MARKET ENABLING INTERFACE TO UNLOCK FLEXIBILITY SOLUTIONS FOR COST-EFFECTIVE MANAGEMENT OF SMARTER DISTRIBUTION GRIDS

Deliverable: D8.1

German Demonstrator — Demonstration of congestion management using market driven utilisation of flexibility options in a LV grid

Specifications and guidelines of tools for an Active LV grid for field testing

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List of Abbreviations

BUC	Business Use Case
CC	Chance Constraint
CHP	Combined Heat & Power
D	Deliverable
DdSE	Data driven State Estimation
DER	Distributed Energy Resource
DN	Distribution Network
DSO	Distributed System Operator
EV	Electric Vehicle
FMO	Flexibility Market Operator
FNA	Flexibility Needs Assessment
FSP	Flexibility Service Provider
GUI	Graphical User Interface
HEMS	Home Energy Management System
HV	High Voltage
LV	Low Voltage
MNS	Mitnetz Strom
MV	Medium Voltage
NWP	Numerical Weather Prediction
OBR	Optimal Bid Recommender
OPF	Optimal Power Flow
PV	Photovoltaic
RES	Renewable Energy Source
SO	System Operator
SSH	Secure Shell
SUC	System Use Case
T	Task
UMEI	Universal Market Enabling Interface
WP	Work Package

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Executive Summary

This Deliverable is developed in the context of the EUniversal project, which aims to overcome existing limitations in the use of flexibility by DSOs. EUniversal tries to achieve this objective by implementing a Universal Market Enabling Interface (UMEI) to facilitate the use of flexibility services and to interlink active system management and DSOs with electricity markets.

This report describes the set-up and integration of grid technical solutions, as well as the API implementation that will allow demonstrating flexibility services developed in the EUniversal project. It explains the environment of the German demonstration, the market platform, smart grid tools and customer aggregation that will be implemented and tested.

1 Introduction

1.1 Background

The European Union is aiming at transforming the energy system towards a sustainable, low-carbon and climate-friendly economy, while - at the same time - putting consumers at its centre and dynamically utilizing their distributed resources. As a consequence, distribution system operators will face new challenges in the ways they operate: To safely host more renewable energy sources (RES) and to integrate new types of load patterns such as electric vehicles and heat pumps and consumer behaviour e.g. the advent of energy communities or the introduction of dynamic electricity pricing, they will need to rely more on flexibility and smart-grid solutions. Distributed flexibility in the grid has been identified as a key enabler towards a more sustainable, low-carbon and climate-friendly electricity system. In such a scenario, consumers become crucial players, due to their potential to relieve grid constraints by adapting their consumption behaviour, reflecting one of the most important Energy Union priorities. Yet, flexibility will also add complexity and create unpredictable power flows in the distribution networks, and thus demand new solutions to transform the challenges into opportunities for the sector and to society.

The primary goal of the EUniversal project is to identify and overcome existing limitations in the use of flexibility by Distribution System Operators (DSOs). As such, the project goal is (among others) to enhance the flexibility used in distribution grids, which will need to operate in an overall context of around 50% electricity production from renewables in 2030. Furthermore, the EUniversal project aims to further guarantee the security of supply, while avoiding unnecessary network investments.

Therefore, within the EUniversal project, a Universal Market Enabling Interface (UMEI) will be implemented to facilitate the use of flexibility services and interlink active system management of distribution system operators with electricity markets. A set of market-oriented flexibility services from Distributed Energy Resources (DERs) will be implemented to serve DSOs' needs cost-effectively, supporting the energy transition.

1.2 WP8 Objectives and relationships between tasks

This report is part of the eighth work package of the EUniversal project. The operative objective of WP8 is to validate the concepts, and tools developed in EUniversal in different contexts and scenarios. It is one of the three DEMOs and assesses flexibility for distribution grids and the market capacity to provide new services.

For this purpose, the work package aims to achieve enhanced observability for the active system management in lower voltage levels, by establishing an estimation and forecast of the grid state from the chosen LV Grids. This will help to aggregate and predict the flexibility potential in the LV Grid. Other objectives of the demonstration are the provision of flexibilities through the UMEI to the market platform and the integration into schedule-based congestion management. In addition to the use of flexibilities for the low voltage grid, the provision to the LV/MV connection point and therefore to the MV Grid is foreseen.

This report is using valuable information from other WPs, namely:

- WP2, for the definition of use cases that will be demonstrated, as well as the UMEI API functional specification, namely with the identification of the interactions between the DSO and Flexibility Market platforms and data exchange.
- WP3, with the use of a flexibility toolbox, identifying the technologies and solutions most suitable to provide flexibility services to the distribution grid
- WP4, for the development of the DSO smart grid tools and their alignment
- WP5, the identification of relevant market mechanisms
- WP6, with a common framework to harmonise, monitor and assess the validation of the result

The knowledge gained in this demonstration is used in turn to support WP10 in the development of business models for the exploitation of EUniversal's results and to provide recommendations for policy makers and regulatory authorities to set up a framework for flexibility markets. The various influences on the demonstrator are also shown in flowchart A.1 in the appendix.

1.3 Structure

This deliverable is structured in three main parts. The first part is composed of four sections, aiming for an individual description of the demonstrator. At first, an alignment of the use cases that will be implemented in the demonstration is shown. The general objective of the demonstration is presented, the pilot regions are described and the status quo, i.e. the situation when the demonstrator starts, is explained to present the overall framework of the demonstration. Then, the external and internal drivers for the demonstration are listed. Finally, previous projects on which the EUniversal demonstrator are linked are presented.

In its second part, the deliverable specifies the system architecture of the demonstrator and the tools that will be used and tested in the field test. In addition, the market connection through the UMEI, the use of the flexibility market and the customer connection to the FSP are described.

The last of the three main parts deals with the preparation of the field test and planned scenarios to be analysed, as well as methodologies for user engagement. The applicability and limitations of the demonstrator are explained and the expected results are presented.

The document is rounded off with a conclusion and outlook for the further course of the demonstrator.

2 General overview of the German demonstrator

2.1 Mapping of related BUC & SUC

A Business Use Case (BUC) describes the steps and activities in a process that are necessary to achieve a business goal. The BUCs, therefore contain the interactions (information exchanges) between stakeholders as business roles participating in the provision of the service. Table 2.1 gives an overview of the two Business Use Cases defined for the German demonstrator. A more detailed description can be found in Deliverable D2.2[1].

Table 2.1 - Overview of Business Use Cases of the German Demonstration

ID	Name	Service	Mechanism	Main Steps
DE-AP	Congestion Management & Voltage Control with market-based active power flexibility	Congestion management and Voltage control	Local flexibility market	• Registration and Prequalification • Bidding and selection • Delivery and monitoring • Settlement
DE-RP	Congestion Management & Voltage Control with market-based reactive power flexibility DE	Voltage control and congestion management	Local flexibility market	• Registration and Prequalification • Bidding and selection • Delivery and monitoring • Settlement

The roles that act in the description of the business process of the defined Use Cases are the Business Roles, as explained in Deliverable 2.2. The main business roles, related to the German Demonstrator and in the two German Business Use Cases are Distribution System Operator (DSO), Flexibility Market Operator (FMO), and Flexibility Service Provider (FSP).

The SUCs, in contrast to the BUCs, aim at a detailed description of the process itself. The SUCs give the functional description needed to support the BUCs by detailing which activities are performed, who is going to execute them and on which system.

In the German Demonstrator, ten System Use Cases have been defined within Task 2.3 and were classified into three domains:

- Smart Grid Operations – including all use cases involving the distribution network operation and planning
- Flexibility Market – including all use cases involving local flexibility market operations
- Flexibility Aggregation and grid users – including all use cases related to the FSP and the consumer/active customer provision of flexibility services in the market.

The list of System Use Cases defined for the German demonstration is presented in Table 2.2.

Table 2.2 - System Use Cases of the German Demonstration

Domain	SUC ID	SUC name	BUC ID	Related Pilot(s)	Owner
Smart Grid Operation	SUC 4	Day-ahead congestion management considering flexibility needs in LV and MV networks	DE AP, DE RP	PT, DE	INESC TEC
	SUC 5	Estimating LV voltage magnitude based on historical data and load forecasts	DE AP	PT, DE	INESC TEC
	SUC 6	Day-ahead congestion forecasting	DE AP, DE RP	DE	VITO
	SUC 7	Voltage control in LV networks based on limited observability and network topology	DE AP	PT, DE	INESC TEC
	SUC 8	LV flexibility needs assessment for voltage and congestion management	DE AP, DE RP	DE	KUL
	SUC 12	Minimizing costs linked to DSO flexibility requirements	DE AP, DE RP	DE	N-SIDE
Flexibility Market	SUC 13	Short-term flexibility procurement	DE AP, DE RP	PL, PT, DE	NODES
Flexibility Aggregation	SUC 16	DER registration and configuration	DE AP, DE RP	PT, DE	CENTRICA
	SUC 17	Bidding aggregation	DE AP, DE RP	PT, DE	CENTRICA
	SUC18	Resources' dispatch and monitoring	DE AP, DE RP	PT, DE	CENTRICA
	SUC 19	Baselining	DE AP, DE RP	PT, DE	CENTRICA
	SUC 20	Collecting and publishing metering data	DE AP, DE RP	PT, DE	CENTRICA
Data Manage ment	SUC 21	DSO data management – German Demonstrator	DE AP, DE RP	DE	MNS/ E.ON

2.2 Demo site characteristics

The German demonstration will take place in LV Grids of the German DSO Mitnetz Strom (MNS - E.ON linked third party). The supply area of MNS is located in the East of Germany, and includes parts of Brandenburg, Saxony-Anhalt, Saxony and Thuringia. The region is home to 2.3 million inhabitants in an area of 30,804 km^2. The length of the grid is about 6,000 km in HV, about 24,000 km in MV and about 44,000 km in LV Level. MNS operates and maintains about 17,000 substations with an installed capacity of more than 5,000 MVA. Therefore, the grid provides a broad variety of scenarios and can demonstrate the novel use cases defined in WP2.

