements related to cyber security, data privacy, time constraints of data exchanges performance, procedures for handling massive flows of data, and functionalities. Functionalities are described in 16 system use cases defined in WP5.

Components of data exchange demos include:

- TSOs and one DSO with their data hubs and customer portals
- Operational data platform ECCo SP (Communication & Connectivity Service Platform) from ENTSO-E
- Flexibility platform used by flexibility service provider.
- Affordable tool for flexibility offering.
- Building Registry system

- Estfeed secure adapters to enable international data exchange through secure channels and in accordance with authorizations from data owner

While the **Affordable Tool** and the **Flexibility Platform** were major new components that have been developed in WP9, Data Hub, Customer Portal and Data Exchange Platform were existing components of Elering to be used in demos. However, Elering's DEP needed to be upgraded in order to facilitate cross-border data exchange.

The BUCs of the WP9 demonstrations are dealing with aspects of data management, including aggregation of consumer loads in a single flexibility marketplace for TSO-DSO flexibility data exchange, cross-border and cross-sectoral communication between different data exchange platforms and with different stakeholders in order to facilitate cross-border exchange of flexibility services:

Affordable tool for small demand-side resources (DSR) units with the following objectives:

- offer consumer loads as flexibility for bidding,
- added options for automatic response to events,
- real-time metrics,
- ensure users'privacy is protected (GDPR)

Operation of single flexibility marketplace for TSO-DSO flexibility data exchange: Detailing a flexibility market platform as well as the related data exchange between the different involved stakeholders and systems. Within this BUC, features regarding the process of massive data are considered out of scope.

Operation of cross-border and cross-sector data exchange model/network:

i) between a data exchange platform in Estonia (Elering), the ENTSO-E's platform in Brussels,

ii) between Lithuanian customers located in the distribution grid of ESO and the Estonian data exchange platform Estfeed,

iii) cross-sector: between the Building sector (Building Registry: data on buidings) and the energy sector (Elering Data Hub: consumption and production data).

3.7.2 EVALUATION OF THE DATA EXCHANGE DEMO KPIS

The KPIs of the Data Exchange demonstration were described in Deliverable D10.1 *Report on selection of KPIs for the demonstrations* And are recapped in Annex 7.

Thirty three KPIs had been defined:

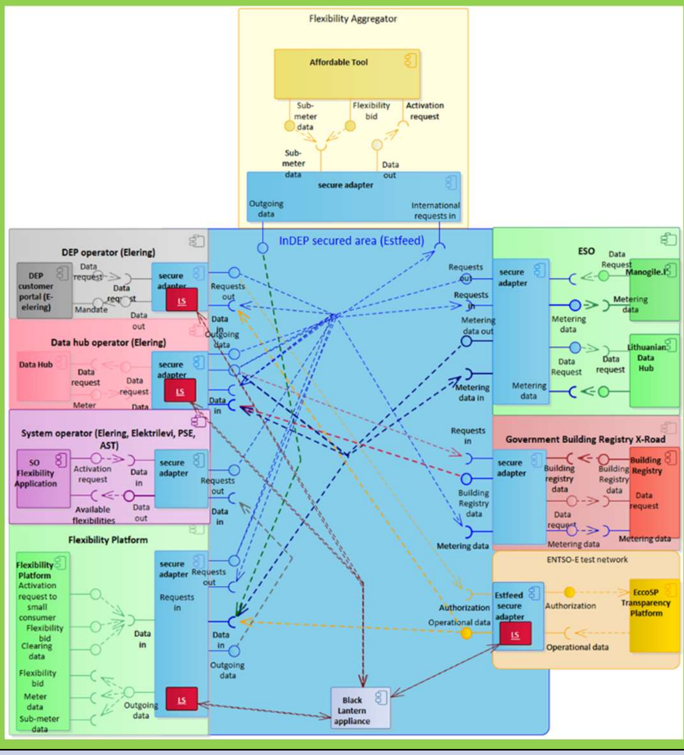
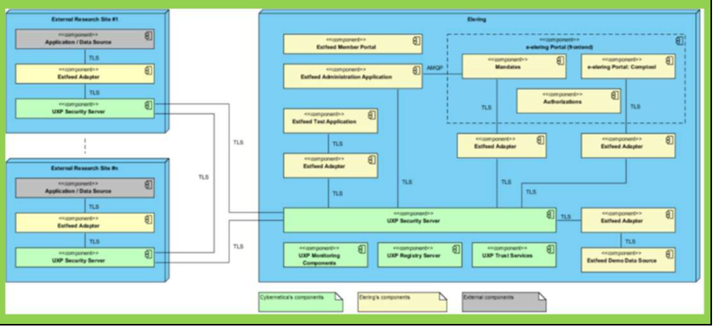
- 3 Global KPIs
- 8 Non-functional KPIs (related to BUCs)
- 22 Functional KPIs (related to SUCs)

The evaluation of the KPIs is detailed in

Table 12 below.

TABLE 12: DATA EXCHANGE DEMONSTRATION KPIS

#	KPI	DEMONSTRATIONS		
		Affordable tool	Flexibility platform	Cross-border exchange of flexibility services
		Task 9.1	Task 9.2	Task 9.3
1. Global KPIs (project level KPIs)				
1.1	KPI name: Easy access to own data KPI description: Increase in number of European consumers (both individuals and organizations) that can access their electricity meter data (i.e. from all metering points, incl. from sub-meters) through a single access point no later than on the following day Unit: % Target value: At least [90] percent of European consumers in 2030	This was demonstrated in the video-demonstration.	N/A	Easy access was simulated in cross-border and cross-sector demos.
1.2	KPI name: Sharing information related to participation in flexibility market KPI description: Increase in availability of all flexibilities to all concerned TSOs and DSOs as a result of sharing information related to participation in flexibility markets Unit: % Target value: At least [90] percent of all flexibilities in Europe are available to all concerned TSOs and DSOs by [2030]	Flexibilities are available and shown in the Affordable Tool and was demonstrated in the video-presentation.	'Joint products' and 'joint procurement' were demonstrated.	N/A

#	KPI	DEMONSTRATIONS		
		Affordable tool	Flexibility platform	Cross-border exchange of flexibility services
		Task 9.1	Task 9.2	Task 9.3
1.3	KPI name: Energy services and applications benefiting from data exchange KPI description: Increase in number of metering points and applications connected by European data exchange model Unit: # Target value: European data exchange model connecting at least 100 million metering points and 1000 applications by [2020] and […] million metering points and […] applications by [2030]	Demonstrators were implemented on simulation level, therefore only a small number of data sources and data users (applications) were integrated with DEP for proof of concept (figure below). 		
2. Non-functional KPIs – (from BUCs)				
2.1	KPI name: Delivery/Implementation KPI description: Application has been delivered into an environment available to partners for testing Unit: tbd Target value: tbd	A dedicated 'research' environment (figure below) of Estfeed DEP was developed and used for demonstrations. 		

#	KPI	DEMONSTRATIONS		
		Affordable tool	Flexibility platform	Cross-border exchange of flexibility services
		Task 9.1	Task 9.2	Task 9.3
2.2	KPI name: Expected flexibility KPI description: it should be possible to calculate within some relative precision (p), actual flexibility available when a command is issued. This must take into account time delays in communication and variability in available flexibility. Unit: relative precision (p) for flexibility availability Target value:	The actual flexibility available was calculated and shown in a graph in the "Consumption" tab.	N/A	N/A
2.3	KPI name: Deliverability of flexibility service at time step t KPI description: the loads, or a percentage (p) of the loads, will turn off within some time (t) after the command to turn off is given. Unit: tbd Target value: tbd	On the time of activation, the consumption would start to lower over time until it reaches the target value. If the order is greater than available flexibility it will stop at the minimum it can deliver.	N/A	N/A
2.4	KPI name: duration of flexibility delivery KPI description: the loads will remain off for the duration promised by the flexibility provider. Unit: tbd Target value: tbd	The activation-order will stay active until the expiration-date has expired.	N/A	N/A
2.5	KPI name: Performance – messaging latency KPI Description: Exchange of date. Received by requesting party in due time Unit: Y or N Target value: Yes	Messages were received through Estfeed DEP without any noticeable delays. E.g. in case of Flexibility Platform demonstration all messages were received under 1 second, mainly constrained by the internet connectivity.		

#	KPI	DEMONSTRATIONS		
		Affordable tool	Flexibility platform	Cross-border exchange of flexibility services
		Task 9.1	Task 9.2	Task 9.3
2.6	KPI name: User satisfaction KPI description: survey on the satisfaction of small distributed flexibility sources (consumers/generators) contributing to the aggregated flexibility Unit: tbd Target value: tbd	No surveys were undertaken among our customers since there was no direct interaction with them and the data was simulated in the demonstration.	N/A	N/A
2.7	KPI name: Open Source KPI Description: will the developments be open-source? share of open source components in the platform Unit: Y or N Target value: Yes or a percentage (For the flexibility platform, 80% of components used open-source components)	NO	YES (Flexibility Platform)	Estfeed DEP itself is open source, but not the demos.
2.8	KPI name: Connectivity KPI Description: the flexibility platform (DEP) can receive information from Estfeed DEP and send information to Estfeed DEP Unit: Y or N Target value: Yes	YES	YES	YES
3. KPIs related to System Use cases – functional KPIs (from SUCs)				
3.1	KPI name: Collect energy data KPI description: N° of data hubs (existing and new data hubs) to be used for collecting the different types of energy data in the demos Unit: # data hubs Target value: at least 6 data hubs	1. sub-meter data	2. grid data provided by SOs 3. market data (e.g. bids) provided by FSPs 4. market data (e.g. baselines, MOLs) provided by FP	5. Elering's data hub for meter data 6. building register data

#	KPI	DEMONSTRATIONS		
		Affordable tool	Flexibility platform	Cross-border exchange of flexibility services
		Task 9.1	Task 9.2	Task 9.3
3.2	KPI name: Transfer energy data KPI description: Data exchange platform capable to transfer different types of data Unit: Y or N Target value: Yes	YES	YES	YES
3.3	KPI name: Provide list of suppliers and ESCOs KPI description: List of suppliers and service providers is available through the data exchange platform. List of aggregators is available through the flexibility platform Unit: Y or N Target value: Yes	N/A	YES	YES
3.4	KPI name: Manage flexibility bids KPI description: Effective flexibility prequalification and bidding processes supported by 'single flexibility platform' Unit: Y or N Target value: Yes	YES	YES	N/A
3.5	KPI name: Manage flexibility activations KPI description: Effective flexibility activation process supported by one 'single flexibility platform' Unit: Y or N Target value: Yes	YES	YES	N/A
3.6	KPI name: Verify and settle activated flexibilities KPI description: Effective verification and settlement processes supported by 'single flexibility platform' Unit: Y or N Target value: Yes	YES	YES	N/A

#	KPI	DEMONSTRATIONS		
		Affordable tool	Flexibility platform	Cross-border exchange of flexibility services
		Task 9.1	Task 9.2	Task 9.3
3.7	KPI name: Manage users' requests KPI description: *SUC not developed yet* Unit: tbd Target value: tbd	SUC was not developed eventually.		
3.8	KPI name: Notify customers KPI description: *SUC not developed yet (*GDPR compliance must be ensured.) Unit: tbd Target value: tbd	SUC was not developed eventually.		
3.9	KPI name: Manage data access permissions KPI description: Personal and other sensitive data can be exchanged based on data owner's consent (authorization). Authorization can be issued on data exchange platform. GDPR compliance must be ensured. Unit: Y or N Target value: Yes	N/A	N/A	YES
3.10	KPI name: Authenticate data users KPI Description: Data users need to be authenticated on data exchange platform before having access to personal and other sensitive data. Representation rights can be given on data exchange platform. GDPR compliance must be ensured. Unit: Y or N Target value: Y	N/A	N/A	YES
3.11	KPI name: Manage data logs KPI Description: Data owner, application and data source can access logs related to data exchange and authorizations on data exchange platform. GDPR compliance must be ensured. Unit: Y or N Target value: Yes	N/A	N/A	YES

#	KPI	DEMONSTRATIONS		
		Affordable tool	Flexibility platform	Cross-border exchange of flexibility services
		Task 9.1	Task 9.2	Task 9.3
3.12	KPI name: Calculate flexibility baseline KPI description: Effective flexibility calculation process supported by 'single flexibility platform' Unit: Y or N Target value: Yes	YES	YES	N/A
3.13	KPI name: Predict flexibility availability KPI description: Effective flexibility prediction processes supported by 'single flexibility platform' Unit: Y or N Target value: Yes	N/A	YES	N/A
3.14	KPI name: Process massive data KPI description: *SUC not developed yet* Unit: tbd Target value: tbd	SUC was not developed eventually.		
3.15	KPI name: Manage sub-meter data KPI description: Effective sub-meter data management processes supported by data exchange platform Unit: Y or N Target value: Yes	YES	N/A	N/A
3.16	KPI name: Exchange data between DER and SCADA KPI description: Effective data exchange processes between DER resources and network operators supported by data exchange platform and flexibility platform Unit: Y or N Target value: Yes	NO, this SUC was not implemented.		

#	KPI	DEMONSTRATIONS		
		Affordable tool	Flexibility platform	Cross-border exchange of flexibility services
		Task 9.1	Task 9.2	Task 9.3
3.17	KPI name: Anonymize energy data KPI Description: DEP enables exchange of anonymized data. Unit: Y or N Target value: Yes	N/A	N/A	YES
3.18	KPI name: Aggregate energy data KPI Description: DEP enables exchange of aggregated data. Unit: Y or N Target value: Yes	NO, this SUC was not implemented explicitly, though it is obvious that DEP is able to exchange aggregated data.		
3.19	KPI name: Integrate new data source KPI Description: *SUC not developed yet* Unit: tbd Target value: tbd	SUC was not developed eventually.		
3.20	KPI name: Integrate new application KPI Description: *SUC not developed yet* Unit: tbd Target value: tbd	SUC was not developed eventually.		
3.21	Detect data breaches KPI Description: *SUC not developed yet* (GDPR compliance must be ensured.) Unit: tbd Target value: tbd	SUC was not developed eventually.		
3.22	Erase and rectify personal data KPI Description: Effective erasure and rectification processes of personal data supported by data exchange platform. GDPR compliance must be ensured. Unit: Y or N Target value: Yes	NO, this SUC was not implemented.		