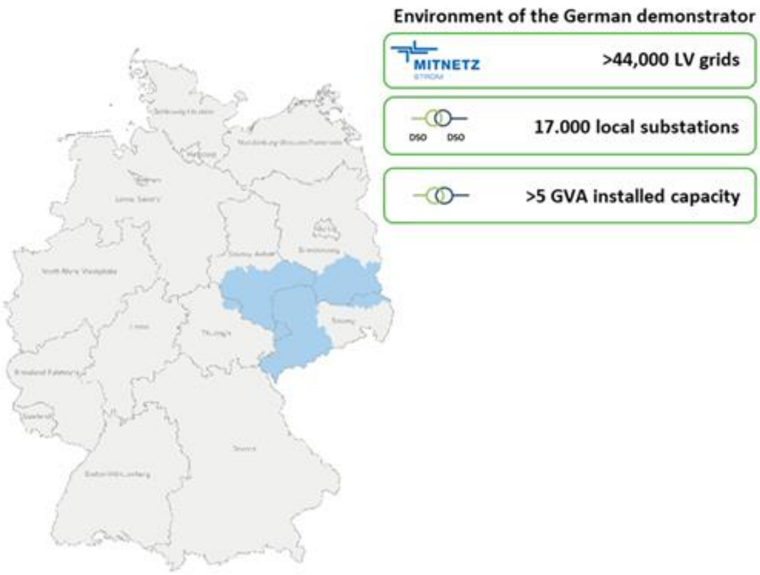

Figure 2.1 - Local classification of the German demonstrator

To achieve the objectives of the demonstration, adequate grid sections with a relevant infeed of RES and cross-sector loads (e.g. storage and heat pump users) were chosen. Various criteria were considered for the selection, such as the number and type of flexible devices in the network, measured congestion/voltage problems in the past or differences in size and topology of the grid (cf. section 4.1.1).

2.3 Internal and external drivers

According to the European Clean Energy Package and the German Federal Climate Change Act, a CO2 reduction of 65% until 2030 - compared to 1990 levels - is envisaged. To meet this target, large amounts of renewable energies (RES) are integrated into the system. With the decarbonisation of energy generation, system operators are facing new challenges in terms of system security and supply reliability, as RES are by nature volatile and can fluctuate significantly. Moreover, the location of generation is changing from large, centralized power plants to mostly decentral resources, which are connected in the distribution grid.

In addition to the decentralization of generation and its "migration" from the transmission grid to the distribution grids, energy consumption is also changing. Because of the increasing sector integration, new participants are joining the energy market. This includes for example the mobility transition with the shift from internal combustion engines to electric vehicles, power-to-X applications and the implementation of electric or hybrid heating systems.

With these new technologies, companies, as well as private individuals are changing from consumers into active customers and are constantly switching roles; sometimes they need energy, sometimes they have some to spare. As a result, the system is becoming increasingly complex. Nevertheless, these active costumers can also be a future source of flexibility for the market, the system and the transmission and distribution grid, and thus help balance supply and demand. To this end, DSOs must be able to coordinate and use flexibility accordingly.

Initial experience to use flexibility for an operation has been gained among others in the EU-SysFlex project (cf. section 2.4.1). The German EUniversal demonstrator aims to extend the gained insights to the low-voltage level and address its specific challenges. Among these properties that require custom solutions are large scale, a large variety in grid topology, connections with high stochasticity and hard to predict behaviour, a limited number of measurement points, scare data on the grid layout. At present, the German low-voltage grid is not monitored at all or only to a limited extent. With the increasing number of renewable generation and the addition of new flexible loads, congestions and voltage problems in the grid are becoming more frequent and observability needs to be increased.

The technical solution contains two key parts that are mandatory for a reliable and secure utilisation of flexibility in the LV-Grid: the first one is the intelligent implementation of a measurement system that is combined with predictive state estimation. This system is necessary for a reasonable integration and demand of RES and flexibility options. Secondly, new control schemes connected to a market interface are essential to offer the available flexibility options to the market. In the German demonstrator, both key parts are addressed by integrating Home Energy Management Systems and the newly developed UMEI into the system environment.

Concerning the legal scoping of the demo, the implementation will be framed by the schedule-based congestion management Redispatch 2.0, which was recently set active in October 2021. Redispatch is used to mitigate congestion in the power flow of the grid. For this purpose, electricity generation is temporarily adjusted: Electricity feed-in is reduced on one side and increased on the other. This procedure simultaneously covers the energy demand and maintains the security of supply. Beforehand, Redispatch was carried out by TSOs only by regulating conventional power plants with a capacity of more than 10 MW. With the new approach in Redispatch 2.0, renewable energy and Combined Heat & Power (CHP) systems larger than 100 kW, as well as remotely controllable systems, will be included in the congestion management. The main intention is to optimize the total costs and thus reduce network charges of the system, as well as secure a reliable operation of the system with a higher share of RES. This means that DSOs are now also involved in the Redispatch process. An iterative process is set up for the exchange of data between the different system operators, which enables an accurate prediction of the needed power adjustment. In EUniversal, the German demonstration aims to stay close to this iteration process, to test a long-term use of flexibility potentials directly for the Redispatch process or in a complementary way.

2.4 Experience from previous projects

The German demonstrator of EUniversal benefits from the experience gained in other projects, research activities and initiatives. In this section, the most important influences are presented and briefly described. The connection to the EUniversal project is explained and the participants from the demonstrator are named. Thereby, no claim is made to completeness in this regard.

2.4.1 EU-SysFlex

The EU-SysFlex project is also part of the Horizon 2020 program. The acronym stands for "Pan-European system with efficient coordinated use of flexibilities for the integration of a large share of RES ". The R&D project has developed new services that will help meet the needs of a system with more than 50% of renewable energy sources.

The German Demonstrator, which is led by MNS and E.ON, is focussing on the provision of flexibility services from DSO connected sources to the TSO's congestion management to mitigate shortages due to line load and voltage limit violation. In addition, the DSO itself is using the same services to sustain a stable and secure grid operation in the distribution grid. Therefore, an iterative process was developed, which is partly also reflected in the introduction of Redispatch 2.0 in Germany (see [2] and Figure A.2 in the appendix).

In EUniversal, the demonstrated approaches and ideas will be extended as shown in Figure 2.2 to the medium and low voltage level, so that the overall potential is increased by using a cascaded process. In addition, new adaptive loads such as heat pumps and EVs will be added to show the benefit of using flexible loads instead of or in addition to reduced RES feed-in in a high generation situation. Furthermore, a flexibility market platform provides the necessary incentive for grid-beneficial behaviour.

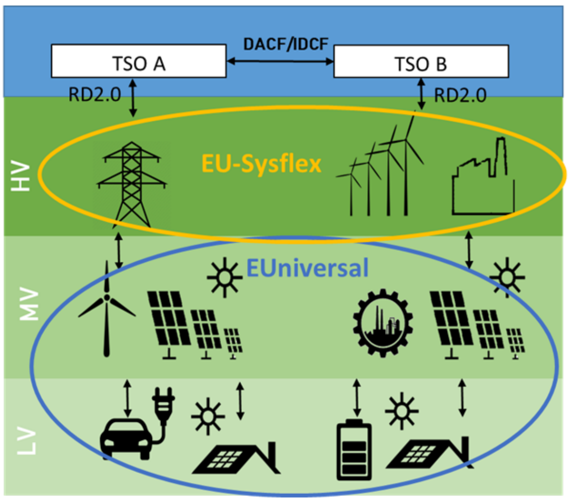

Figure 2.2 - Interconnection between EU-SysFlex & EUniversal

2.4.2 Pilot project for the application of the NODES flexibility market at MNS

Within the pilot project, carried out in Schwarzheide (Brandenburg), the market traded flexibility of an industrial park was used for congestion management. The demonstrator took place in a HV grid of MNS. In the process, the DSO as well as the aggregator of the flexibility (Entelios) used the marketplace of NODES and showed the benefit of lower costs and fewer power adaptions compared to RES curtailment. The project also outlined the possible use case of congestion management on medium-voltage level, which will be one of the objects of investigation in EUniversal (cf. [3]).

2.4.3 InteGrid

The InteGrid project aimed at demonstrating the feasibility of smart distribution networks, coping with a high amount of renewable energy sources (RESs) and making use of the available distributed energy resources (DERs) flexibility for various functions and business cases. A platform called DSOs Grid-Market Hub was developed to enable all stakeholders to actively participate in the energy market and distribution grid management. EUniversal intends to go further with UMEI, exploring a solution that is universal, open, modular, and adaptable, promoting the interaction between system operators and market parties. This entails creating the necessary conditions to unlock the flexibility potential, regardless of the regulatory frameworks and the future governance models to be adopted by each country.