4. CONCLUSIONS

4.1 KPI ANALYSIS OF THE VARIOUS EU-SYSFLEX DEMONSTRATIONS

This section provides an overview of the main conclusions regarding the KPI Analysis of the various EU-SysFlex demonstrations. Particular attention is paid to the identified technical limitations and economic viability potential problems as seen by the demonstrations.

4.1.1 FINNISH DEMONSTRATION

The Finnish VPP demonstration showed the capability of aggregating assets located in LV and MV distribution networks in order to operate them in the TSO's reserve markets (FCR-N, FCR-D, mFRR) and for the DSO's reactive power compensation needs to stay within the limits of the PQ-window. The active power assets consisted of industrial-, office- and residential-scale BESS as well as aggregated EV charging points and a simulation with residential electric storage heating loads. For the proof-of-concept of reactive power market, an industrial scale BESS and a PV-plant were used. The demonstration also included forecasting and optimization.

All KPIs from the demonstration have been successfully evaluated and are summarised in Table 13. Overall, the active power demonstrations showed that the distributed energy resource can provide a reliable and accurate solution for flexibility services.

These KPIs allowed to identify some limitations mainly related to small-scale BESS control, the ability of some aggregated assets to meet the requirements of frequency regulation markets and the economic viability of a DSO reactive power market:

- The active power demonstration revealed that industrial scale and office scale BESS provide a reliable, fast and accurate service for the TSO's FCR-N reserve market. However, regarding customer-scale BESS, controlling of individual small assets was technically difficult and the demo failed to fulfil the requirements for FCR-N market. Besides, the aggregation platform used with individual small assets had major issues as it was at an early development stage and the reliability of the aggregation platform was only 39,7%. This showed that small distributed energy resources require a reliable and agile aggregation platform. As a consequence, the aggregation of small-scale BESSs turned out to be uneconomical for customers and the flexibility service provider.
- With respect to the aggregation of EV charging stations, the average charging power of Helen's public chargers (70 kW) was was not high enough to comply with the 1 MW minimum bid to the FCR-D market. Therefore, the participation was simulated. The results showed that the system in use is not capable to meet the strict time requirements of the FCR-D market.
- As regards the participation of aggregated of residential electric heating loads (i.e. hot water tanks) to the mFRR market, a simulation of the potential benefits from the mFRR market has been performed for 727 customers. The technical tests performed could not meet the requirements for the mFRR market.
- A technical proof of concept has been developed for a new market mechanism to manage reactive power in the TSO/DSO connection point. Even though the operation of such a reactive power market – in the specific Helsinki case and demonstration period - could allow a large decrease in possible penalties (-16%)

for going out of local PQ-window, at this stage creating a totally new market is not seen economically viable in the case of Helsinki.

TABLE 13: THE FINNISH DEMONSTRATION KPI RESULTS

		Active power, real environment demos				Active power, simulated scenarios	Reactive power, real environment demo
	Sub-demos	Industrial-scale BESS 1.2 MW, 600 kWh ("Suvilahti BESS")	Medium-scale BESS 120 kW ("office-scale")	EV charging stations (calculated cases)	Customer-scale batteries (calculated cases)	flexibility of electric heating loads (simulated for 727 customers)	Reactive power market demo (Suvilahti BESS, PV plant in Kivikko, Helsinki)
KPI	**Service provision**	FCR-N (real market operation)	FCR-N (real market operation)	FCR-D (technical test)	FCR-N (technical test)	mFRR (simulation)	Qcompensation
# 1	Increase in revenue of the flexibility service provider	45184 € (4107 €/mo)*	7609 € (634 €/mo)*	Estimated revenue increase = 3066 €	Estimated revenue increase = 943 €	56 415 €/year ****	NA
# 2	Decrease in penalties for going out of the PQ window	NA	NA	NA	NA	NA	-16%
# 3	Reactive power market utilization factor	NA	NA	NA	NA	NA	27%
# 4	Flexibility service reliability	RMSE=0.174MW approx. 35 % of the offered capacity	RMSE=0.0239MW approx. 24% of the offered capacity	RMSE=1.151 MW	NA	NA	Excluding single BESS error: 6.28 kvar Hours of full delivery=93.5%
# 5a	Reliability of the aggregation platform	NA	99,23%	Success rate = 100%***	Success rate = 39,7%	NA	NA
# 5b	Usability of the asset	94.8%	99,47%	NA	NA	NA	Suvilahti BESS: 99.5% Kivikko PV-plant: 100% Combined: 99.75%
# 6	Customer acceptance	NA	NA	NA	100%	NA	NA
# 7	Profits of service provision	22259 € (2024 €/mo)*	5573 € (464 €/mo)**	NA	62€/year	23 249€/a	NA

NA = not applicable

*High yearly variation

**Customer profits

***Counting only the succesfull test days

****From manifold simulation cases, this option presented a case with max income to an aggregator and to customers.

4.1.2 PORTUGUESE VPP DEMONSTRATION

The Portuguese VPP demonstration showed the capability of aggregating assets located in LV and MV distribution networks in order to operate them in the TSO's reserve markets (FCR-N, FCR-D, mFRR) and for the DSO's reactive power compensation needs to stay within the limits of the PQ-window. The KPIs from the demonstration are summarised in

Table 13. Out of four KPIs, only three have been evaluated due to the lack of needed historic RES forecasts and missing input data for water inflows into reservoirs in the case of KPI 5 (Quality of forecasts of available Renewable Energy Sources (RES) power and water level of pumped storage plants).

TABLE 14: THE PORTUGUESE VPP DEMONSTRATION KPI RESULTS

KPI	Service provision	aFRR day-ahead market
# 1	Increase in revenue of the flexibility service provider	~2%
# 3	Variation in the imbalances in participation of RES in energy markets	imbalances reduced by ~18% imbalance costs reduced by ~38%
# 4	Market price forecasts quality	Averaged over an entire year all tested forecast methods are unbiased The “Expert Model” has a much smaller variance than the other two (“similar day” and “hour of week”) in both considered markets
# 5	Quality of forecasts of available Renewable Energy Sources (RES) power and water level of pumped storage plants	NA

NA = not applicable

The VPP approach in Scenario 2 showed a low ~2% overall profit sum increase compared to the sum of revenues from single single assets (PHS, and wind parks). The main interest of the VPP from an economic point of view lies in the reduction of imbalances by ~18% and imbalance costs by ~38% provided there is a smart forecast. Both economic KPIs (KPI #1 and #3) depend on the accuracy of the predicted power delivered by the renewable sources, the predicted market prices and market bidding optimization. Price variations over the day offer the possibility to earn money with storage performing energy arbitrage which depends on the accuracy of the market price predictions. Similarly, good predictions for the variable renewable energy production are essential for the correct timing of bids and amount of power in the bids at the market and the avoidance of imbalance costs, which are more difficult to avoid, when the renewable sources don’t behave as predicted.

As regards forecasting market buying and selling prices, four different methods (day-ahead, intraday and aFRR) have been considered: “Perfect”, “Expert Model”, “Similar Day” and “Hour of Week”. The simulations carried out show that, averaged over an entire year, all forecast methods are unbiased. The “Expert Model” has however a much smaller variance than the other two in both considered markets.
The results are similar for the day-ahead, intraday and aFRR markets.

4.1.3 FRENCH VPP DEMONSTRATION

The French VPP demonstration showed the capability of the wind power plant and the BESS to provide multiple flexibility services to the grid. It was showed that the provision of active power flexibility (FCR) in addition to energy arbitrage helps increasing the VPP revenue. From the VPP operation point of view, a VPP operating program scheduling based on stochastic optimization has been proven effective to reduce costly power imbalances (by more than ~5%) with respect to the commitments and entails higher overall revenues.
The KPIs from the demonstration are summarised in

Table 15. They are related to FCR provision only (KPIs 2, 4, 5, 6), energy arbitrage only (KPI 3) or both FCR provision and arbitrage (KPI 1). No KPIs have been assessed on the FFR, aFRR and multi-services provision.

TABLE 15: THE FRENCH VPP DEMONSTRATION KPI RESULTS

KPI	Service provision	Energy Arbitrage	FCR
# 1	Increase in revenue of the VPP by providing multi-services	~7% on average as compared to energy arbitrage only.	
# 2	Increase in revenue of the VPP by allocating reserve on multi-resources	NA	~7.23% (same as KPI 1)
# 3	Reduction in power imbalances by application of stochastic optimization	-4.5% (together with an increase in revenue of 0.25%)	NA
# 4	Compliance of the assessed FCR gain with the TSO's requirement	NA	Assessed FCR gain of the VPP conformed to the required quality level 53% of time (lower than the 90% expected performance.
# 5	Availability of the reserved power capacity for FCR provision	NA	64%
# 6	Reliability of the communication platform	NA	99.7%

NA = not applicable

The key performance indicators (KPIs) were assessed by precisely simulating the behaviour of the whole VPP system, in real or almost real conditions, over weeks. The following limitations were highlighted:

- Forecast errors could significantly reduce the full income of the VPP due to the costs for power imbalances settlement. A VPP program scheduling based on stochastic optimization, by considering probabilistic generation forecasts, can efficiently reduce power imbalances with respect to the commitments, which could result in higher overall revenues.
- From the VPP operation point of view, a VPP operating program scheduling based on stochastic optimization has been proven effective to reduce costly power imbalances with respect to the commitments and entails higher overall revenues. It has been assessed that more than ~5% of negative power imbalances can be mitigated and this goes along a slight increase of the VPP revenue.
- Globally, the performance of the frequency services provided by the wind farm and the BESS complied with the requirements imposed by the TSO. In the case of FCR provision, the percentage of time during which the assessed FCR gain of the VPP conformed to the required quality level was only 53%, which was lower than the 90% expected performance. This can be partially explained by the fact that the method applied to assess the actual gain of the FCR response was originally designed for conventional power plants and not for variable resources. Moreover, the performance of the FCR response procured from an industrial-scale VPP will also be largely improved.
- Even though the performance of the VPP was shown to be satisfactory, the demonstration highlighted two important key points that deserved particular attention:
    - The availability of the reserve provided by the VPP is greatly dependent on the accuracy of the wind forecasts.
    - The accuracy of the estimation of wind instantaneous available active power (AAP) is another key factor to ensure the performance of the frequency reserve provided, notably in terms of FCR control gain assessment.

4.1.4 GERMAN DEMONSTRATION

The demonstration showed that the coordination of flexibility providing System Operator (SO) and flexibility demanding SO is key for an efficient use of flexibilities and that an efficient schedule-based management of active and reactive power for redispatch and voltage control is feasible. The developed grid optimisation and processes (day-ahead and intraday processes for active power flexibilities, and process for reactive power flexibilities) allow schedule-based congestion management including balancing of adjusted infeed and load. This reduces the amount of needed frequency control reserve and allows the procurement of cost efficient flexibilities. The KPIs from the demonstration are recapped in Table 16:

TABLE 16: THE GERMAN DEMONSTRATION KPI RESULTS

KPI	Service provision	Provision of active and reactive power flexibility by the DSO to the TSO to support congestion management and voltage control
#1	Active power flow forecast quality	PV: Significant improvement of nRMSE (intraday: -5%, day-ahead: -4.3%) Significant reduction of bias (-10%) Wind: Slight reduction of nRMSE (-0.6%) for intraday Mean bias eliminated
# 2	Processing duration of the forecast chain	Entire chain: 3 min 10 s (very good even if slightly above the targeted 3 min)
# 3	Accuracy of the state estimation	Accuracy of active power estimation is higher than of reactive power estimation
# 4	Reduction of curtailment	Precise quantification of curtailed energy is not feasible For maximum capacity, the reduction varies from 0 % to 90 %
# 5	Active and reactive power flexibilities at the TSO/DSO interface	Both approaches – IEE.NetOpt and PQ-Maps - show good results in accuracy. The higher the input accuracy the better the results
# 6	Increase in efficiency of grid operation	Average of 5 % grid losses reduction (up to 9 %)

The main messages that can be derived from the analysis of the KPIs are as follows:

- The accuracy of forecast is the most important factor for reliable prediction of network states (KPIs #1, #2))
- The prediction of reactive power deviates more than active power (KPI #3)
- The complexity for grid operators can be reduced by German demonstration's Decision Support Tools (KPI #5).
- The efficiency of grid operation can be increased by approximately 5 %. (KPIU #6)

In the case of the German demonstration, the KPI evaluation process didn't highlight any specific limitation. Since settlement was out of scope of the German demonstration, a precise quantification of curtailed energy (KPI 4) was not feasible. This indicates further need of investigation.

4.1.5 ITALIAN DEMONSTRATION

Even if the control of RES by the DSO is not currently allowed, this experimentation has proved that the DSO is capable to implement network observability for the TSO and can perform controllability of connected generators involved in the experimentation. The DSO is able to provide suitable active and reactive power flexibility at its interface with the TSO and to interface dynamically with the latter, by respecting the existent communication protocols. The KPIs from the demonstration are recapped in

Table 17:

TABLE 17: THE ITALIAN DEMONSTRATION KPI RESULTS

KPI	Service provision	Provision of active and reactive power by the DSO to the TSO to support mFRR/RR and congestion management Provision of reactive power by the DSO to the TSO to support congestion management and voltage control
#1	Tracking error measured at TSO/DSO interface	The weather and climate conditions of the specific day when the field test was performed did not allow a significant production from the PV plants. Therefore, results can not be used to prove the full achievement of the requested setpoint at Quarto Primary Substation
# 2	Tracking error measured at DER interface	Between 0% and 0.25% The calculated error decreases as the requested Q value increases
# 8	Increase in hosting capacity at the primary substation	An increase of ΔHC% = 18% has been calculated with a conservative approach
# 6	Increase in reactive power capability at primary substation	Decrease in reactive power capability ΔC_RP% was about -1%. This result may be explained by the bad meteorological conditions of the season where the test has been executed - which do not support the production from PV plants – and the limited dispatchable resources involved in the simulation itself which does not contemplate the two Statcom modules and the Storage
# 7	Line voltage profile	Calculated ΔV(t) [%] (difference between the nominal voltage value and the effective operational one) decreases for each considered moment during the field test

The results of the demonstration highlighted the fact that the RES participation during the automated process of flexibility provision from the DSO to the TSO is widely affected by the seasonality of the PV production and the physical limits of capability curves while performing reactive power regulation. This suggests that it is needed to increase the number of participants to flexibility services and to define a wider flexibility service portfolio implementing also the active power regulation. Due to bad weather conditions and thus poor electricity production from PV plants, it was not possible to assess KPI #1 and the result of KPI #6 can not be considered as relevant.