Regarding smart grid solutions, the same reasoning of using preventive management of the distribution grid is being adopted in EUniversal, but with a higher focus on the benefits coming from coordinated management of the different voltage levels.

Figure 2.3 shows the general architecture of the InteGrid project, revealing some of the foundations of EUniversal.

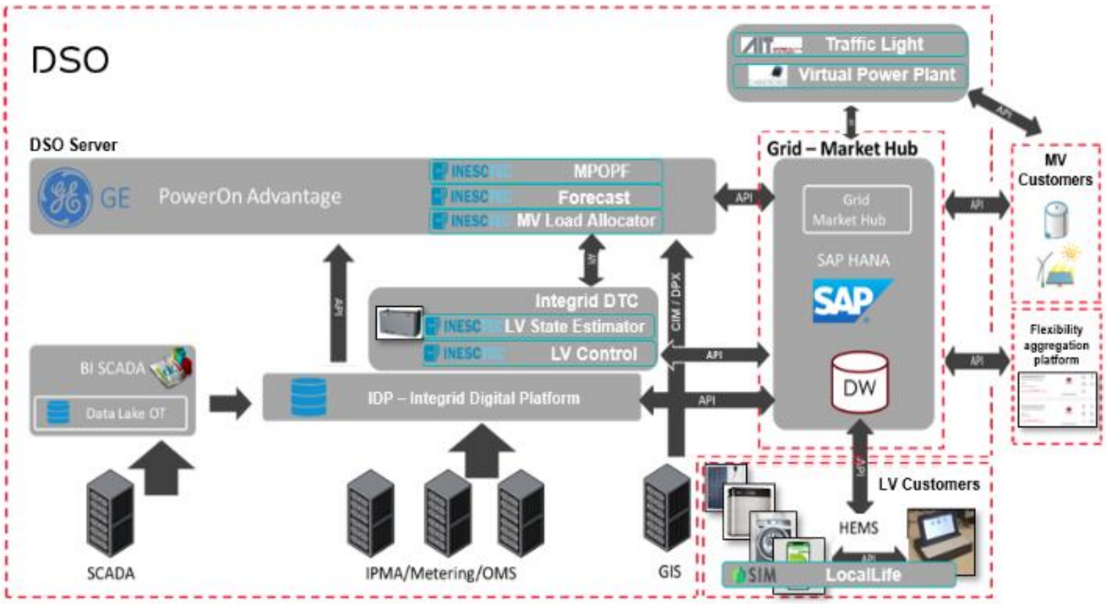

Figure 2.3 - General architecture of InteGrid

3 Development work within the demonstrator

3.1 System Architecture

The main purpose of this chapter is to provide an insight into the system architecture, with a general description of the principles of operation and an overview of main components and services taking a crucial role in system stability and reliability. From a technical EUniversal project perspective, the main system goal is to provide the conditions for the sustainable functioning of the system components and establish a resilient interconnection between them. In terms of data transfer and storage, privacy and security policies must be respected. The distributed system architecture should combine all the necessary elements to implement timely data exchange between its participants, meeting the stated requirements. In order to accomplish this technique, it is necessary to create a responsive, scalable system, enabling comprehensive data exchange and analysis at various system levels and allowing a reliable interaction of various applications, calculation tools and data sources.

3.1.1 Design principles

The EUniversal system is built on a high-performance Microsoft Azure Cloud server based on an Ubuntu 18.04 operating system. The system architecture is designed according to the following essentials:

- Containerised architecture as the basis of the system architecture;
- Separate Docker container[1] for each application/tool/database system;
- Nginx as general high-performance routing part;
- Predefined time-scheduled interaction with external parties:
    - Data from the data sources is downloaded by the system at specified time intervals via REST API (preferred);
    - Data is being pushed to the system by the data sources at specified time intervals via SSH file transfer protocol (alternative);
    - Results of data processing and analysis are transmitted via REST API by the system to the market platform at specified time intervals.
- Separate Docker logging architecture with the ability to access logs in containers without direct access to the system;
- Data synchronizer application with built-in REST API as a central system unit responsible for data verification and data exchange between all system actors.

[1] A container is a standard unit of software that packages up code and all its dependencies, so the application runs quickly and reliably from one computing environment to another. A Docker container image is a lightweight, standalone, executable package of software that includes everything needed to run an application: code, runtime, system tools, system libraries and settings. [4]

3.1.2 System components

The full system architecture is shown in Figure 3.1 and represented by the following components:

- External data sources;
- System users;
- Knowledge database system;
- Data synchronizer – data processing and exchange part;
- Dockerised applications & tools – data analysis and calculation part.

All the system processes and data flows are subdivided into several logical levels: system and data access, data collecting, data processing, internal and external data exchange.

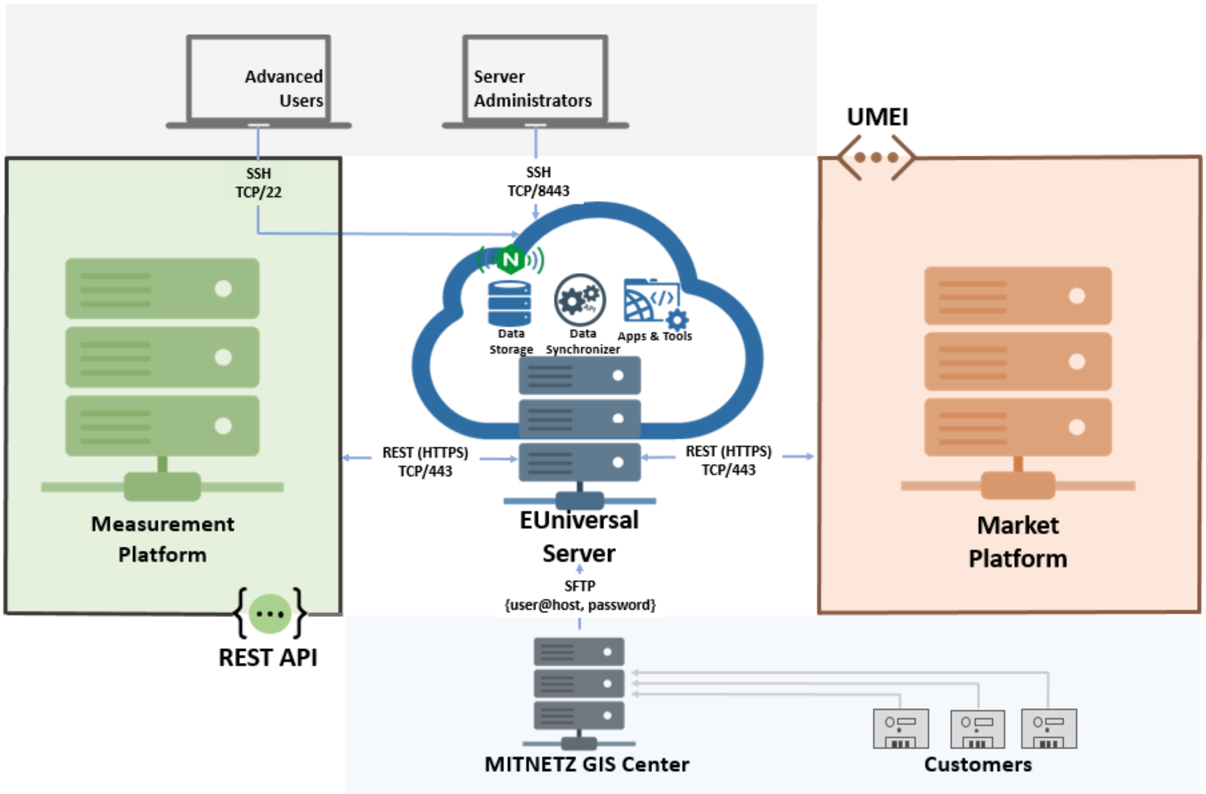

Figure 3.1- Full system architecture

Nginx implements the role of a high-performance router in the system, handling multiple connections in a single process. Processes communicate with each other using shared memory for cache data, sessions, and other shared resources. Each process is initialized with a given configuration and a set of listening sockets inherited from the master process.

3.1.3 Data Access

The data access diagram is presented in Figure 3.2.

Data in the EUniversal system is accessible to a limited number of users, specifically to administrative staff and privileged users who need to be allowed temporary access to the server during the deployment phase of the EUniversal project. Access rights for privileged users are requested from the system administrator. The connection to the server is established via SSH protocol - the main protocol for remote administration of servers on the Linux operating system. Simultaneous work on the server is allowed for multiple users. MNS GIS Centre will also be provided with limited access to the system to transmit readings of meters installed at the customers' side.

Only system administrators have access to the data stored in the knowledge database system on the server. All system processes, such as scheduled updates and backups, data synchronization and Docker containers operation on the server are also monitored and maintained by the system administrators.