From the measurements in the field it was possible to verify that the evolved voltage regulation allows to increase the hosting capacity at the primary substation and allows to maintain the voltage levels below threshold in the critical nodes of the network, in order to allow the correct operations even in limit situations (high production or high load) and facilitate the integration of additional DERs on the network portion affected by the project.

4.1.6 PORTUGUESE FLEXHUB DEMONSTRATION

The Portuguese Flexhub demonstrator has successfully proven the technical feasibility of finding new sources of active and reactive power flexibility for both the DSO and TSO in the case of the specific high voltage distribution grids and scenarios considered. The application to other grids shouldn't entail major problems since detailed grid topology and forecasts are usually available. The technical results related to the Equivalent Dynamic Model of the distribution grid suggest that the methodology and solution proposed performed very well in the modelling of the dynamics of the distribution grid, and much better than other traditional simplified approaches with a very affordable computational cost. The proposed methodological approach relying in a Grey Box can be easily exploited to derive robust equivalent models and parameter sets, with the key advantage of adopting models that can be easily integrated in commercially available tool while keeping a high accuracy for the obtained responses.
The KPIs of the demonstration are recapped in

Table 18. All KPIs have been assessed successfully. Two of them (#4 and #5) have a validity which is limited to the considered grids (Frades for KPI #4 and Evora for KPI #5) and are difficult to extrapolate to other cases:

TABLE 18: THE PORTUGUESE FLEXHUB DEMONSTRATION KPI RESULTS

KPI	Service provision	Local Reactive Power Market	Innovative active power market design (TLQ process)	Grid dynamic equivalent model
# 1	Bidding price estimation of providing reactive power	1.2 and 2.7 €/ Mvar (depends on month and hour of the day)		
# 2	System cost cost of providing reactive power	Larger usage of reactive power flexibility by the DSO to balance its grid than by the TSOs to operate its own. TSO sees payments obligations slightly higher than half those seen by the DSO. However, costs are inferred from past data that do not certainly represent properly a future scenario with high RES		
# 3	Bidding price estimation of providing active power		<u>RES generation</u>: RES will offer downwards flexibility at null or negative prices. Positive active power flexibility provision has not been considered here. <u>Demand response resources (load shedding)</u>: the flexibility provision is equivalent to selling a positive power at a stricly positive price. <u>Storage resources</u>: Storage facilities will offer upwards flexibility when the price is higher than the cost of charging this energy incremented with the storage losses due to the efficiency. Similarly, they will offer downwards flexibility when the price of buying this energy is lower than the incomes at which this energy was or will be sold, including the efficiency losses.	
# 4	Estimation of the increment of reactive power flexibility for the network operators (TSO and DSO)	Assessed for the particular case of Frades grid and is therefore difficult to extrapolate to other cases. In general, voltages tend to be more limiting than lines capacity. Relaxing voltage ranges could increase the flexibility.		
# 5	Estimation of the increment of active power flexibility for the TSO		The results obtained are very specific for the chosen Évora grid and cannot be generalized. The upward flexibility is mostly ensured by the storage device capacity and does not change significantly depending on the scenarios. The presence of curtailable loads does not increase the downward flexibility activated by the TLQ process	
# 6	Error in the reactive power provision service	Nil The actual amount of reactive power provided at the TSO-DSO connection point is		

		guaranteed provided that there is enough flexibility available		
# 7	Error in the active power provision service		Lower than 4% Error is very grid- and resource location dependent and should be assessed in each case.	
# 8	Execution time of the Q market clearing process	Less than 2 s (for Frades grid) Linear increment with the grid size.		
# 9	Execution time of TLQ process for the P market participation		10 s max (for Evora grid). No computational issues foreseen for larger grids.	
# 10	Network secure operation margins while delivering reactive power	Voltages remain between their acceptable limits		
# 11	Network secure operation margins while delivering active power		Voltage and load capacity levels remain between their acceptable limits (for Evora Grid)	
# 12	Modelling error of the dynamic model			<u>Voltage-short-circuit sensitivity</u>: The equivalent model has to a very good level of adherence to the detailed model <u>Voltage-Wind power operational point sensitivity</u>: The equivalent model is able to follow the aggregated active and reactive power dynamic response of the detailed model with a high level of success.
# 13	Benefit of a dynamic model vs a static resistive model			<u>voltage-short-circuit sensitivity</u>: The equivalent model is able to follow the behavior of the detailed model, even for untrained conditions. <u>Voltage-Wind power operational point sensitivity</u>: The equivalent model reveals a high level of adherence to the detailed model.

These KPIs allowed to identify some limiting factors mainly related to grid size and topology and RES marginal cost:

1. Regarding the reactive power flexibility provision, the shared cost between TSO and DSO (KPI 2) is grid-specific and depends on TSO needs. In addition, reactive power is a local service whose cost, from the point of view of the SO should be assessed by considering other local provisions of reactive power that should be added. Even though the assessment of this cost remains out of the scope of this work, it seems reasonable to expect a low impact on the whole systems costs. However, given the specificities of the demonstration, a broader set of networks and networks topology should be tested to extract meaningful conclusions about the economic benefits for both the assets owners and the grid operators.
2. In the case of short term active power flexibility provision (PT-FXH-AP BUC) and considering non-dispatchable resources, larger productions are usually not possible, and reducing generation has a direct impact on the revenues since it has not associated any kind of fuel savings. In this sense they may be willing to participate in providing active power to the TSO only bidding with a negative price (**KPI 3**).
3. Grid topology can have a relevant impact on the amount that the flexibility providers can actually deliver at the DSO-TSO connection point due to grid losses. In the case of short term active power flexibility provision (PT-FXH-AP) the error in the active power provision service delivered to the TSO at the TSO-DSO

connection point is very grid- and resource location dependent. Large errors imply large energy losses whose costs should be assessed and shared properly in each case, something not addressed in the demonstrator. In the case of the EVORA grid, it was general lower than 4% (**KPI 7**).

4. Execution times observed for the demonstration grids were low, and seem to increase (as the simulations showed) linearly with the grid size (**KPI 8 and 9**). However, when going to significantly larger grids, execution times could start increasing in a more exponential way. Therefore, this aspect should be further investigated with different grid topologies and sizes to confirm these first observations.

4.1.7 DATA EXCHANGE DEMONSTRATION

The KPIs described in

Table 12 show that the development and implementation of the BUCs and SUCs were successful. Some of the KPIs have not been assessed:

- No evaluation of user satisfaction (KPI 2.6) : no surveys were undertaken among customers since there was no direct interaction with them and the data was simulated in the demonstration.
- SUC not developed: KPIs 3.7, 3.8, 3.14, 3.19, 3.20, 3.21
- SUC developed but not implemented: KPIs 3.16, 3.18, 3.22

The only possible limitation identified here is related to the development of the affordable tool was not open-source (KPI 2.7). This could be a hindrance for evolutivity and replicability.

4.2 MAIN TAKE-AWAYS FROM THE KPI ANALYSIS

At the core of the EU-SysFlex project were industrial-scale solutions that were tested in WP6 to WP9.

- Three of them (Finland (WP6), Portuguese VPP (WP7) and France (WP8)) were dedicated at operating Virtual Power Plants (VPPs) to show how more services and more value could be provided to the system when assets such as generation sources, storage and demand-side response are aggregated.
- Three other demonstrations (Germany (WP6), Italy (WP6) and Portuguese FlexHub (WP7)) were dedicated at accessing and operating flexibilities embedded in the distribution grid in order to deliver services both to the TSO and the DSO, thereby improving coordination between both system operators.
- And finally a set of demonstrations within Work Package 9 focused on enhanced data exchange to favour the exchange of flexibilities in particular across borders and across sectors.

As mentioned earlier, KPIs have been defined according to a bottom-up approach, each demonstration defining its own KPIs that were to reflect the successes and failures. They necessarily vary from one demonstration to another even within a same group (VPP, TSO-DSO coordination, Data Exchange) and, for some demonstrations, do not cover the full scope of the trials but only specific aspects that demo leaders intended to quantify (e.g. France where KPIs only cover experiments related to FCR provision and energy arbitrage whereas over aspects were covered by the demonstration such as FFR and aFRR provision and ramp-rate limitation). This makes it rather difficult to carry out a cross-analysis of the results. In the following sections, the results are merely presented per group of demonstrations and according to the KPIs categories presented in the introductory paragraph.

4.2.1 VIRTUAL POWER PLANTS (VPP) OPERATION

Three demonstrations (Finland, France, Portugal) were aiming at aggregating assets in order to provide flexibility services. These ‘Virtual Power Plants’ were located on different voltage levels, used different types of assets, and provided different types of services to the TSO and/or the DSO.

- The Finnish demonstration aggregated small distributed assets in LV and MV networks (BESS, EV chargers, heating loads) and operated them to the TSO’s frequency regulation markets (FCR-N, FCR-D, mFRR). Besides, a proof-of-concept of reactive power market was demonstrated for the DSO’s reactive power compensation needs to stay within the limits of the PQ-window. In the demonstration, the reactive power assets were an 0.8 Mvar solar PV inverter and the industrial-scale 0.9 Mvar BESS.

- The French demonstration tested the concept of aggregation of several resources connected to the MV distribution grid (12MW wind farm, PV generation, 2MW/3MWh BESS) for multi-services provision (FFR, FCR, and aFRR). In addition, other features were tested such as ramp-rate control and stochastic optimisation for energy arbitrage. However, the KPIs only dealt with FCR provision and energy arbitrage.
- The Portuguese Virtual Power Plant (VPP) was aiming at providing flexibility from centralized resources, including pump storage plants (PSP) and wind power plants connected to the transmission level, and providing frequency regulation (aFRR) and balancing reserves (mFRR/RR). The resources used for the VPP demo comprised of a Variable Speed Hydro Power Plant 756 MW (2 x 378 MW), Venda Nova III, and two nearby Wind Farms (115 MW from 57 turbines & 50 MW from 25 turbines), the Alto da Coutada WF and the Falperra WF.

4.2.1.1 LOCAL ECONOMIC IMPACTS OF THE SOLUTIONS

The demonstrations dealing with VPP analysed economic impacts such as the increase in revenue for the flexibility provider or the decrease in possible penalties for not complying with the requirements (Finland). In the case of large-scale VPPs located on the transmission grid or MV grid, the analysis shows a moderate increase in revenue for the flexibility provider (as compared to the operation of uncoordinated single assets) but a strong interest for reducing imbalance costs. On the contrary, the aggregation of small assets on the LV grid for frequency regulation services (tested in Finland) turned out to be not economically viable at that stage. Neither was the reactive power market proof of concept for the DOS (Finland).

- In the Finnish demonstration, the increase in revenue related to the participation of various types of BESS in the FCR-N market was analysed. It revealed that the participation of an industrial-scale BESS (1.2MW/0.6MWh) could bring a large increase in revenue to the service provider. The increase of revenue was rather small in the case of a medium-scale BESS (120kW/136kWh). Finally, the aggregation of small-scale BESS (13 batteries of 3kW in average) turned out to be uneconomical for customers and the flexibility service provider. As regards the technical proof of reactive power market, it was shown that even though the operation of such a market could allow a large decrease in possible penalties (-16%) for going out of local PQ-window, at this stage its creation is not seen as economically viable.
- The French demonstration, which aggregated a 2MW/3MWh Li-ion storage and a 12MW wind farm, showed that the participation of the VPP in the FCR market could bring an average of 7% revenue increase, compared with the traditional management strategy of performing energy arbitrage only in the Spot market. One identified issue was that the participation in FCR leads to an additional uncertainty on the SoC level, which could sometimes prevent the VPP from respecting its commitment in the Spot market. However, the simulation results tend to show that the gain from the FCR provision is higher than the penalties generated by this uncertainty. The study revealed that it is beneficial to have a joint participation of the wind farm and the storage in FCR provision when both are available. Besides, the interest of a program scheduling based on stochastic optimization for the VPP management was analysed in the case of Energy Arbitrage with a focus on the mitigation of power imbalances. It turned out that the stochastic optimization proved effective to reduce costly power imbalances by ~4.5%.

- The Portuguese VPP approach showed a small (~2%) overall profit sum increase for aFRR provision compared to the sum of revenues from single single assets (PHS, and wind parks). In this case, the main interest of the VPP from an economic point of view lies rather in the reduction of imbalances by ~18% and imbalance costs by ~38%.

4.2.1.2 ABILITY OF THE SOLUTION IN MEETING SO' TECHNICAL NEEDS WITH RESPECT TO FLEXIBILITY SERVICE PROVISION

The compliance to the TSO's requirements of existing services provision with existing or new assets was studied in the French and in the Finnish demo for frequency regulation services provision. In the Finnish demo, the compliance of FCR-N, FCR-D and mFRR provision by aggregated LV and MV assets was studied whereas the French demo focused on the compliance of the actual gain of the VPP while offering the FCR service. In both cases, some results were either not compliant (FCR-D and mFRR provision in Finland) or not as high as expected initially (FCR in France).

- In the Finnish demo, the industrial scale and office scale BESSs provided a reliable service for the TSO's FCR-N reserve market whereas customer-scale BESS, failed to fulfil the requirements for FCR-N market as controlling of individual small assets was technically difficult. With respect to the aggregation of EV charging stations, the results showed that the system in use was not capable to meet the strict time requirements of the FCR-D market (requirement < 5 s from frequency change) as the communication delays were found to be too slow. Finally, concerning the participation of aggregated residential electric heating loads (i.e. hot water tanks) to the mFRR market, the tests performed with the first generation AMR meters and systems revealed that the time limits of the mFRR market were not reachable for a high amount of simultaneously operated AMR meters. The second generation AMR meters and systems could possibly bring a solution for this requirement.
- As regards the French VPP demo, the percentage of time during which the assessed FCR gain of the VPP conformed to the required quality level for the total duration of all tests was about 53%, much lower than the initial expected performance (90%). This can be partially explained by the fact that the method applied to assess the actual gain of the FCR response was originally designed for conventional power plants and not for variable resources. Moreover, the VPP demonstrator being at a reduced scale, the performance of the FCR response procured should be largely improved when up-scaling the VPP.

4.2.1.3 AVAILABILITY AND ACCURACY OF SUB-SYSTEMS (FORECAST, COMMUNICATION INFRASTRUCTURE).

Some KPIs dealt with the sub-systems and were addressing the accuracy of forecast (in the Portuguese VPP) and the availability of the communication infrastructure (in France). No specific problem was found:

- In Portugal, several algorithms have been developed concerning market buying and selling price forecasts (day-ahead, intraday and aFRR). Averaged over an entire year all forecast methods are unbiased. The "Expert Model" forecasts, that predict future price values by a linear combination of selected passed values, has a much smaller variance than the other two in all considered markets. Forecasts of available renewable power (wind farms and photovoltaic systems) and forecasting of water level of pumped storage plants couldn't be done due to a lack of input data.

- In France, the calculated overall availability of the whole ICT (Information and Communication Technology) infrastructure and interface, which is one of the most important subsystems of the VPP, equals to 99.7%, meaning that the implemented VPP communication platform proved to be highly reliable most of the time during normal operation.

4.2.1.4 RELIABILITY AND AVAILABILITY OF THE FLEXIBILITY SERVICES PROVIDED.

The reliability of the flexibility services provided was measured by calculating the RMSE in Finland for FCR-N and FCR-D provision and for the reactive power market and in France in the case of FCR provision. The availability of the assets was evaluated in Finland. Gobally, the frequency regulation services and the provision of reactive power services (Finnish demonstrator only) had a good reliability at a demonstration stage. In some cases, high RMSE values highlighted some faulty periods in which failures or malfunctions occurred. When these periods were removed from the calculations, the service provision was found to be reliable. The vaialbility of the assets was found to be higher than 95%.

- The reliability of the service provided by the BESS in the Finnish demonstrator (Flexibility service reliability) was evaluated by calculating the RMSE (Root mean squared error) between the hourly accepted bids and the realized power exchanges. As regards the Suvilahti (industrial-scale) BESS operated in the FCR-N market in the year 2020, on average the RMSE is 0.174 MW which represents approximately 35 % of the offered capacity. The RMSE could have been lower if the communication between the systems had not undergone some trouble in April and if the BESS had not malfunctioned in December. As regards the office scale BESS, the RMSE for the test period was 0.0239 MW which represents approximately 24 % of the offered capacity. This is significantly better than with the industrial scale BESS Finally, as regards the aggregation of EV chargers, the RMSE for the test period was 1.151MW which underlines the problems faced with the system during the tests. The availability of the assets was excellent (about 95% for the industrial-scale BESS and 99.5% for the office-scale BESS).
- The reactive power market proof-of-concept was operated successfully. When removing the effect of an error caused by a fault situation of the BESS on 31st May, the compensation service provision of both assets was found to be reliable (RMSE =6.28MW, Hours of full delivery=93.5%). The availability of the assets was 99.75 %, however the reactive power market utilization factor was only 27 % as the amount of additional reactive power from the market depends strongly on the time (season, weekday, hour).
- In France, it was found that on average, the FCR procured from the VPP was fully available during 64% of the total test time. The availability of the FCR power margin is quite dependent on the quality of the forecasts as well as on the wind generation level. This availability is likely to be improved with an update of the Operational Planning Scheduler.

4.2.1.5 CUSTOMERS' ACCEPTANCE

The Finnish demo was the only one dealing with distributed assets belonging to end-use customers. For all assets owned by end-use customers, the stakeholders'acceptance is very critical. Scaling-up the experiment or replicating it can not be reached without these customers. Accessing data requires agreements. Besides, the smaller the customer the smaller are the profits. Therefore, the technology, equipment, control systems should be simple enough to use and economical. Currently the customer-scale BESS owners are forerunners and so far only a few customers have purchased a BESS with their PV system. Helen's customers were contacted and discussed a possibility to participate in the demonstration. All of them agreed to participate.

4.2.2 TSO-DSO COORDINATION

Three demonstrations (Germany, Italy, Portugal) were aiming at accessing and operating flexibilities embedded in the distribution grid in order to deliver flexibility services such as congestion management and voltage support both to the TSO and the DSO, thereby improving coordination between both system operators.

- The German demonstration aimed at demonstrating the provision of active and reactive power flexibility to the TSO (50Hertz) from decentralized resources connected to the HV distribution grid of MITNETZ STROM in order to support congestion management and voltage control at the interface grid node with the transmission system.
- The Italian demonstration aimed at establishing the proof of concept for the provision of active power flexibilities (mFRR/RR and congestion management) and reactive power flexibilities at the Primary Substation interface (voltage control and congestion management in real-time). This would prove that e-distribuzione is able to provide a better observability of DERs and an aggregated information of network capability at its interface with the TSO (Primary Substation of the MW network).
- The Portuguese Flexibility Hub demonstration was conceived as a TSO-DSO coordination platform for the provision of short-term reactive and active power flexibility to the TSO from DSO grid connected resources, and longer term relevant information to the TSO for its planning process, by sharing with the TSO a grid dynamic equivalent model.

In all cases, the demonstration has been done taking into account transmission grid and distribution network mutual needs and constraints and thus improving data exchanges between the two System Operators.

4.2.2.1 LOCAL ECONOMIC IMPACTS OF THE SOLUTIONS

Some economic aspects were analysed in the Portuguese FlexHub demonstration only with respect to reactive power provision and to active power provision.
The costs of reactive power provision depend on the assets and were found to be low. The observed bidding prices ranged approximately between 1.2 and 2.7 €/ Mvar (over a year of observation). In the specific case of this demonstrator, results show a larger usage of reactive power flexibility by the DSO to balance its grid than by the TSOs to operate its own. Considering the low marginal cost of providing the services and the values obtained for this particular demonstrator grid, a low impact on the whole systems costs can be expected.

With respect to the provision of active power, the bidding price estimation of assets has been done qualitatively. Only renewable generation, demand response and storage were considered.

- As regards renewable generation units, the possibility to provide positive active power flexibility has not been considered in the demo. For downwards active energy flexibility, the TSO will resort to renewable generation bids with null or negative prices.
- As far as demand response is concerned, only load shedding has been considered. The flexibility will typically imply a consumption reduction which is equivalent to selling a positive power at a strictly positive price.
- As for storage facilities, it has been considered that they would be willing to sell upwards flexibility when the price is larger than the cost of previously buying this energy incremented with the storage losses due to the efficiency. Similarly, they would be willing to sell downwards flexibility if the price of buying this energy is lower than the incomes at which this energy was or will be sold, including the efficiency losses.

4.2.2.2 ABILITY OF THE SOLUTION IN MEETING SYSTEM OPERATORS’ TECHNICAL NEEDS WITH RESPECT TO FLEXIBILITY SERVICE PROVISION

The compliance to the TSO’s requirements of flexibility services provision was studied in all three demonstrations. Different aspects were analysed such as i) the accuracy of the state estimation and the reduction of curtailment in the german demo, ii) the tracking error and the increase in flexibility service provision capability in the Italian demo, and iii) the tracking error and the increment of active or reactive power flexibility for the network operators in the FlexHub demonstration. The system operators’ needs were met with a good accuracy in all cases and no specific problem was highlighted by these KPIs.

- **Germany**: The achieved accuracy of the state estimation was at the same level as the measurement error. Therefore, the developed state estimation tool meets the requirements. The demonstration showed that the accuracy of active power estimation is higher than of reactive power estimation due to the stronger non-linearity of reactive power. Curtailment has been reduced in all investigated cases but its precise quantification over time was not feasible and would need further investigation.
- **Italy**: The tracking error (resulting error between the requested Reactive Power Set-point and the measured one) has not been evaluated at the TSO/DSO interface due to poor weather conditions of the specific day when the field test was performed. The tracking error measured at the DER interface has been simulated and ranges between 0% and 0.25% and decreases as the requested Q value increases.
- The expected increase of reactive power capability at primary substation level has been calculated but the bad meteorological conditions and the limited dispatchable resources involved did not allow to achieve a realistic result.
- **Portuguese FlexHub**: The error in the reactive power provision service is null unless there is a lack of flexibility.
- It can be observed that the error in the provision of the active power provision services was in general lower than 4% for the particular EVORA grid, this error being however very grid- and resource location dependent.

4.2.2.3 IMPACTS ON THE POWER SYSTEM AND IN PARTICULAR ON THE DISTRIBUTION GRID WHERE CONGESTION MUST BE AVOIDED WHEN PROVIDING FLEXIBILITY SERVICES FROM DISTRIBUTED RESOURCES

Some impacts on the power system have been assessed, in particular on the distribution grid where congestion must be avoided when providing flexibility services from distributed resources. Various indicators were calculated depending on the demo: i) the grid losses reduction (Germany); ii) the hosting capacity increase (Italy); iii) the network secure operation margins while delivering active or reactive power (Italy, Portuguese FlexHub, Germany). It was found that the network secure operation margins (voltage profiles) were respected while delivering active or reactive power. The German demo achieved a significant grid losses reduction compensating the incurred costs.

- **Germany**: Depending on the available flexibility, German demonstration has shown an average of 5 % grid losses reduction (up to 9 %). Due to these reduced grid losses, costs for operating the innovative tools of the German demonstration are compensated.
  Since the German demonstration always considers (n-1)-cases when calculating available flexibility range, security margins can be reduced. It was investigated that, due to measurement errors when activating maximum flexibility at the TSO/DSO interface, voltage limits within the distribution grids could be breached. This risk is even larger considering deviation of forecast. Such risk only occurs at critical nodes within the grid. To identify the location and violation strength to enhance the efficiency in grid operation further investigation is needed. With todays operational security margins no limit violation was detected.
- **Italy**: An increase in hosting Capacity of $\Delta HC\%$ = 18% has been calculated at Quarto Primary Substation to estimate the rise in the potential connectable power to the distribution network.
- The line voltage profile has been analyzed on the most critical involved secondary node from the voltage rise point of view, due to production of energy from distributed generation. The calculated ΔV(t) [%] (difference between the nominal voltage value and the effective operational one) decreases.
- **Portuguese FlexHub**: The estimation of the increment of active or reactive power flexibility for the network operators (TSO and DSO) was done for particular grids (Frades grid for Q and Evora grid for P) and is therefore difficult to extrapolate to other cases. While delivering the expected reactive power, it was found that voltages remain between their acceptable limits and thus the resources activation respect the secure operation margins of the DSO grid. When upward and downward active power flexibility were activated the voltage and load capacity levels remained also between their acceptable limits.

4.2.2.4 ACCURACY OF THE FLEXIBILITY SERVICES PROVIDED AT THE TSO/DSO INTERFACE.

This aspect was addressed in the German demo only. Two different tools have been developed (IEE.NetOpt and PQ-Maps) to help scheduling preventive and corrective measures in congestion management and voltage control. Both approaches show good results in accuracy. The IEE.NetOpt tool is currently in line with the requirements of today's regulatory framework whereas, the PQ-Maps tool cannot be used in daily operation because the German regulation requires for schedule-based congestion management (redispatch) the segregated lists of available active and reactive power flexibilities at the DSO-TSO interface. This needed function is not integrated in PQ-Maps yet.

4.2.2.5 RELIABILITY AND AVAILABILITY OF THE SERVICES PROVIDED OR OF SUB-SYSTEMS (FORECAST, COMMUNICATION INFRASTRUCTURE).

The reliability and the availability of the sub-systems (forecast, communication infrastructure) have been studied in Germany with respect to the forecast quality and in Portugal with respect to execution times observed for the Q-Market clearing process and the TLQ process.

No specific problem was highlighted by the demo results. However, in the case of Portugal, the grid-size dependence of execution times would need further attention:

- **Germany**: A forecasting system was implemented which forecasts the individual generators and loads on the busbars or transformers at the MV/HV level for a period of up to a maximum of 48 hours into the following days. The PV forecast was significantly improved by post-processing. The wind forecast had an acceptable quality at the beginning and experienced a slight improvement of nRMSE in the intraday area.
- **Portuguese FlexHub**: Execution times observed for the demonstration grids were low but depend on the grid size and complexity. This should be further investigated with different grid topologies and sizes.

4.2.3 DATA EXCHANGE DEMONSTRATION

The KPIs of the Data Exchange demonstrations are of a different nature than those of the other EU-SysFlex demonstrations. The latter are generally oriented towards the flexibility providers or the System operators whereas the fomer are IT-related. The development and implementation of the BUCs and SUCs were successful and no specific problem was highlighted by the KPIs.

5. ANNEX 1: FINNISH DEMO KPIS

The Finnish demonstrator was testing the following services:

- Active power flexibility provision to TSO ancillary (frequency) services (FCR-N, FCR-D, mFRR)
- Reactive power flexibility provision to support the DSO to stay within the limits of PQ window and eventually to support the TSO in the voltage control of HV network

The initial KPIs of the Finnish demonstrator were described in Deliverable D10.1 *Report on selection of KPIs for the demonstrations*. They have been slightly updated during the EU-SysFlex project by adding two additional KPIs:

- KPI #5b: Usability of the asset
- KPI #7: Profits of service provision,

All KPIs are recapped below:

KPI n°1			
KPI name	**Increase in revenue of the flexibility service provider**	FIN	
Main objective	Calculation of the total increase in revenue by providing new services with a specific set of resources compared to the BaU services and resources.		
KPI Description	The Revenue is calculated by multiplying the provided power by the price of the service summed over a set of resources and a set of markets/services.		
Unit	€		
Formula	$$R = \sum_{s \in S} \sum_{a \in A} \sum_{t=1}^{T} \boldsymbol{P}_{s,a,t} \cdot \boldsymbol{\pi}_{s,a,t}$$ where: S is the set of available markets/services A is the set of available resources t is one of the T time periods considered $\boldsymbol{P}$ is the realized power exchanged π is the price		
Target value	Estimated costs of operating the flexibility		
Baseline scenario	Operating with the existing pre-SysFlex capacities		
Smart-Grid scenarios	With EU-SysFlex innovations. Horizon: demo period Operating the resources on other markets, or on a combination of markets.		