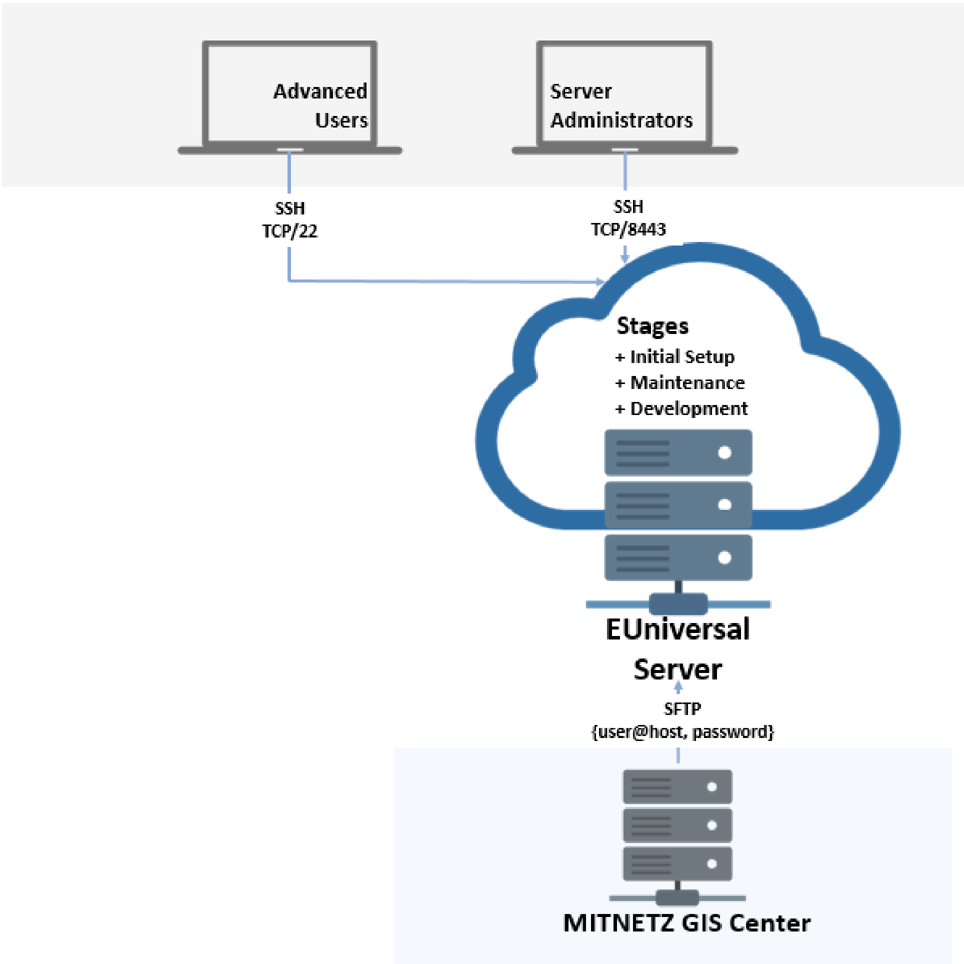

Figure 3.2 - Data Access in the EUniversal system

3.1.4 Data collection

The principle of data collection in the system is shown in Figure 3.3.

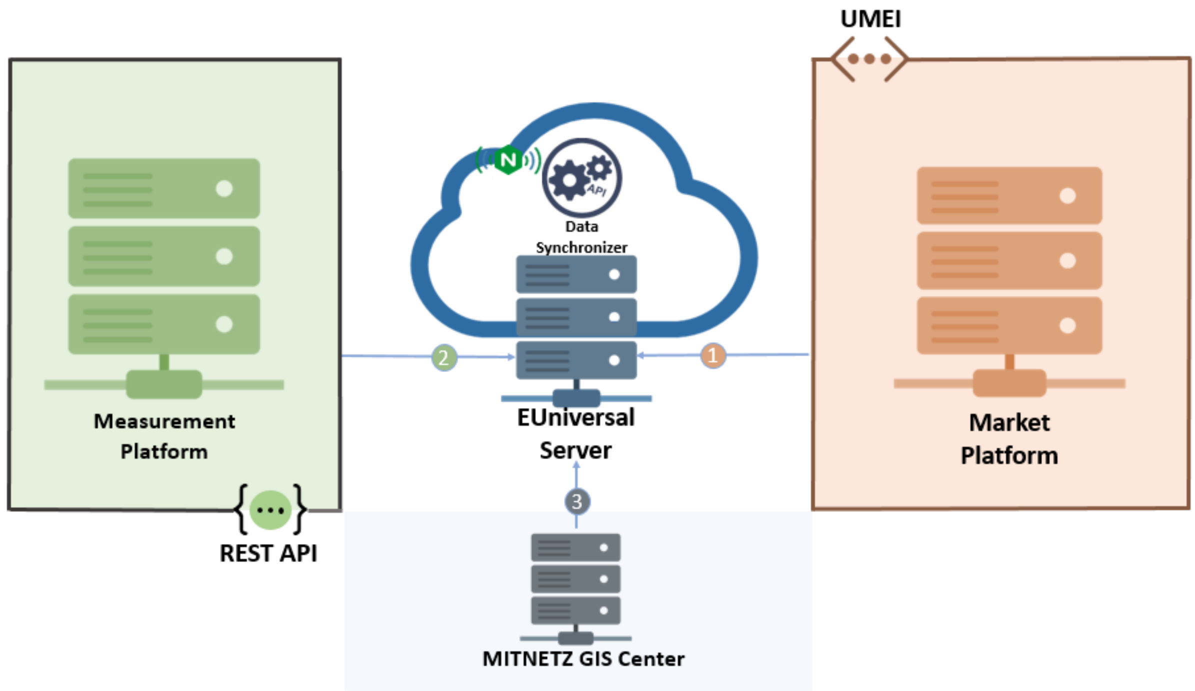

Figure 3.3 - Collecting data from external sources into the system

The data comes to the system from the following data sources:

- Measurement platform;
- Market platform;
- MNS GIS Centre;
- Forecast system (optional).

These are detailed in Table 3.1. The data synchronizer is a centralized unit, an application with a built-in REST API interface that implements the functions of data requesting, processing, verifying and collecting from all sources, database servers and tools.

Table 3.1 - Data Sources German Demonstration

№	Data Source	Data	Description	Data Type	Data Cycle
1	Market Platform	Existing assets, grid assignments, grid areas, grid nodes, energy market, meter reading, price areas, settlement orders, trades	Information about existing assets, grid areas and nodes, market platforms, placed orders, available flexibility resources, settlements and trades	.json	~ 1 hour

2	Measurement Platform	Node location, line current, voltage, active/ reactive/ apparent power	Information about all nodes of the analyzed system with the measured values of current, voltage and power for each particular node for the specified time stamps (historical and up-to-date information)	.json	~ 1 hour
3	MNS GIS Center	Active and reactive power, current, voltage measurements, grid layout, network structure	Information from smart meters (current, voltage, active and reactive power) installed on consumers side for a certain time interval	.csv	~ 15 min
4	Forecast system (optional)	Forecasts of load, renewable energy sources and weather	Predicted values of active and reactive power consumption for each node of the analysed system (short-term forecast)	.csv	~ 1 hour

3.1.5 Introducing the data exchange

The data exchange diagram is presented in Figure 3.4.

The data synchronizer and the market platform are involved in external data exchange, which is carried out through REST API via HTTPS protocol. Information about existing assets, grid areas, placed orders, settlements and trades comes from the market platform to the synchronizer, where it is processed and then transferred to the knowledge database system. As soon as the synchronizer receives any data calculation results intended for the market platform from the containerised applications running on the server, it parses them first, converts them to the format requested by the market platform and then delivers them directly to the market platform via UMEI or REST API. External data exchange is also feasible according to a pre-set schedule.

Internal data exchange is carried out through REST API and an HTTP protocol and is implemented between the following system components: knowledge database system, dockerised data analysis applications/tools and synchronizer. The synchronizer is the central data exchange part of the system, combining all the processes of data processing, analysis and transmission to the other system components.

Each application/tool is deployed in a separate Docker container, which allows independent and therefore secure operation of the applications/tools on the system. The transfer of data from one dockerised application to another is performed using independent Docker volumes or by means of the internal IP address of a particular Docker container through a synchronizer. The interaction between applications and the knowledge database system is also carried out using the synchronizer. Once a particular application requires data from the database, it sends a request to the synchronizer via REST API; the synchronizer processes this request and queries the required data for the appropriate period in the database system. After receiving a response from the database, the synchronizer verifies it, converts (if necessary) and then transmits it back to the application from which it was requested.

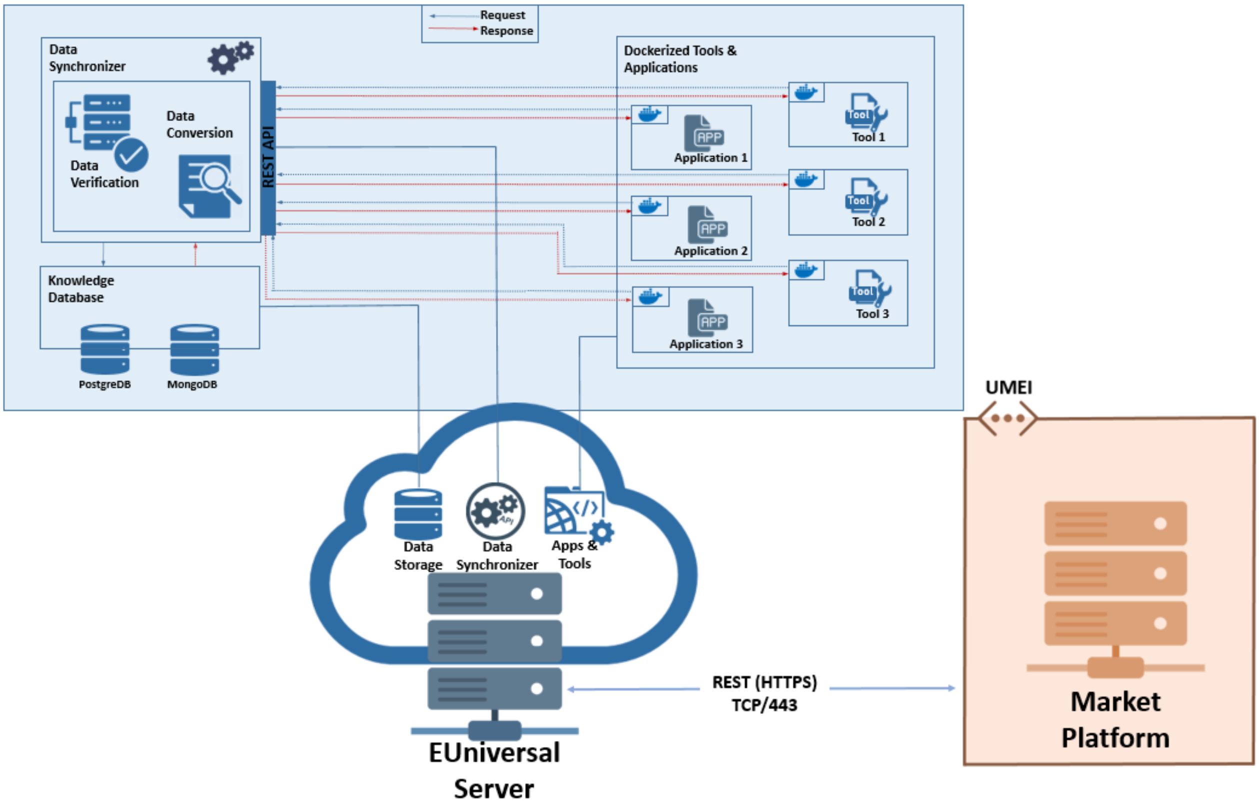

Figure 3.4 - External and internal data exchange

3.1.6 Internal data exchange

Internal data exchange implies communication between the dockerised tools and the central orchestration part of the server – synchronizer. Communication is based on the request-response pattern and driven by the common architectural style - REST. The synchronizer sends requests for certain operations to the replier tool, which processes the received request, verifies the data transmitted in the request body in case something was passed, and then returns the message in the response body about whether the operation is successful or not. REST (an acronym for Representational State Transfer) is the API protocol style, providing standards and abstraction principles for better communication between different active parts of the server (e.g. tools and applications) and using the standard web HTTP protocol. REST uses CRUD (create, read, update, delete) interaction style represented by the following HTTP operations, respectively:

- POST – a method for creating/pushing a new resource to the system;
- GET – a method for retrieving specified information (e.g. status of operation) or set of data;
- PUT – a method implementing the updating or replacing of an existing resource;
- DELETE – a method to remove the specified resource from the system.

In addition to the resource path, the creation of requests is accompanied by different headers and “Accept” parameters. Concerning data exchange and communication between tools and synchronizer on the server, the commonly used header and “Accept” parameter is “application/json”, so the format of inputs and outputs for all the tools is JSON. The most used HTTP requests are POST and GET. POST is mostly used to push input data to the particular tool, while GET is used to trigger the calculations, request the status of the tool or the results of the calculation.

The internal data exchange in scope is shown in Figure 3.5.

Internal data exchange is carried out in two phases and goes through API calls. The following applications and tools are engaged in the data exchange process:

- State Estimation Tool;
- Congestion Forecasting and Prevention Tool;
- Flexibility Needs Assessment Tool;
- Optimal Bid Recommender;
- Synchronizer (orchestrating part).

The division into phases is based on the principle of the tools’ dependence on the results produced by the others. If some tools do not need outputs produced by each other, they operate in the same phase and receive POST requests with corresponding content from the synchronizer simultaneously. As soon as input data from the synchronizer are received by the tools, the synchronizer makes GET request to trigger the calculations and monitors the status of the request processing. Once the status of the calculation triggering request is completed and the results are ready, the synchronizer retrieves them through an additional appropriate GET request. The only exception in terms of retrieving results is the congestion forecasting & prevention tool – once its calculation results are available, they are sent from the tool side through a POST request back to the synchronizer. As soon as the synchronizer receives the results from the tools operating in the first phase, it processes them, stores them in the database and forwards them to the tools in the next phase, which depends on the results of the previous phase. After all the calculation phases are passed, the calculation interval is over. Then the DSO creates buy and sell orders to the market platform as well as displays the calculation results in the graphical user interface, represented by the GridOS platform.

The first phase involves the synchronizer, state estimator and congestion forecasting & prevention tool. The second phase involves synchronizer, flexibility needs assessor and optimal bid recommender. The data flow is described in the following Table 3.2.

Table 3.2 - Overview internal data exchange

Phase	Step	Periodicity	Operation description	Requester tool	Replier tool	Request			Response		
						HTTP method	Parameters / Body	Format	Status	Content / Body	Format
I	1.1.1	every 24 hours	Push historical data	Synchronizer	State Estimator	POST	Historical data	JSON	200 OK	-	-
		every 15 min	Push real measurements	Synchronizer	State Estimator	POST	Real measurements	JSON	200 OK	-	-
	1.1.2	every 15 min	Initiate state estimator	Synchronizer	State Estimator	GET	Network ID	JSON	200 OK	-	-
	1.1.3		Request real-time state estimation results	Synchronizer	State Estimator	GET	Network ID	JSON	200 OK	Most recent snapshot of the network, optimal power flow (OPF) calculated	JSON
	1.2.1	every 15 min	Push weather forecasts	Synchronizer	Congestion Forecasting & Prevention Tool	POST	Weather forecasts	JSON	200 OK	-	-
			Push grid measurements	Synchronizer	Congestion Forecasting & Prevention Tool	POST	Grid measurements	JSON	200 OK	-	-
	1.2.2	every 15 min	Trigger the calculation	Synchronizer	Congestion Forecasting & Prevention Tool	GET	List of cases to be calculated	JSON	200 OK	-	-
	1.2.3	as soon as ready	Push calculation results	Congestion Forecasting & Prevention Tool	Synchronizer	POST	List of calculated results: headrooms for the specified list of cases	JSON	200 OK	-	-

II	2.1.1	every 15 min	Push grid layout	Synchronizer	Flexibility Needs Assessor	POST	The updated version of grid layout	JSON	200 OK	-	-
			Push optimal power flow & generic load profiles	Synchronizer	Flexibility Needs Assessor	POST	OPF and generic load profiles provided by State Estimator (step 1.1.3)	JSON	200 OK	-	-
		every 24 hours	Push Annual Load Consumption	Synchronizer	Flexibility Needs Assessor	POST	Load consumption for the previous year	JSON	200 OK	-	-
		every 15 min	Push nodal day-ahead forecast of P and Q	Synchronizer	Flexibility Needs Assessor	POST	Nodal day-ahead forecast of P and Q	JSON	200 OK	-	-
	2.1.2	every 15 min	Initiate flex needs assessment	Synchronizer	Flexibility Needs Assessor	GET	t.b.d.	JSON	200 OK	-	-
	2.1.3	as soon as ready	Retrieve the results of flex needs assessment	Synchronizer	Flexibility Needs Assessor	GET	t.b.d.	JSON	200 OK	Nodal and zonal flexibility needs assessment	JSON
	2.2.1	every 15 min	Push updated grid hierarchy, sell-orders, baselines and headrooms + start the calculation session	Synchronizer	Optimal Bid Recommender	POST	Updated grid hierarchy, sell-orders, baselines and headrooms (step 1.2.3)	JSON	200 OK	Session ID	JSON
	2.2.2	as soon as ready	Retrieve calculation results for the session	Synchronizer	Optimal Bid Recommender	GET	Session ID	JSON	200 OK	Activation Cost, Power Accepted in Orders, Congested Grid Zones	JSON