KPI n°2

KPI name	**Decrease in penalties for going out of the PQ window**	KPI ID	
Main objective	Estimate the value of the market that is being developed in the project for the DSO		
KPI Description	Calculating the cost of being out of the PQ window with and without the market support. The costs consist of two parts which are related (when being out of the window) to the 1) reactive power, 2) reactive energy.		
Unit	%		
Formula	$\frac{\boldsymbol{C_{hmarket}} - \boldsymbol{C_h}}{\boldsymbol{C_h}}$ The invoicing period is a month and the measurement data is hourly PQ data. Only those hours exceeding the PQ limits are taken into account, however, during a month, the 50 highest exceeding hours are free of charge and out of consideration. For those hours of interest, the costs include 1) the cost of reactive power and 2) the cost of reactive energy. $C = C_{power} + C_{energy}$ For power cost: For those *k* hours exceeding the PQ limits, the 51^{st} highest absolute value of Q determines the cost of power. $C_{power} = c_{power} * \boldsymbol{\Delta}Q_{51st\ max}$ *$\Delta Q_{51st\ max}$ is the amount of reactive power exceeding the PQ limits of the 51^{st} highest hour (*accurated definition compared to KPI definition presented in *D10.1 Report on the selection of KPIs for the demonstrations*) For energy cost: For those *(k-50)* hours exceeding the PQ limit are taken into account, the exceeding reactive energy is the penalized energy. $C_{energy} = c_{energy} * \sum_{51}^{k} \lvert \Delta Q \rvert$ Where: $\boldsymbol{C_h}$ is the cost for deviating from the allowed Q band when operating BaU $\boldsymbol{C_{hmarket}}$ is the cost for deviating from the allowed Q band when Q market is used $\boldsymbol{C_{power}}$ is the cost for reactive power		

	C_{energy} is the cost for reactive energy k is the number of hours when exceeding the PQ limits during a month $\Delta Q_{51st\ max}$ is the amount of reactive power exceeding the PQ limits of the 51st highest hour ΔQ is the amount of reactive power exceeding the PQ limits during an hour
Target value	Less than zero
Baseline scenario	w/o EU-SysFlex (compensators)
Smart-Grid scenario	with EU-SysFlex innovations. Horizon: demo period

KPI n°3			
KPI name	**Reactive power market utilization factor**	KPI ID	
Main objective	The goal is to measure the need for such a market and estimate the value for the aggregator		
KPI Description	Calculation of the number of hours that the market is being used to compensate the reactive power during the test period		
Unit	%		
Formula	$\frac{\sum h}{T_{test\ period}} \cdot 100\ \%$ Where: $\sum h$ is number of hours that the market is being used to compensate the reactive power $T_{test\ period}$ is the duration of the test period		
Target value	>0		
Baseline scenario	No baseline		
Smart-Grid scenario	with EU-SysFlex innovations. Horizon: demo period		

KPI n°4			
KPI name	**Flexibility service reliability**	KPI ID	
Main objective	Difference between the offered bids and the realized power exchanges.		
KPI Description	The root mean squared error (RMSE) between the bid power exchanges and the realized ones. This error includes forecasting errors, but also the other sources of errors in the system (e.g. communication failures, asset owner overriding the command, …)		

Unit	MW
Formula	$RMSE = \sqrt{\frac{\sum_{t=1}^{T}(P_{R,t} - P_{B_v,t})^2}{T}}$ Where: t is one of the T time periods considered P_R is the realized power exchanged P_{B_v} is the power accepted (or validated) from the bid on the market
Target value	Towards 0.
Baseline scenario	No baseline
Smart-Grid scenario	with EU-SysFlex innovations. Horizon: demo period

KPI n°5a			
KPI name	**Reliability of the aggregation platform**	KPI ID	
Main objective	The goal is to measure how reliably the platform delivers and receives information		
KPI Description	Calculating the hours that the communication is travelling through the platform		
Unit	%		
Formula	$AV[\%] = \frac{T_{com}}{T_{op}} \times 100\%$ Where: T_{com} [s] is the total duration in which all the aggregation platform is working correctly as defined in the demonstration specifications. T_{op} [s] is the total operational time of the aggregator during the tests carried out.		
Target value	$AV[\%] > x\%$, as good as possible		
Baseline scenario	No baseline		
Smart-Grid scenario	With EU-SysFlex. Horizon: demo period		

KPI n°5b			
KPI name	**Usability of the asset**	KPI ID	
Main objective	The goal is to measure asset usability		
KPI Description	Calculating the hours that the asset is available and usable for operation		
Unit	%		
Formula	$AV[\%] = \frac{T_{com}}{T_{op}} \times 100\%$ Where:		

	$\boldsymbol{T_{com}}$ [s] is the total duration in which asset is working correctly as defined in the demonstration specifications. $\boldsymbol{T_{op}}$ [s] is the total operational time of the asset during the tests carried out.
Target value	$\boldsymbol{AV}[\%] > x\%$, as good as possible
Baseline scenario	No baseline
Smart-Grid scenario	With EU-SysFlex. Horizon: demo period

KPI n°6			
KPI name	**Customer acceptance**	KPI ID	
Main objective	The goal is to have an attractive service that encourages the customers to give permission to use their resources (eg. electricity loads or battery storages) by the aggregator/utility company		
KPI Description	Measuring how well customers will engage to take part in grid stabilization. KPI can additionally be supported by conducting an interview with a defined group of customers, eg. key customers.		
Unit	%		
Formula	$\frac{\boldsymbol{accepted\ contracts}}{\boldsymbol{offered\ contracts}} \cdot \mathbf{100\%}$		
Target value	15% – 25%		
Baseline scenario	No baseline		
Smart-Grid scenario	With EU-SysFlex innovations. Horizon: demo period		

KPI n°7			
KPI name	**Profits of service provision (revenues of service provision-costs of service provision)**	FIN	
Main objective	Calculation of the benefit for the customers when they are provided new services with a specific set of resources compared to the BaU services and resources.		
KPI Description	The Revenue is calculated by multiplying the provided power by the price of the service summed over a set of resources and a set of markets/services and subtracted the cost of grid service and energy retail.		
Unit	€		
Formula			

	$R_{net}(T) = R(T) - C(T)$ where: $C(T) = C_{gridE}(T) + C_{gridP}(T) + C_{spot}(T)$ $C_{gridE}(T) = \sum_{n=1}^{T} P_{mFRR}(n)\pi_{gridE}(n)$ $C_{spot}(T) = \sum_{n=1}^{T} P_{mFRR}(n)\pi_{spot}(n)$ R_{net} is net income for the customers *R* is revenue from the markets (see KPI1) *C* is cost for the customers arisen from cost of grid tariff and energy tariff C_{gridE} is cost for the customers arisen from energy in the grid tariff C_{gridP} is cost for the customer arisen from demand in the grid tariff C_{spot} is cost for the customer arisen from spot based energy tariff $\boldsymbol{P}$ is the realized power exchanged π is the price
Target value	Estimated costs of operating the flexibility by taking into account the grid tariff and energy tariff
Baseline scenario	Operating with the existing pre-SysFlex capacities
Smart-Grid scenarios	With EU-SysFlex innovations. Horizon: demo period Operating the resources on other markets, or on a combination of markets.

6. ANNEX 2: PORTUGUESE VPP DEMO KPIS

KPI n°1	
KPI name	**Increase in revenue of the flexibility service provider (Overall economic performance of delivery via a VPP)**
Main objective	Assess total revenue increase
KPI Description	Calculation of the increase in revenue (from all services provision) brought about by using a VPP (as opposed to the individual operation and dispatch of units)
Unit	%
Formula	$$\Delta_{revenue}=\frac{Rev_{VPP}-\sum_{n=1}^{N}Rev_{Unit\,n}}{\sum_{n=1}^{N}Rev_{Unit\,n}}\cdot 100\%$$
Target Value	> 0
Baseline scenarios	Wind Parks without feed-in tariffs and going individually to the energy markets. The hydro power plant (VNIII) not belonging to a balancing area and go individually to the market.
Smart-Grid scenarios	With EU-SysFlex innovation. Aggregated (WP + VNIII) to the energy markets and the VPP as a balancing area.

KPI n°3	
KPI name	**Variation in the imbalances in participation of RES in energy markets**
Main objective	Assess the variation on the imbalances due to the VPP innovation
KPI Description	Two scenarios are compared: one in which RES reach the market through a VPP and another in which RES participate as a single unit
Unit	% (MWh)
Formula	$$\Delta_{Imabalance}=\frac{Imb_{VPP}-Imb_{single\ unit}}{Imb_{VPP}}\cdot 100\%$$ "Imb" stand for the imbalances (in MWh) of a given RES unit in both participation scenarios
Target Value	< 0
Baseline scenarios	Wind Parks without feed-in tariffs and going individually to the energy markets. The hydro power plant (VNIII) not belonging to a balancing area and go individually to the market.
Smart-Grid scenarios	With EU-SysFlex innovation. Aggregated (WP + VNIII) to the energy markets and the VPP as a balancing area.

KPI n°4	
KPI name	**Market price forecasts quality**
Main objective	Determine the accuracy of the new VPP price forecasting tools
KPI Description	Comparison of forecasted and actual prices in the intra-day, day ahead and ancillary services markets
Unit	% (€)
Formula	Forecast error: deviation between the actual market price for a given moment t (day, hour) and the forecasted price, as percentage of the actual value. $$\varepsilon_{mkt\ prices}(t) = \frac{p_{actual}(t) - p_{estimated}(t)}{p_{estimated}(t)} \cdot 100\ \%$$
Target Value	The target value should be higher than the reference taken from the current forecasting tools from EDP's trading unit (to be determined)
Baseline scenarios	No
Smart-Grid scenarios	Demo period

KPI n°5	
KPI name	**Quality of forecasts of available Renewable Energy Sources (RES) power and water level of pumped storage plants**
Main objective	Determine the accuracy of the new VPP forecasting tools for RES availability and water level at hydro power plants.
KPI Description	Comparison of forecasted and actual available power from RES
Unit	% (MW)
Formula	$$\varepsilon_{RES\ Power}(t) = \frac{P_{actual}(t) - P_{estimated}(t)}{P_{estimated}(t)} \cdot 100\ \%$$
Target Value	The target value should be higher than the reference taken from the current forecasting tools from EDP's trading unit (to be determined)
Baseline scenarios	No
Smart-Grid scenarios	Demo period

7. ANNEX 3: FRENCH DEMO KPIS

KPI n°1			
KPI name	**Increase in revenue of the VPP by providing multi-services**	KPI ID	*IR1*
Main objective	Assess the increase in revenue by providing frequency regulation services such as FCR in addition to the only energy purchase/sale (i.e. energy arbitrage).		
KPI Description	A VPP composed of renewables and storage could contribute to providing ancillary services such as frequency containment reserve, in addition to the traditional energy arbitrage in the Spot market. Within the VPP, the use of the operational planning scheduler will help make optimal decisions when providing multiple services to maximize the global revenue of the VPP. This will encourage new players to participate in ancillary service markets.		
Unit	%		
Formula	$IR1[\%] = \frac{G_{EUSysFlex} - G_{BaU}}{G_{BaU}} \times 100\%$ Where: $G_{EUSysFlex}$ [€] is the VPP revenue when ancillary services are provided. G_{BaU} [€] is the VPP revenue in the BaU (Business as Usual) scenario (the only activated service is the energy arbitrage).		
Target value	> 0		
Baseline scenario	Without EU-SysFlex innovation: assets aggregated for electricity energy purchase/sale; no frequency service is provided.		

KPI n°2			
KPI name	**Increase in revenue of the VPP by allocating reserve on multi-resources**	KPI ID	*IR2*
Main objective	Assess the increase in revenue by allocating the committed services on multiple resources within the VPP.		
KPI Description	In a context of aggregation of various assets, the services committed at the VPP level could be procured from different resources when they are available. For example, both wind generators and battery storage have the technical capability of providing symmetrical frequency reserves. The optimal way of reserve allocation inside a VPP depends on the availability and the operating point of each asset controlled, as well as on its use in the next scheduling time period. The use of an optimizer will help make optimal decisions when managing multi-resources for FCR provision, in order to maximize the global revenue of the VPP.		
Unit	%		

Formula	$IR2[\%] = \frac{R_{EUSysFlex} - R_{BaU}}{R_{BaU}} \times 100\%$ Where: $R_{EUSysFlex}$ [€] is the VPP revenue when frequency containment reserve is procured from various assets, within their allowed technical limits. R_{BaU} [€] is the VPP revenue in the BaU (Business as Usual) scenario, where FCR is only provided either by the battery storage or by the wind farm.
Target value	≥ 0
Baseline scenario	Without EU-SysFlex innovation: no coordinated reserve procurement is achieved within the VPP.

KPI n°3			
KPI name	**Reduction in power imbalances by application of stochastic optimization**	KPI ID	*IMB*
Main objective	Assess the reduction in power imbalances of the VPP while performing stochastic programming.		
KPI Description	Given that no guaranteed feed-in-tariffs for the PV and wind generation are considered in the demonstration, the net energy provided/consumed by the VPP has to be sold/purchased on the electricity market. Deviations from day-ahead and intraday schedules are valued at the positive/negative imbalance settlement prices, which are "penalizing" compared to the Spot prices. Therefore, it seems economically interesting to reduce power deviations from the committed schedules at the VPP level, which may be achieved by applying a scenario-based stochastic optimisation.		
Unit	%		
Formula	$IMB[\%] = \frac{IMB_{stochastic} - IMB_{deterministic}}{IMB_{deterministic}} \times 100\%$ Where: $IMB_{stochastic}$ [MWh] is the negative power imbalances when the VPP schedules are generated by applying stochastic programming. $IMB_{deterministic}$ [MWh] is the negative power imbalances when the VPP schedules are generated by applying deterministic programming.		
Target value	< 0		

KPI n°4			
KPI name	**Compliance of the assessed FCR gain with the TSO's requirement**	KPI ID	*CSP*

Main objective	Evaluate the performance of the FCR service provided by the VPP based on the requirements specified by the French TSO (RTE) in the current grid code.
KPI Description	According to the current rules of RTE, if one asset provides FCR with an actual gain lower than 20% of the contracted value, for more than 10% of the monitored period, the service is then considered as partially unavailable. In other words, to comply with RTE's requirements, the assessed FCR gain must mostly remain above 80% of the contracted theoretical value. Otherwise, the participating asset will be warned, and penalties will be applied if no corrective action is taken. Although the current market and technical requirements are not necessarily appropriate for assessing the reserve provided by renewables and may need to be adapted in the future, due to lack of references, this KPI assesses the "performance" of the VPPs' FCR by applying the current requirements.
Unit	%
Formula	$CSP[\%] = \frac{T_{compliant}}{T_{compliant} + T_{non-compliant}} \times 100\%$ Where: $T_{compliant}$[min] is the time duration in which the FCR provided by the VPP is compliant with the TSO's current requirement in terms of gain. $T_{non-compliant}$[min] is the time duration in which the FCR provided by the VPP is not compliant with the TSO's current requirement in terms of gain.
Target value	As close to 90% as possible

KPI n°5			
KPI name	**Availability of the reserved power capacity for FCR provision**	KPI ID	*ARP*
Main objective	Evaluate the availability of the FCR reserve that should be provided by the VPP in each commitment period.		
KPI Description	The current market rules require that FCR provision has to be committed a day ahead for at least a duration of 4 hours and in a symmetric form. In practice, on the very day, the FCR is rarely fully delivered and the mobilized reserve depends on the grid frequency. However, the committed reserve is deemed "available" only when it can be entirely delivered if extreme frequencies occur. In the context of the French VPP, the availability of the FCR could be affected by the variability of wind generation, notably when the reserve is allocated on this resource.		
Unit	%		

Formula	$ARP[\%] = \frac{TPS}{TPS + TRS} \times 100\%$ Where: TPS [min] is the time duration in which the FCR provided by the VPP is considered as fully "available". TRS [min] is the time duration in which the FCR provided by the VPP cannot be considered as fully "available" for different technical reasons.
Target value	as close to 100% as possible

KPI n°6			
KPI name	**Reliability of the communication platform**	KPI ID	*AVC*
Main objective	Evaluate the performance of the communication and IT platform based on *GeneSys* solution applied in the French demonstration.		
KPI Description	To ensure the interoperability and scalability of the WP8 demonstration, a new full-IEC-61850-based and hardware-agnostic software and communication platform was developed and implemented by EDF R&D. The availability of the whole ICT (Information and Communication Technology) infrastructure and interface is essential to ensure the robust data exchanges between the centralised control and all the assets, so as to guarantee a proper functioning of the VPP and its full services delivery capacity. This availability can be measured in percentage of the time during which the communication infrastructure is working as expected.		
Unit	%		
Formula	$AVC[\%] = \frac{T_{com}}{T_{op}} \times 100\%$ Where: T_{com} [s] is the total duration in which all the communication platform is working correctly as defined in the demonstration specifications. T_{op} [s] is the total running time of the VPP during the experimental tests.		
Target value	as close to 100% as possible		

8. ANNEX 4: GERMAN DEMO KPIS

KPI n°1	
KPI name	Decrease in costs for congestion management
Main objective	
KPI Description	Costs for congestion management and curtailment should be less with demonstrator or at least not higher
Unit	%
Formula	details how to measure which cost-components are unclear
Target value	
Baseline scenario	w/o EU-SysFlex innovations
Smart-Grid scenario	with EU-SysFlex innovations

KPI n°2	
KPI name	**Intraday update process duration**
Main objective	the intraday update process needs to be done in a certain time (for developing KPI can be divided into minor KPI for each step)
KPI Description	Calculation of the amount of time between information input ($\boldsymbol{T_i}$) and finalized adjusted schedule ($\boldsymbol{T_s}$)
Unit	s
Formula	$\boldsymbol{d = T_s - T_i}$ where: $\boldsymbol{T_i}$ is the time of information input $\boldsymbol{T_s}$ is the time of finalized adjusted schedule
Target value	5 minutes
Baseline scenario	
Smart-Grid scenario	

KPI n°3	
KPI name	**Keeping deadlines of the day ahead process**
Main objective	
KPI Description	The day ahead process begins and ends at certain times, plus there are different times in this process for information exchange, all these times have to be met
Unit	Y or N
Formula	met deadline yes or no no deviation
Target value	
Baseline scenario	
Smart-Grid scenario	

KPI n°4	
KPI name	**Meet TSO need in adjustment of schedule (active power adjustment error)**
Main objective	the aggregated need of schedule adjustment from TSO needs to be segregated for adjusting the schedule of single units, therefore the accuracy of optimization is important
KPI Description	in field-test, see if the adjustment of single units ($\boldsymbol{P_u}$) result in correct adjustment at TSO-DSO-interface ($\boldsymbol{P_{TDI}}$)
Unit	MW
Formula	$$\Delta \boldsymbol{P_S} = \boldsymbol{P_{TDI}} - \boldsymbol{P_u}$$ Where $\boldsymbol{P_u}$ is the active power adjustment of single units [MW] $\boldsymbol{P_{TDI}}$ is the active power adjustment at TSO-DSO-interface [MW]
Target value	$\Delta \boldsymbol{P_S} \leq value$
Baseline scenario	
Smart-Grid scenario	

KPI n°5	
KPI name	**Meet TSO need in adjustment of reactive power (Reactive Power Adjustment error)**
Main objective	same as for active power, but within close to real time adjustment

KPI Description	in field-test, see if the adjustment of single units ($\boldsymbol{Q_u}$) result in correct adjustment at TSO-DSO-interface ($\boldsymbol{Q_{TDI}}$)
Unit	MVaR
Formula	$$\Delta \boldsymbol{Q_S} = \boldsymbol{Q_{TDI}} - \boldsymbol{Q_u}$$ Where $\boldsymbol{P_u}$ is the reactive power adjustment of single units [MVaR] $\boldsymbol{P_{TDI}}$ is the reactive power adjustment at TSO-DSO-interface [MVaR]
Target value	$\Delta \boldsymbol{Q_S} \leq value$
Baseline scenario	
Smart-Grid scenario	

KPI n°6	
KPI name	**Meet TSO need in adjustment of voltage (Voltage Adjustment error)**
Main objective	same as reactive power, but voltage value
KPI Description	
Unit	V
Formula	$$\Delta \boldsymbol{U_S} = \boldsymbol{U_{TDI}} - \boldsymbol{U_u}$$ Where $\boldsymbol{U_u}$ is the voltage adjustment of single units [V] $\boldsymbol{U_{TDI}}$ is the voltage adjustment at TSO-DSO-interface [V]
Target value	$\Delta U \leq value$
Baseline scenario	
Smart-Grid scenario	

KPI n°7	
KPI name	**meet TSO need in delivering data**
Main objective	Needed data for demonstrator must be included in amount, accuracy and detail (e.g. sensitivity of each TSO-DSO-interface and interdependence between each TSO-DSO-interface
KPI Description	
Unit	Y or N
Formula	yes or no for each information needed (under discussion with TSO 50Hz)
Target value	Every needed information included

Baseline scenario	
Smart-Grid scenario	

KPI n°8	
KPI name	**Grid efficiency** $= 1 - \frac{P_o}{P_w}$
Main objective	standard use case of demonstrator is optimizing grid for most efficient operation, considering needs of connected parties including TSO
KPI Description	comparing losses without using adjustments stated in optimization (P_w) and with using these (P_o)
Unit	%
Formula	$$\eta = \frac{P_o}{P_w}$$ Where P_w represents the losses without using adjustments stated in optimization P_o represents the losses using adjustments
Target value	
Baseline scenario	
Smart-Grid scenario	

KPI n°9	
KPI name	**Percentage of scheduled flexibility**
Main objective	to prevent curtailment you need a planning process to address the needed amount of flexibility for congestion management in a schedule
KPI Description	ratio between scheduled flexibility (F_s) and the sum of scheduled adjustment and curtailment (F_c)
Unit	%
Formula	$$f = \frac{F_s}{(F_s + F_c)}$$ Where F_s is the scheduled flexibility F_c is the sum of scheduled adjustment and curtailment
Target value	

Baseline scenario	
Smart-Grid scenario	

KPI n°10	
KPI name	**Active power flow forecast quality – day-ahead**
Main objective	an accurate forecast is needed for a satisfactory planning process in congestion management; quality of adjusted schedule at 10pm for the next day
KPI Description	difference between measured ($\boldsymbol{m(t)}$) and day ahead scheduled ($\boldsymbol{s_d(t)}$) active power flow
Unit	MW
Formula	$$\boldsymbol{qd(t) = m(t) - s_d(t)}$$ Where $\boldsymbol{m(t)}$ is the measured active power flow $\boldsymbol{s_d(t)}$ is the day ahead scheduled active power flow
Target value	
Baseline scenario	
Smart-Grid scenario	

KPI n°11	
KPI name	**Active power flow forecast quality – intraday**
Main objective	an accurate forecast is needed for a satisfactory planning process in congestion management; quality of schedule 2h before measurement
KPI Description	difference between measured ($\boldsymbol{m(t)}$) and intraday scheduled ($\boldsymbol{s_i(t)}$) active power flow can also be quadratic average or mean value of multiple deviations
Unit	MW
Formula	$$\boldsymbol{qi(t) = m(t) - s_i(t)}$$ Where $\boldsymbol{m(t)}$ is the measured active power flow $\boldsymbol{s_i(t)}$ is the intraday scheduled active power flow
Target value	less than x MW as aggregated value less than 0.x MW as segregated value
Baseline scenario	

Smart-Grid scenario	

9. ANNEX 5: ITALIAN DEMO KPIS

KPI n°1	
KPI name	**Tracking error measured at TN_O/DN_O interface [%]**
Main objective	
KPI Description	Error between Reactive Power Set-point requested by TN_O $\boldsymbol{Q^*(t)}$ and the Reactive Power measure at TN_O/DN_O interface $\boldsymbol{Q(t)}$
Unit	%
Formula	$$e_{TSO/DSO}(t) = \frac{\lvert Q(t) - Q^*(t) \rvert}{Q^*(t)}$$ From the CDF (Cumulative Distribution Function) of $e_{TSO/DSO}(t)$ it can be calculated the 5th and 95th percentile of $e_{TSO/DSO}(t)$, or rather $e_{TSO/DSO}(t)_{(5\%)}$ and $e_{TSO/DSO}(t)_{(95\%)}$, that is the value for which 95% of all measurements fall below or above.
Target Value	0
Baseline scenarios	TBD it is not foreseen a baseline scenario
Smart-Grid scenarios	Optimization functionalities fully operating

KPI n°2	
KPI name	**Tracking error measured at DER interface [%]**
Main objective	
KPI Description	Error between Reactive Power Set-point requested by DN_O $\boldsymbol{Q^*(t)}$ and the Reactive Power measure at DN_O/DER interface $\boldsymbol{Q(t)}$
Unit	%
Formula	$$e_{DER}(t) = \frac{\lvert Q(t) - Q^*(t) \rvert}{Q^*(t)}$$ From the CDF (Cumulative Distribution Function) of $e_{DER}(t)$ it can be calculated the 5th and 95th percentile of $e_{DER}(t)$ or rather $e_{DER}(t)_{5\%)}$ and $e_{DER}(t)_{(95\%)}$, that is the value for which 95% of all measurements fall below or above
Target Value	0
Baseline scenarios	TBD it is not foreseen a baseline scenario
Smart-Grid scenarios	Optimization functionalities fully operating

KPI n°3	
KPI name	**Tracking error Monitoring at STATCOM interface [%]**
Main objective	
KPI Description	Error between Reactive Power Set-point requested by DN_O $\boldsymbol{Q}^*(\boldsymbol{t})$ and the Reactive Power measure at DN_O/STATCOM Interface $\boldsymbol{Q}(\boldsymbol{t})$
Unit	%
Formula	$$e_{STATCOM}(t) = \frac{\lvert Q(t) - Q^*(t)\rvert}{Q^*(t)}$$ From the CDF (Cumulative Distribution Function) of $e_{STATCOM}(t)$ it can be calculated the 5th and 95th percentile of $e_{STATCOM}(t)$%, or rather $e_{STATCOM}(t)_{(5\%)}$ and $e_{STATCOM}(t)_{(95\%)}$, that is the value for which 95% of all measurements fall below or above.
Target Value	0
Baseline scenarios	TBD it is not foreseen a baseline scenario
Smart-Grid scenarios	Optimization functionalities fully operating

KPI n°4	
KPI name	**Tracking error Monitoring at storage interface [%]**
Main objective	
KPI Description	Error between Reactive Power Set-point requested by DN_O $\boldsymbol{Q}^*(\boldsymbol{t})$ and the Reactive Power measure at DN_O/BESS interface $\boldsymbol{Q}(\boldsymbol{t})$
Unit	%
Formula	$$e_{BESS}(t) = \frac{\lvert Q(t) - Q^*(t)\rvert}{Q^*(t)}$$ From the CDF (Cumulative Distribution Function) of $e_{BESS}(t)$ it can be calculated the 5th and 95th percentile of $e_{BESS}(t)$%, or rather $e_{BESS}(t)_{(5\%)}$ and $e_{BESS}(t)_{(95\%)}$, that is the value for which 95% of all measurements fall below or above.
Target Value	0
Baseline scenarios	TBD it is not foreseen a baseline scenario
Smart-Grid scenarios	Optimization functionalities fully operating

KPI n°5	
KPI name	**Increase in active power capability at primary substation**
Main objective	
KPI Description	Increase in active power capability at primary substation.
Unit	%
Formula	$$\Delta C_{AP}\% = \frac{\sum_t(\Delta P_{SG} - \Delta P_{base})}{\sum_t \Delta P_{base}} \cdot 100\%$$ where: - ΔP_{base} is the active power capability at primary substation for baseline scenario, expressed as a time-function - ΔP_{SG} is the active power capability at primary substation for Smart Grid scenario, expressed as a time-function - $\Delta C_{AP}\%$ is the variation of active power capability expressed in percentage
Target	$\Delta C_{AP}\% > 0$
Baseline scenarios	1. No optimization functionalities; OLTC and curtailment only; no local flexibility market; 2. Optimization functionalities fully operating; OLTC and flexibility market; non-operating BESS
Smart-Grid scenarios	1. Optimization functionalities fully operating; OLTC and BESS; flexibility market 2. Optimization functionalities fully operating; OLTC and flexibility market; BESS operating