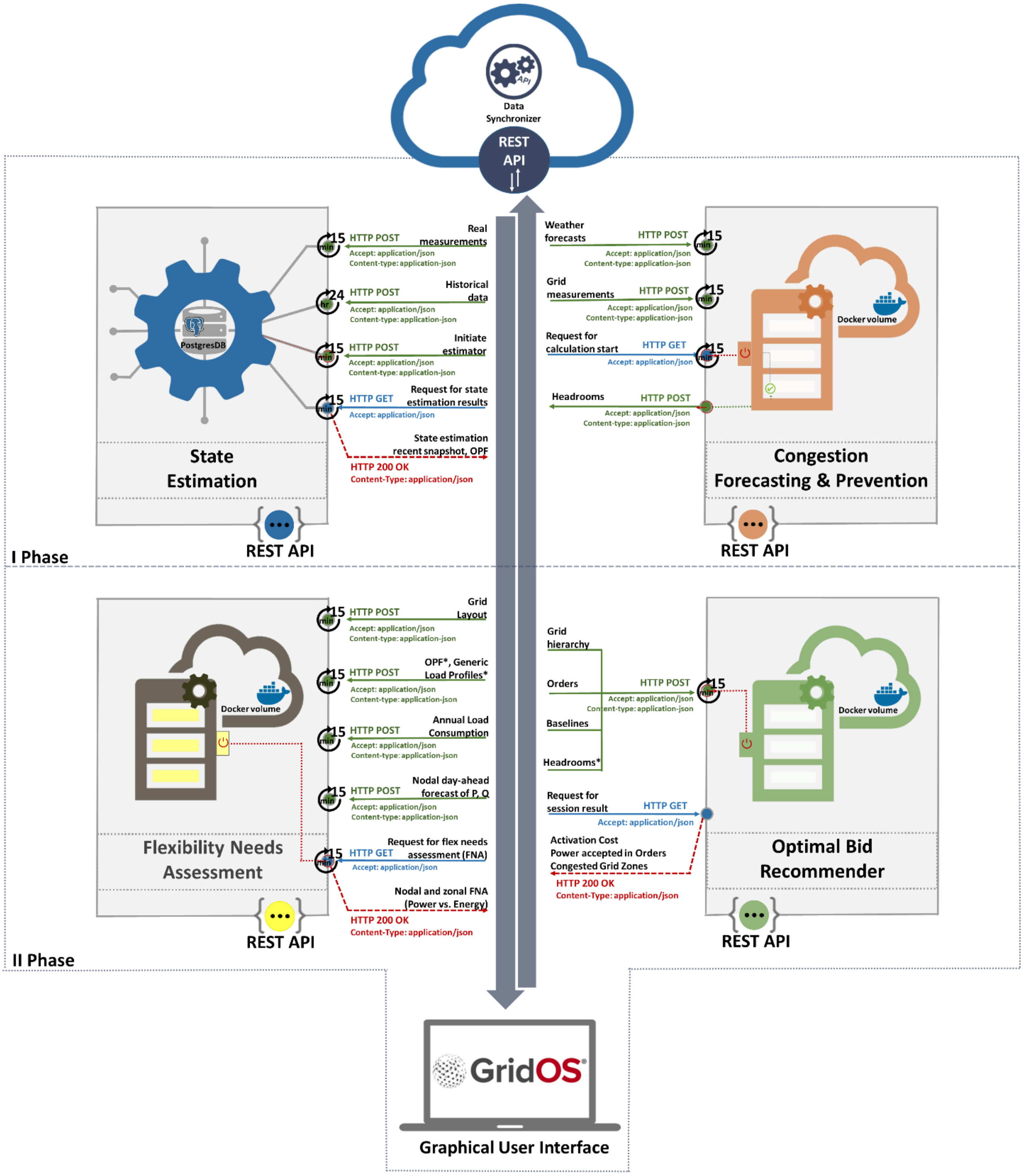

Figure 3.5 – Internal data exchange in scope

3.2 Smart Grid Tools

Within the demonstrator, large parts of the smart grid applications developed in the EUniversal project are tested under real operation conditions. Figure 3.5 gives a simplified view of the process and responsibilities of these tools. All of them, excluding the GUI (GridOS), was developed in the context of EUniversal.

Figure 3.5 - Overview Smart Grid Tools

In this chapter, the smart grid tools are briefly introduced. For further information, please refer to Deliverables 4.1 and 4.2 for the Smart Grid tools, as well as Deliverable 5.1 regarding market processes.

3.2.1 Day-ahead LV Congestion Forecast and Asset Headroom calculation

The Low Voltage distribution grid is a challenging environment, characterised by a partially unknown grid layout (e.g., the phase connectivity of single-phase connections is typically unknown), sparse non-real-time measurement points, and highly stochastic profiles (due to unpredictable end consumer behaviour). Nevertheless, it is important to have an accurate view on when and where there is a high risk for congestions so that the DSO has the right information to acquire or limit LV flexibility to eliminate such congestion risk.

The day-ahead LV congestion forecast tool is a statistical power flow-based tool that uses statistical and artificial intelligence techniques to calculate the probability density of voltage and current levels at all nodes in a LV network, given the available data and taking into account all unknown variables. Inputs are:

- The LV grid layout
- Historic and recent grid and connection profile measurements
- Weather forecasts
- Information on the flexible assets, as available to the DSO
- If available: a forecast of the voltage at the MV/LV transformer. If not available, 230V/400V is assumed.

The output is the risk for congestion, per feeder and transformer, per quarter hour time step and for the next 48h. Congestions considered are overvoltage, undervoltage, overcurrent and transformer overloading.

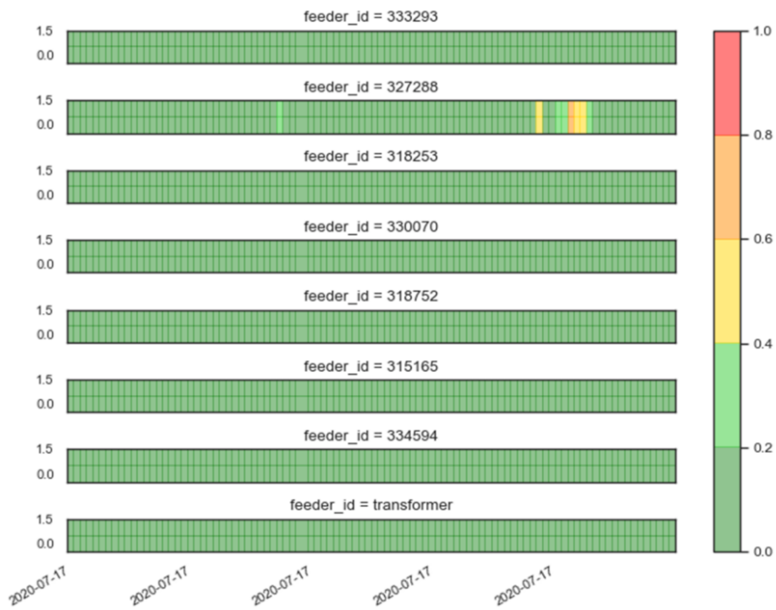

Figure 3.6 - Visualisation of the congestion risk per ¼ hour for a MV/LV transformer and its LV feeders

Based on the congestion forecast, the available headroom per asset is calculated, i.e., how many kW are available for use by the flexible devices, for example, to offer flexibility for MV congestion management or ancillary services. If there is no congestion risk, the headroom will equal the sum of the capacity of all flexible devices on the asset considered. If there is a risk for congestion, then the headroom will be lower, to ensure congestions are avoided. The next tool in the chain can then freely select flex bids within the headroom constraint so that the safe operation of the LV grid is ensured.

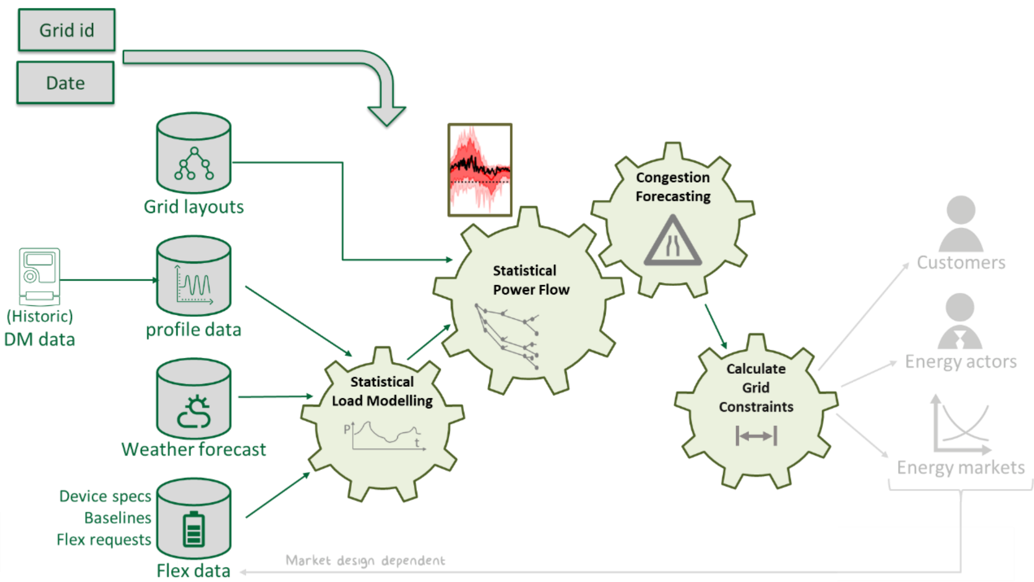

Figure 3.7 - Calculation flow of the congestion forecast and headroom calculation

3.2.2 Data-driven State Estimator (DdSE)

The Data-driven State Estimator (DdSE) is a tool specially designed to provide a real-time snapshot of the low voltage network, comprising voltage magnitudes and active power injections (if measurements are available) for each phase of every node. The methodology takes advantage of information gathered by the smart grid infrastructure along with real-time measurements and exogenous information like weather forecasts and calendar information (hour of the day, day of the week, etc.) while avoiding full knowledge about network topology and electrical characteristics.