KPI n°6	
KPI name	**Increase in reactive power capability at primary substation**
Main objective	Increase in reactive power capability at primary substation.
KPI Description	
Unit	%
Formula	$$\Delta C_{RP}\% = \frac{\sum_t(\Delta Q_{SG} - \Delta Q_{base})}{\sum_t \Delta Q_{base}} \cdot 100\%$$ where: - ΔQ_{base} is the reactive power capability at primary substation for baseline scenario, expressed as a time-function - ΔQ_{SG} is the reactive power capability at primary substation for Smart Grid scenario, expressed as a time-function $\Delta C_{RP}\%$ is the variation of reactive power capability expressed in percentage
Target Value	$\Delta C_{RP}\% > 0$
Baseline scenarios	1. No optimization functionalities; OLTC only; fixed reactive power capability for DERs

	2. Optimization functionalities fully operating; OLTC operating; variable reactive power capability for DERs; non-operating BESS and STATCOM
Smart-Grid scenarios	**1.** Optimization functionalities fully operating; OLTC, BESS and STATCOM operating; variable reactive power capability for DERs **2.** Optimization functionalities fully operating; OLTC operating; variable reactive power capability for DERs; BESS and STATCOM operating

KPI n°7	
KPI name	**Line voltage profiles**
Main objective	Power Quality improvements (in this case voltage quality) [%]
KPI Description	
Unit	%
Formula	$$\boldsymbol{\Delta V(t) = \lvert V^*(t) - 1 \rvert}$$ Where $\boldsymbol{V^*(t)}$ is the normalized voltage profile, obtained as follows: $$\boldsymbol{V^*(t) = \frac{V(t)}{V_n}}$$ • $\boldsymbol{V(t)}$ is the voltage profile • Vn is the nominal voltage value From the CDF (Cumulative Distribution Function) of $\boldsymbol{\Delta V(t)}$ it can be calculated the 5th and 95th percentile of $\boldsymbol{\Delta V(t)}$%, or rather $\boldsymbol{\Delta V(t)}_{(5\%)}$ and $\boldsymbol{\Delta V(t)}_{(95\%)}$, that is the value for which 95% of all voltage line measurements fall below or above.
Target Value	**0**
Baseline scenarios	BAU scenario: No optimization functionalities
Smart-Grid scenarios	Optimization functionalities fully operating

KPI n°8	
KPI name	**Hosting Capacity variation**
Main objective	Smart Grid solutions allow better network operations resulting in an increase in HC. This may drive to a higher penetration of DERs and, consequently, to a potentially higher participation to ancillary services provision
KPI Description	
Unit	%
Formula	$$\boldsymbol{\Delta HC\% = \frac{HC_{SG} - HC_{base}}{HC_{base}} \cdot 100\%}$$ where: - $\boldsymbol{HC_{base}}$ is the network hosting capacity for baseline scenario

	- HC_{SG} is the network hosting capacity for Smart Grid scenario - $\Delta HC\%$ is the variation of the network hosting capacity expressed in percentage
Target Value	$\Delta HC\% > 0$
Baseline scenario	No optimization functionalities; OLTC and curtailment only;
Smart-Grid scenario	Optimization functionalities fully operating; OLTC, BESS, STATCOM operating; flexibility market

KPI n°9	
KPI name	**Availability of the communication infrastructure**
Main objective	Ensure highest connectivity It should be assessed for each specific service and in relationship to their latencies. It's also necessary to refer to the analysis which will be made on WP5 to use more specific KPIs related to TLC matters.
KPI Description	
Unit	%
Formula	$\frac{MTBF}{MTBF + MTTR}$ Where MTBF is generally specified in the units of hours. One year has 24*365 = 8760 hours. In general, hardware MTBFs are in the range of 100,000 hours or more and software MTBFs are in the range of 10,000 to 50,000 hours. MTBF (Mean Time Between Failure) is the measure of failure rate. MTTR (Mean Time to Repair) represents the average time required to detect, troubleshoot, obtain replacement parts and service personnel, and restore product functionality. Availability improvement is gained significantly faster by decreasing MTTR than by increasing MTBF. Increasing k times MTBF is equivalent with decreasing k MTTR.
Target value	
Baseline scenario	
Smart-Grid scenario	

KPI n°10	
KPI name	**PV Forecast Quality**

Main objective	MAE – mean absolute error of PV plants [kW]
KPI Description	
Unit	kW
Formula	$$MAE = \sum \lvert F - M \rvert$$ Where F is Forecast value and M is measured value of Power, of each PV plant
Target value	As close as possible to 0
Baseline scenario	BAU scenario: AS-IS algorithms based on weather forecast from external provider
Smart-Grid scenario	EU-Sysflex approach: improvements of algorithms and weather forecast fully operating

KPI n°11	
KPI name	**PV Normalized Forecast Quality**
Main objective	NMAE – normalized mean absolute error of PV plants [%]
KPI Description	
Unit	
Formula	$$NMAE = \frac{MAE}{Pnom}$$ Where *Pnom* is nominal Power of Power Plant
Target value	As close as possible to 0
Baseline scenario	BAU scenario: AS-IS algorithms based on weather forecast from external provider
Smart-Grid scenario	EU-Sysflex approach: improvements of algorithms and weather forecast fully operating

10. ANNEX 6 : PORTUGUESE FLEXHUB DEMO KPIS

KPI n°1	
KPI name	**Bidding price estimation of providing reactive power**
Main objective	The objective is estimating the cost or price of providing reactive power from the wind generator available in the FlexHub demonstration. This estimation could also provide some insight for other assets types, as well as helping to assess this system service.
KPI Description	Bidding price estimation, based on the costs of providing the service.
Unit	€/MVARh
Formula	Calculations could consider fixed and variable costs, and in general depend on the asset considered, see for example “A Model for Reactive Power Pricing and Dispatch of Distributed Generation”, H. Haghighat; S. Kennedy.
Target value	No target
Baseline scenario	Currently reactive power should be inside a regulated range near zero and penalties are applied if this range is exceed.
Smart-Grid scenario	FlexHub reactive power market will allow to provide other reactive power values, suitable for the TSO, and outside the range mentioned.

KPI n°2	
KPI name	**Service cost of providing reactive power.**
Main objective	Bids are used to provide the TSO reactive power request. However, guaranteeing that no DSO grid constraints are violated, may also imply some resources usage. The objective of this KPI is to assess the service cost and its allocation between TSO and DSO according their respective resources usage.
KPI Description	The OPF market clearing will provide the service cost. By clearing without TSO reactive power requirements, the cost of the resources used by the DSO alone can be estimated.
Unit	€/MVARh and %
Formula	As described two OPF must be run and costs subtracted.
Target value	No target
Baseline scenario	No TSO reactive profile requested.
Smart-Grid scenario	TSO reactive profile requested.

KPI n°3	
KPI name	**Bidding price estimation of providing active power**
Main objective	The objective is to estimate a reasonable price for the wind power generators to participate in the new active power reserve market proposed. This cost could be estimated by assessing the energy opportunity costs with past data.
KPI Description	Bidding price estimation of providing active power in the proposed extended tertiary reserve market.
Unit	€/MWh
Formula	Cost-benefit analysis considering energy and reserve historical market prices, forecasted generation profiles, and other technical issues could be used.
Target value	No target.

Baseline scenario	No participation in replacement reserve services
Smart-Grid scenario	Participating in the extended replacement reserve service

KPI n°4	
KPI name	**Estimation of the increment of reactive power flexibility for the network operators (TSO and DSO).**
Main objective	Assessment of the increased reactive power regulation that can be provided from the assets in the DSO grid with the proposed market and corresponding regulation, for the demonstration assets.
KPI Description	The increment of reactive power regulation will depend on the technical features of wind generators and electronic equipment, but also on the regulatory changes allowing the provision of this service with the proposed market, to benefit from the existing distribution grid flexibility.
Unit	MVARh
Formula	$\sum_{assets}(Q.T),\ st\ grid\ constraints$ (reactive power by time)
Target value	No target
Baseline scenario	Without reactive power market (BAU)
Smart-Grid scenario	With the proposed reactive power market

KPI n°5	
KPI name	**Estimation of the increment of active power flexibility for the TSO**
Main objective	Assess the increment of active power regulation that can be provided from the assets of the FlexHub demonstration.
KPI Description	The increment of active power regulation will depend on the technical features of the wind generators and their electronic equipment, and on the opportunity cost of providing this service.
Unit	MWh
Formula	$\sum_{assets}(P.T),\ st\ grid\ constraints$ (active power by time)
Target value	No target
Baseline scenario	Without replacement reserve market participation (BAU)
Smart-Grid scenario	With the participation in the proposed active power market

KPI n°6	
KPI name	**Error in the reactive power provision service**
Main objective	Assess the difference between the requested reactive power and the reactive power finally provided.
KPI Description	Due to non-continuous regulations, losses, grid constraints, etc, it becomes of interest assessing the error of providing the reactive power hypothetically requested by the TSO.
Unit	%
Formula	$(Provided\_Q - Req\_Q)/Req\_Q$
Target value	Null error

Baseline scenario	Ideal performance
Smart-Grid scenario	Real performance

KPI n°7	
KPI name	**Error in the active power provision service**
Main objective	Assess the difference between the requested active power and the active power finally provided.
KPI Description	Due to non-continuous regulations, losses, grid constraints, etc, it becomes of interest assessing the error providing the active power hypothetically requested by the TSO.
Unit	%
Formula	$(Provided\_P - Req\_P)/Req\_P$
Target value	Null error
Baseline scenario	Ideal performance
Smart-Grid scenario	Real performance

KPI n°8	
KPI name	**Execution time of the Q market clearing process**
Main objective	The computational processes involved are complex and it is difficult to forecast the time required. The objective is to assess this time to test the feasibility of such a service, or the need of especial computational resources.
KPI Description	The whole process will be simulated under different conditions to test the execution times and assess the feasibility of the proposal, the need of special requirements to comply with initially proposed time-periods, or the need of enlarging these times.
Unit	s
Formula	Measured time of the whole process execution
Target value	Below the delivery time period (15 min)
Baseline scenario	Ideal performance
Smart-Grid scenario	Real performance

KPI n°9	
KPI name	**Execution time of TLQ process for the P market participation**
Main objective	The computational processes involved are complex and it is difficult to forecast the time required. The objective is to assess this time to test the feasibility of such a service, or the need of especial computational resources.
KPI Description	The whole process will be simulated under different conditions to test the execution times and assess the feasibility of the proposal, the need of special requirements to comply with initially proposed time-periods, or the need of enlarging these times.
Unit	s
Formula	Measured time of the whole process execution
Target value	Below the delivery time period (15 min)

Baseline scenario	Ideal performance
Smart-Grid scenario	Real performance

KPI n°10	
KPI name	**Network secure operation margins while delivering reactive power**
Main objective	The objective is to test how the resources activation respect the secure operation margins while making a more efficient usage of the grid.
KPI Description	Different simulations may allow to see how the service is differently provided when the grid margins security coefficients vary, pushing the grid closer to the grid constraints violation.
Unit	%
Formula	An average measure of how the grid constraints are violated will have to be designed, by comparing the resulting line flows and voltage nodes with their margins.
Target value	No target
Baseline scenario	No flexhub reactive power market
Smart-Grid scenario	With the flexhub reactive power market

KPI n°11	
KPI name	**Network secure operation margins while delivering active power**
Main objective	The objective is to test how the resources activation respect the secure operation margins while making a more efficient usage of the grid.
KPI Description	Different simulations may allow to see how the service is differently provided when the grid margins security coefficients vary, pushing the grid closer to the grid constraints violation.
Unit	%
Formula	An average measure of how the grid constraints are violated will have to be designed, by measuring, for each constraint line flow and voltage node, how far they are from their limits.
Target value	No target
Baseline scenario	Without replacement reserve market participation (BAU)
Smart-Grid scenario	With the participation in the proposed active power market

KPI n°12	
KPI name	**Modelling error of the dynamic model BUC**
Main objective	The objective is to assess the errors between the real grid behavior and the behavior as represented by the simplified dynamic model
KPI Description	Since the model is a simplified representation of the distribution grid, this KPI is to determine how well the proposed model is performing in terms of errors. Different performance test will need to be designed to see how the models performs.
Unit	%
Formula	Error of the model performance under frequency or voltage disturbances.

Target value	No error
Baseline scenario	Ideal model performance
Smart-Grid scenario	Real model performance

KPI n°13	
KPI name	**Benefit of a dynamic model vs a static resistive model**
Main objective	The objective is to qualitatively assess the benefits of using a dynamic representation of the distribution grid, instead of a conventional resistive model, for the TSO dynamic analysis.
KPI Description	Since dynamic analysis should have a good dynamic representation of the whole grid, the dynamic model BUC tries to improve the static models traditionally used by for the distribution grids. A better dynamic representation of these grids should improve the quality of the models the TSO uses for dynamic analysis. This KPI tries to qualitatively assess these benefits.
Unit	Qualitative assessment
Formula	List of benefits and drawbacks of such approach
Target value	No target
Baseline scenario	The distribution grid is represented with a static resistive model
Smart-Grid scenario	The distribution grid is represented with the equivalent dynamic model

11. ANNEX 7: DATA EXCHANGE DEMO KPIS

In the following table, the green color in the cells means that KPIs are only assessed for the related demonstrations.