Figure 3.8 exemplifies and illustrates a set of potential explanatory variables that can be used for voltage magnitude estimation. In brief, the method explores recent and current measurements collected by the subset of smart meters with real-time communication, together with voltage observations from the previous day and all the meters installed in the LV network and at the MV/LV substation. Information about the most recent numerical weather predictions (NWP), like global horizontal irradiance or ambient temperature, can also be integrated into the model. The same is valid for measurements collected by a weather station. Information about demand response actions or dynamic price signals is another potential explanatory variable that can be included. The voltage magnitude at instant t is estimated using the most similar occurrences of the variable in the past.

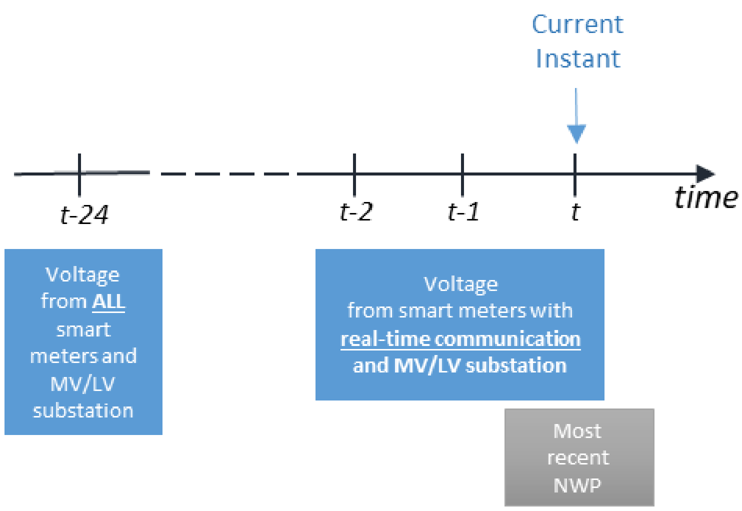

Figure 3.8 - Set of potential explanatory variables

Main innovations

The DdSE presents the following main innovations:

- Real-time state estimation in LV networks is performed using a very limited number of real-time telemetry, although assuming that all smart meter voltage measurements are sent to the historical database periodically (e.g. every 24 hours or every week).
- The network observability, in this case, defined by the number of nodes for which there is historical data or real-time measurements, is not required. Since the state estimation is achieved for each node individually, the existence of a portion of the

network without real-time telemetry or smart meters does not prevent the execution of the estimator (as it happens with the traditional approaches to the state estimation problem).

- Neither topological information nor electrical characteristics of the elements of the network are necessary. Nonetheless, the knowledge of the phase where each measured value corresponds to improves the estimation.

In addition, depending on the progress of the overall demonstration, the following innovations could be developed:

- The estimation results express conditional uncertainty involved, in the form of a set of quantiles. This feature gains particular relevance in the context of increasing the awareness of the operator by defining what kind of information is truly important to be passed to the operator (e.g. probabilistic alarms of occurrence of overvoltages).
- Weather measurements/forecasts can be included to improve the estimation with considerable benefits in networks with a strong presence of renewable resources. Compared to the state of the art, this is the first tool that includes information about the weather in LV state estimation, which is particularly important for networks with high integration levels of PV (even under a self-consumption regime).

Modes of operation

Three different modes of operation were developed for the DdSE:

1. Real-time state estimation – A new set of real-time measurements arrives via RESTful API and triggers a new state estimation. Results are stored in a database to be later delivered upon request.
2. Update historical and tune hyper-parameters – The set of historical measurements gathered by all the smart meters during that day arrive via RESTful API and are used to tune the hyper-parameters of the estimation algorithm.
3. Reset hyper-parameters and perform feature selection – After deployment (i.e., before any state estimation in a new grid) this option must be used via RESTful API to optimize the initial hyper-parameters and assess the sources of information.

User interface

From the point of view of a user, two methods (via RESTful API) are available to interact with the DdSE:

1. Request real-time state estimation – Retrieves the most recent snapshot of the network built by the state estimator.
2. Initiate state estimator – Used initially, after deployment, to optimize internal parameters (though a default configuration is available). The operator can also use this method every time considerable changes occur in the network (e.g. different topology, new consumers, new producers, etc.) to improve the state estimations.

3.2.3 Optimal bid recommender

Minimizing costs linked to DSO flexibility requirements

Among the challenges to be tackled in the design of a flexibility market, one is to minimize the cost of the flexibility that will be provided to the system. In this process, questions will arise from the DSO side such as:

- Is it more interesting to accept bid A or bid B?
- Is it better to accept one large flexibility offer or several small ones?
- Two bids have been issued at two different locations on the grid. Which one will have the biggest impact to reduce congestions?

These are the questions that the bid recommender will answer by analyzing the flexibility offers submitted to the market platform and putting them about the grid needs and limitations.

This process requires not having a direct matching of the buy and sell bids but waiting, until several offers are available on the market platform, to be able to select the best ones considering the forecasted state of the grid. For this, only 'sell' bids will be submitted continuously to the market platform.

During the examination of required inputs for the bid recommendation, it was noticed that N-Side platform requirements in terms of access to data etc. as flexibility market operator could not be fulfilled due to information security requirements resulting from the operation of critical infrastructures at MNS as well as internal regulations superseding GDPR requirements to protect customers from MNS. Therefore, N-SIDE has shifted roles and is now a technology and tool provider in WP8.

At regular intervals, the DSO will launch the bid recommender tool that will analyze and identify the combination of bids that solves as many congestions as possible and at the lowest price. Based on the output of the Optimal Bid Recommender (OBR), the DSO will then be able to submit 'buy' bids that match the recommended 'sell' bids.

At every call, the bid recommender (running on the servers of the DSO) will receive the needed inputs, which can be separated, into three categories (cf. Figure 3.9)

- <u>The grid static data:</u> macro view of the topology (i.e. which zones are connected)
- <u>The grid state forecast (dynamic):</u> headroom per transformer, headroom per feeder
- <u>The market-related information:</u> baseline of each flexible asset, flexibility bids (price and volume)

Once all the required information is gathered, a market-clearing engine will determine optimal bids to select to resolve the grid congestions with a minimal cost. This process is based on a mathematical optimization problem.

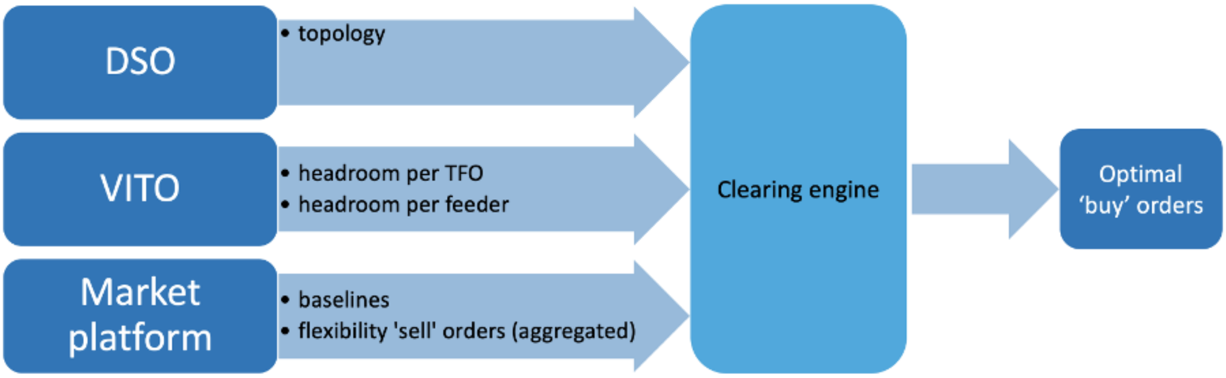

Figure 3.9 - Inputs and Outputs of the Optimal bid recommender

After a solution is found, the bids to be selected will be transmitted to the DSO. In case some congestions cannot be solved with the flexibility offers available on the market platform (i.e. not enough flexibility is offered), DSO needs will be published on the market platform through flexibility 'buy' offers. The DSO, likely based on the limit price based on the regulation, will choose the price of these offers beforehand.

3.2.4 Day-ahead flexibility needs assessment tool development

Flexibility needs assessment tool is developed. Four primary contributions of this work in detail are: (a) use of chance constraint flexibility needs assessment, (b) provision of zonal flexibility needs, (c) network state-driven flexibility activation signal, and (d) effect of reactive power flexibility activation with distribution network load power factor.

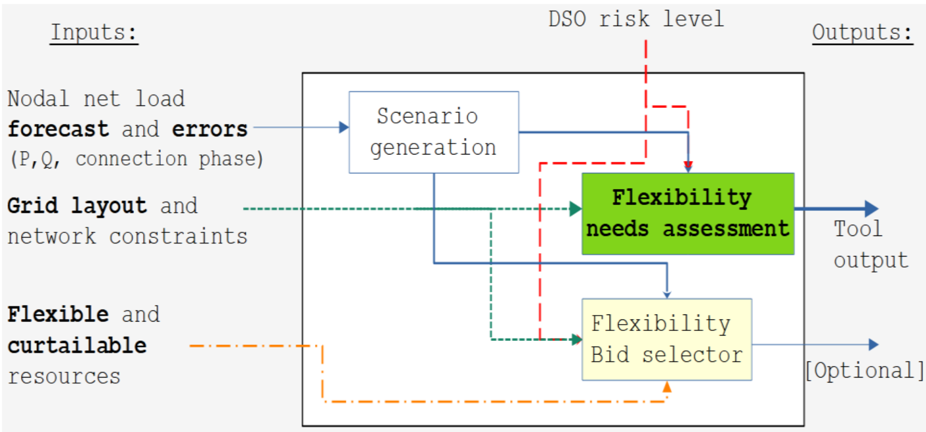

Figure 3.10 - Inputs, outputs and internal execution flexibility needs assessment tool

In the chance constraint flexibility needs assessment, based on the time-series of nodal load profiles and their forecast errors, a large number of scenarios are generated. These scenarios are used for flexibility needs assessment, which captures day-ahead uncertainty. Furthermore, flexibility needs assessment optimal power flow (FNA-OPF) is proposed. This FNA-OPF is implemented for each of these scenarios to identify the flexibility needs of the distribution network (DN). This needs assessment for all scenarios most probably will be a fat-tailed distribution, implying that if a robust needs assessment is performed over all probable scenarios, then it will lead to strong over-procurement of flexible resources. To avoid such an over-design, the application of chance-constrained robust flexibility needs assessment is proposed. In this formulation, the chance constraint (CC) levels decide the amount of risk-averse or risk-prone planning the DSO wants to perform. A high level of CC will lead to a small amount of ramp-up and ramp-down flexibility. This is denoted as the DSO risk level in the figure above.