#	KPI	DEMONSTRATIONS				
		Affordable tool	Flexibility platform	Cross-Border exchange of flexibility services		
		(A)	(B)	(C)	(D)	(E)
				Elering + Energinet	Elering + ESO	Elering + ENTSO-E
1. Global KPIs (project level KPIs)						
1.1	KPI name: Easy access to own data KPI description: Increase in number of European consumers (both individuals and organizations) that can access their electricity meter data (i.e. from all metering points, incl. from sub-meters) through a single access point no later than on the following day Unit: % Target value: At least [90] percent of European consumers in 2030					
1.2	KPI name: Sharing information related to participation in flexibility market KPI description: Increase in availability of all flexibilities to all concerned TSOs and DSOs as a result of sharing information related to participation in flexibility markets Unit: % Target value: At least [90] percent of all flexibilities in Europe are available to all concerned TSOs and DSOs by [2030]					
1.3	KPI name: Energy services and applications benefiting from data exchange KPI description: Increase in number of metering points and applications connected by European data exchange model Unit: # Target value: European data exchange model connecting at least 100 million metering points and 1000 applications by [2020] and […] million metering points and […] applications by [2030]					
2. Non-functional KPIs – (from BUCs)						

#	KPI	DEMONSTRATIONS				
		Affordable tool	Flexibility platform	Cross-Border exchange of flexibility services		
		(A)	(B)	(C)	(D)	(E)
				Elering + Energinet	Elering + ESO	Elering + ENTSO-E
2.1	KPI name: Delivery/Implementation KPI description: Application has been delivered into an environment available to partners for testing Unit: tbd Target value: tbd					
2.2	KPI name: Expected flexibility KPI description: it should be possible to calculate within some relative precision (p), actual flexibility available when a command is issued. This must take into account time delays in communication and variability in available flexibility Unit: relative precision (p) for flexibility availability Target value:					
2.3	KPI name: Deliverability of flexibility service at time step t KPI description: the loads, or a percentage (p) of the loads, will turn off within some time (t) after the command to turn off is given. Unit: tbd Target value: tbd					
2.4	KPI name: duration of flexibility delivery KPI description: the loads will remain off for the duration promised by the flexibility provider. Unit: tbd Target value: tbd					

#	KPI	DEMONSTRATIONS				
		Affordable tool	Flexibility platform	Cross-Border exchange of flexibility services		
		(A)	(B)	(C)	(D)	(E)
				Elering + Energinet	Elering + ESO	Elering + ENTSO-E
2.5	KPI name: Performance – messaging latency KPI Description: Exchange of date. Received by requesting party in due time Unit: Y or N Target value: Yes					
2.6	KPI name: User satisfaction KPI description: survey on the satisfaction of small distributed flexibility sources (consumers/generators) contributing to the aggregated flexibility Unit: tbd Target value: tbd					
2.7	KPI name: Open Source KPI Description: will the developments be open-source? share of open source components in the platform Unit: Y or N Target value: Yes or a percentage (For the flexibility platform, 80% of components used open-source components)					
2.8	KPI name: Connectivity KPI Description: the flexibility platform (DEP) can receive information from Estfeed DEP and send information to Estfeed DEP Unit: Y or N Target value: Yes					
3. KPIs related to System Use cases – functional KPIs (from SUCs)						
3.1	KPI name: Collect energy data KPI description: N° of data hubs (existing and new data hubs) to be used for collecting the different types of energy data in the demos Unit: # data hubs Target value: at least 6 data hubs					

#	KPI	DEMONSTRATIONS				
		Affordable tool	Flexibility platform	Cross-Border exchange of flexibility services		
		(A)	(B)	(C)	(D)	(E)
				Elering + Energinet	Elering + ESO	Elering + ENTSO-E
3.2	KPI name: Transfer energy data KPI description: Data exchange platform capable to transfer different types of data Unit: Y or N Target value: Yes					
3.3	KPI name: Provide list of suppliers and ESCOs KPI description: List of suppliers and service providers is available through the data exchange platform. List of aggregators is available through the flexibility platform Unit: Y or N Target value: Yes					
3.4	KPI name: Manage flexibility bids KPI description: Effective flexibility prequalification and bidding processes supported by 'single flexibility platform' Unit: Y or N Target value: Yes					
3.5	KPI name: Manage flexibility activations KPI description: Effective flexibility activation process supported by one 'single flexibility platform' Unit: Y or N Target value: Yes					
3.6	KPI name: Verify and settle activated flexibilities KPI description: Effective verification and settlement processes supported by 'single flexibility platform' Unit: Y or N Target value: Yes					

#	KPI	DEMONSTRATIONS				
		Affordable tool	Flexibility platform	Cross-Border exchange of flexibility services		
		(A)	(B)	(C)	(D)	(E)
				Elering + Energinet	Elering + ESO	Elering + ENTSO-E
3.7	KPI name: Manage users' requests KPI description: *SUC not developed yet* Unit: tbd Target value: tbd					
3.8	KPI name: Notify customers KPI description: *SUC not developed yet (*GDPR compliance must be ensured.) Unit: tbd Target value: tbd					
3.9	KPI name: Manage authorizations (permissions) KPI description: Personal and other sensitive data can be exchanged based on data owner's consent (authorization). Authorization can be issued on data exchange platform. GDPR compliance must be ensured. Unit: Y or N Target value: Yes					
3.10	KPI name: Authenticate data users KPI Description: Data users need to be authenticated on data exchange platform before having access to personal and other sensitive data. Representation rights can be given on data exchange platform. GDPR compliance must be ensured. Unit: Y or N Target value: Y					

#	KPI	DEMONSTRATIONS				
		Affordable tool	Flexibility platform	Cross-Border exchange of flexibility services		
		(A)	(B)	(C)	(D)	(E)
				Elering + Energinet	Elering + ESO	Elering + ENTSO-E
3.11	KPI name: Manage security logs KPI Description: Data owner, application and data source can access logs related to data exchange and authorizations on data exchange platform. GDPR compliance must be ensured. Unit: Y or N Target value: Yes					
3.12	KPI name: Calculate flexibility baseline KPI description: Effective flexibility calculation process supported by 'single flexibility platform' Unit: Y or N Target value: Yes					
3.13	KPI name: Predict flexibility availability KPI description: Effective flexibility prediction processes supported by 'single flexibility platform' Unit: Y or N Target value: Yes					
3.14	KPI name: Process massive data KPI description: *SUC not developed yet* Unit: tbd Target value: tbd					
3.15	KPI name: Manage sub-meter data KPI description: Effective sub-meter data management processes supported by data exchange platform Unit: Y or N Target value: Yes					

#	KPI	DEMONSTRATIONS				
		Affordable tool	Flexibility platform	Cross-Border exchange of flexibility services		
		(A)	(B)	(C)	(D)	(E)
				Elering + Energinet	Elering + ESO	Elering + ENTSO-E
3.16	KPI name: Exchange data between DER and SCADA KPI description: Effective data exchange processes between DER resources and network operators supported by data exchange platform and flexibility platform Unit: Y or N Target value: Yes					
3.17	KPI name: Anonymize data KPI Description: *SUC not developed yet* Unit: tbd Target value: tbd					
3.18	KPI name: Aggregate energy data KPI Description: *SUC not developed yet* Unit: tbd Target value: tbd					
3.19	KPI name: Integrate new data source KPI Description: *SUC not developed yet* Unit: tbd Target value: tbd					
3.20	KPI name: Integrate new application KPI Description: *SUC not developed yet* Unit: tbd Target value: tbd					
3.21	Detect data breaches KPI Description: *SUC not developed yet* (GDPR compliance must be ensured.) Unit: tbd Target value: tbd					

#	KPI	DEMONSTRATIONS				
		Affordable tool	Flexibility platform	Cross-Border exchange of flexibility services		
		(A)	(B)	(C)	(D)	(E)
				Elering + Energinet	Elering + ESO	Elering + ENTSO-E
3.22	Erase and rectify personal data KPI Description: Effective erasure and rectification processes of personal data supported by data exchange platform. GDPR compliance must be ensured. Unit: Y or N Target value: Yes					

12. REFERENCES

12.1 EU-SYSFLEX DELIVERABLES

Sinitsyna K et al. EU-SysFlex project Deliverable 6.7. *The German Demonstration-Flexibility of Active and Reactive Power from HV Distribution Grid to EHV Transmission Grid*. February 2022

Tegas S et al. EU-SysFlex project Deliverable 6.8. *Italian demonstrator - DSO support to the transmission network operation*. March 2022

Ojala O et al. EU-SysFlex project Deliverable 6.9. *Finnish demonstrator – Market based integration of distributed resources in the transmission system operation*. September 2021

Silva B et al. EU-SysFlex project Deliverable 7.6. *Report for scalability and replicability analysis and flexibility roadmap (WP7)*. October 2021

Wang Y et al. EU-SysFlex project Deliverable 8.4. *French demonstration: "multi-resources multi-services" virtual power plant*. January 2022

Kukk K et al. EU-SysFlex project. *Cross-border and crosssectoral data exchange demonstrators – Summary Report*. October 2021

12.2 EUROPEAN ELECTRICITY GRID INITIATIVE (EEGI)

Costa Rausa C. et al. '*Grid+ Project (Supporting the Development of the European Electricity Grids Initiative). Deliverable D3.4: "Define EEGI Project and Programme KPIs"*', 2013.

'*European Electricity Grid Initiative Research and Innovation Roadmap 2013-2022*'. Grid+ European Project, 2013.

12.3 ETIP-SNET

Technofi, EASE, EDSO, ENTSO-E, RSE, and VITO. '*Final 10-Year ETIP SNET R&I Roadmap Covering 2017-26*'. Contract ENER C2/2014-642 / S12.698798. ETIP-SNET, 2016.

Technofi, RSE, Bacher, EASE, EDSO, ENTSO-E, and EERA. '*ETIP-SNET Implementation Plan 2017-2020*'. Contract H2020 731220 — IntEnSys4EU "Integrated Energy System - A Pathway For Europe". ETIP-SNET, 2017.

12.4 RTE

RTE. '*Socioeconomic Assessment of Smart Grids. Synthesis*', 2015.

12.5 UPGRID EUROPEAN PROJECT (2015-2017)

Delgado I and Aguado I. '*UPGRID Project. Deliverable D1.4 R1: "Scope and Boundaries of Project Demonstrations. Report on Common KPIs"*'. Iberdrola-ITE, 2015.

———. '*UPGRID Project. Deliverable D1.4 R2: "Scope and Boundaries of Project Demonstrations. Report on Common KPIs"*'. Iberdrola-ITE, 2015.

———. '*UPGRID Project. Deliverable D8.1: "Monitoring & Impact Assessment of Project Demonstrations. Report about KPIs Analysis and Methods of Comparison"*'. Iberdrola-ITE, 2017.

12.6 DISCERN EUROPEAN PROJECT (2013-2016)

Nordström L. '*DISCERN Project (Distributed Intelligence for Cost-Effective and Reliable Distribution Network Operation). Deliverable D1.1: "List of Agreed KPIs with Associated Metrics and Refined Smart Grids Unctionalities List"*'. KTH, 2014.

Birch, A. '*DISCERN Project (Distributed Intelligence for Cost-Effective and Reliable Distribution Network Operation). Deliverable D1.2: "Intermediate Demonstration Projects KPI Fulfilment Report - Definition and Calculation Methodology of DISCERN KPIs"*'. DNV GL, 2015.

DNV GL. '*DISCERN Project (Distributed Intelligence for Cost-Effective and Reliable Distribution Network Operation). Deliverable D1.5: "KPI Fulfilment Report - Data Gathering and Evaluation of DISCERN KPIs"*', 2016.

———. '*DISCERN Project (Distributed Intelligence for Cost-Effective and Reliable Distribution Network Operation). Deliverable D8.1: "Business Case on Use Cases and Sensitivity Analysis"*', 2016.

Birch, A, Itschert L, and Spanka K. '*Definition and Calculation Methodology of Project KPIs – the DISCERN Approach*'. 2015 50th International Universities Power Engineering Conference (UPEC), Stoke-on-Trent (UK), 2015.

Grid4EU European Project (2011-2016)

Consiglia, L. '*Grid4EU Project (Innovation for Energy Networks). Deliverable GD2.2: "Project KPIs Definition and Measurement Methods"*'. ENEL Distribuzione, 2012.

———. '*Grid4EU Project (Innovation for Energy Networks). Deliverable GD2.7: "Final KPIs Report"*'. ENEL Distribuzione, 2016.

Lebosse C. '*Grid4EU Project (Innovation for Energy Networks). Deliverable DD6.9-2: "Final Assessment of the Demonstrator's Operation Using the KPIs"*'. ERDF, 2016.

IGREENGrid European Project (2013-2016)

Poli D and Rossi M. '*IGREENGrid Project. Deliverable D4.1: "Report Listing Selected KPIs and Precise Recommendations to EEGI Team for Improvement of List of EEGI KPIs"*'. RSE, 2014.

Sebastian Viana M and Chaniolleau J. '*IGREENGrid Recommendations to EEGI Regarding the Key Performance Indicators*'. ERDF, 2015.

———. 'IGREENGrid Key Performance Indicators Definition'. ERDF, 2015.

———. 'IGREENGrid Key Performance Indicators Methodology'. ERDF, 2015.

Mora P, and Rossi M. '*IGREENGrid Project. T2.2 – Assessment Methodology Based on Indicative Key Performance Indicators (KPIs). KPIs of Demo Projects*' RSE, 2013.

EvolvDSO European Project (2013-2016)

Bartolucci, G. '*EvolvDSO Project (Development of Methodologies and Tools for New and Evolving DSO Roles for Efficient DRES Integration in Distribution Networks). Deliverable D6.1: "Report with Recommendations for Deployment of Developed Tools and Methods"*'. e-distribuzione, 2017.

Clerici, D. '*EvolvDSO Project (Development of Methodologies and Tools for New and Evolving DSO Roles for Efficient DRES Integration in Distribution Networks). Deliverable D5.2: "Impact Assessment at Country Level"*'. e-distribuzione, 2016.

IDE4L European Project (2013-2016)

Salazar F, Martin F, and Hormigo M. '*IDE4L Project (Ideal Grid for All). Deliverable D7.1: "KPI Definition"*'. UFD, 2014.

ADVANCED European project (2012-2014)

Dromacque C, Benintendi D, Idstein D, Schmidt T, Barron M and Xu S. '*ADVANCED Project (Active Demand ANd Consumers Experience Discovery). Deliverable D1.2 "Report on the Validated KPIs"*'. VaasaEtt, 2014.

13. COPYRIGHT

Copyright © EU-SysFlex, all rights reserved. This document may not be copied, reproduced, or modified in whole or in part for any purpose. In addition, an acknowledgement of the authors of the document and all applicable portions of the copyright notice must be clearly referenced.

Changes in this document will be notified and approved by the PMB. This document will be approved by the PMB.

The EC / Innovation and Networks Executive Agency is not responsible for any use that may be made of the information it contains.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under EC-GA No 773505.