Zonal vs nodal flexibility needs

Our proposed flexibility needs assessment tool provides the temporal and locational flexibility needs of a DN in a day-ahead setting. Figure 2 shows the ramp up and down flexibility power needs of a 76-bus low voltage distribution network. This DN is segregated into zones 12. The developed tool maximizes the silhouette score of clusters with CC level at 5%, as illustrated in Figure 3.11 and Figure 3.12.

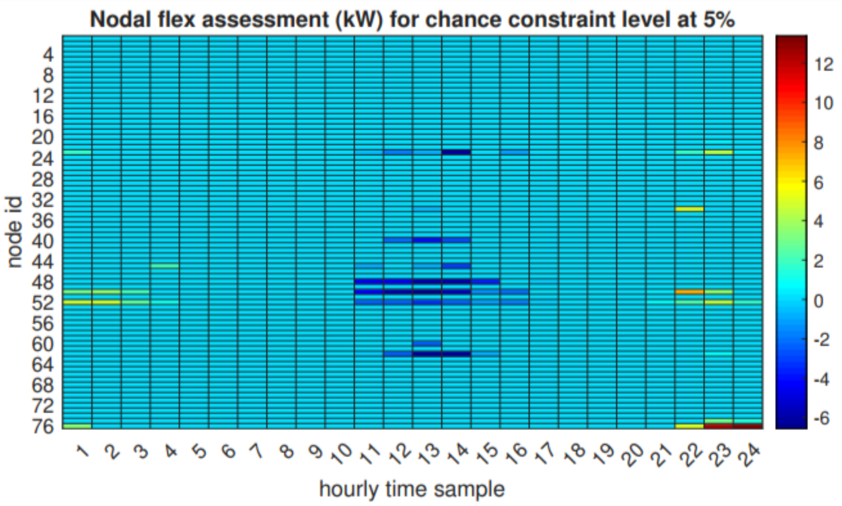

Figure 3.11 - Nodal flexibility ramp up and ramp down power needs of a DN

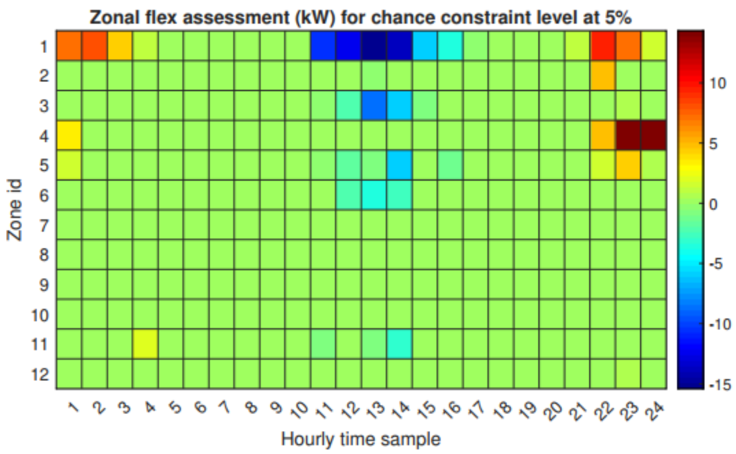

Figure 3.12 - Zonal flexibility ramp up and ramp down power needs of a DN

Identifying the zones of an LVDN will help DSO in planning the flexibility needs of a network, even though the analytical division of a DN is expected to work well. However, due to the sheer large number of DN feeders, it becomes crucial to have a standardized framework for dividing DN into zones based on electrical and/or geographical distances. For example, in the UK, there are more than 1.3 million LV feeders. In this context, a clustering framework to identify the best-suited LVDN zonal partition, using electrical distance as a measure, is developed. Zonal flexibility assessment can provide some slack in procuring or planning flexibility. Power flows in a DN could have many solutions. Especially if nodal load flexibility is considered as an optimization variable many different flexibility dispatches could feasibly resolve network issues. Zonal assessment will assist DSO's to quickly find alternatives to some flexibility needs in a particular zone.

Network state-driven flexibility activation signal

A resource dispatch optimal power flow (RD-OPF) is also proposed. In addition to the flexibility needs assessment, a network state-driven flexibility activation (FAS) signal is also generated, which takes into consideration the nodal voltage sensitivities. These FAS can be utilized to value different flexibility resources in a DN. The FAS is composed of a nodal voltage component, a projected nodal thermal loading component, and voltage and current imbalance components. The proposed FAS is analogous to OPF dual variables, which are frequently used as locational marginal prices or LMPs.

Reactive power flexibility

Figure 3.13 shows that the active power flexibility needs of a distribution network reduce with reactive power compensation. For a distribution network load power factor of 0.8, up to 50.6%, lower active energy is needed for the secure operation of the grid. The profit increases much faster for lower levels of flexibility than for higher levels of flexibility. Note that in Figure 4 (b) the profit is reducing as the value of the objective function in presence of a high degree of active power flexibility significantly decreases. Due to the reduction in objective value, the value of reactive compensation gradually deteriorates and saturates to a certain level. The proportional increase in active energy reduction and profit with different levels of power factors shows the significance of the distribution network load power factor and reactive compensation. For networks with low values of distribution network power factor - even with a high R/X ratio - reactive compensation planning will be required.

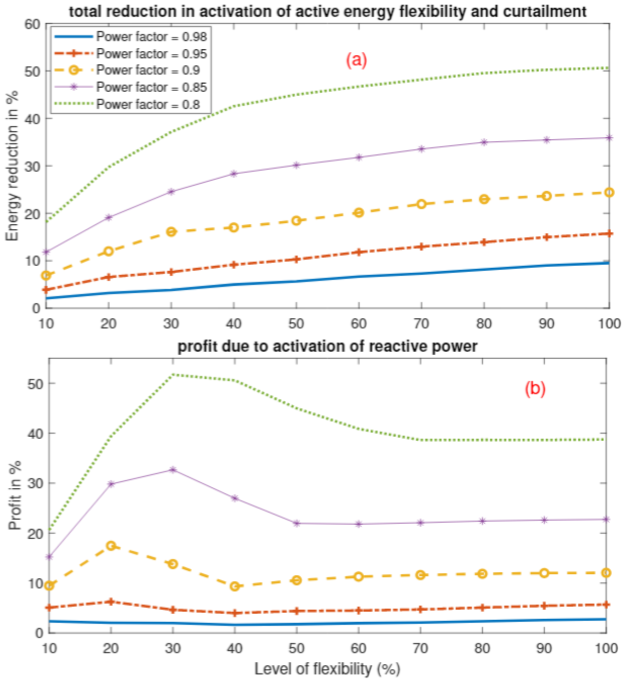

Figure 3.13 - Effect of reactive power activation on active power flexibility needs and profit

Consideration of distribution network imbalance in flexibility activation

Dispatchable resource activation should consider the distribution network imbalances in voltage and current, which may be a concern for network stability. In our formulation, we consider the voltage and current imbalances and appropriately dispatch flexible resources, so that DN imbalances are not aggravated and can be contained within prescribed limits.

3.3 Market platform

The NODES market platform will be used to make flexibility accessible to the DSO (MNS), according to the general market characteristics. It serves as a communication and trading environment for buyers and sellers, where the price is determined by supply and demand. The NODES market platform is an open, transparent and independent marketplace that is positioned at the centre of the market framework, to facilitate a coordinated exchange and interaction among the various market agents. It covers all market-relevant processes related to registration and prequalification, trading and post-trading processes, i.e., validation and settlement. However, it is important to note that validation and settlement will not be tested during this demonstration, as the UMEI standard interface, the operational alignment of tools and services, asset availability and the analytical potential of the smart grid tools are the core features to be tested during the pilot and EUniversal as a project.

On the NODES market platform, FSPs/Aggregators can offer their assets of different technologies to compete against each other on a level playing field. Hence, asset owners of flexibility can stack values across the different market necessities and sell flexibility directly to the grid operators. DSOs or TSOs, in turn, can address their need for flexibility for up/down regulation to solve identified existing and future grid constraints. The bottom-up market design allows for the purchase of flexibility services across all grid levels, including ancillary services and congestion management, facilitating the effective application of available flexibility in terms of asset type, time, location, and price to a specific grid problem.

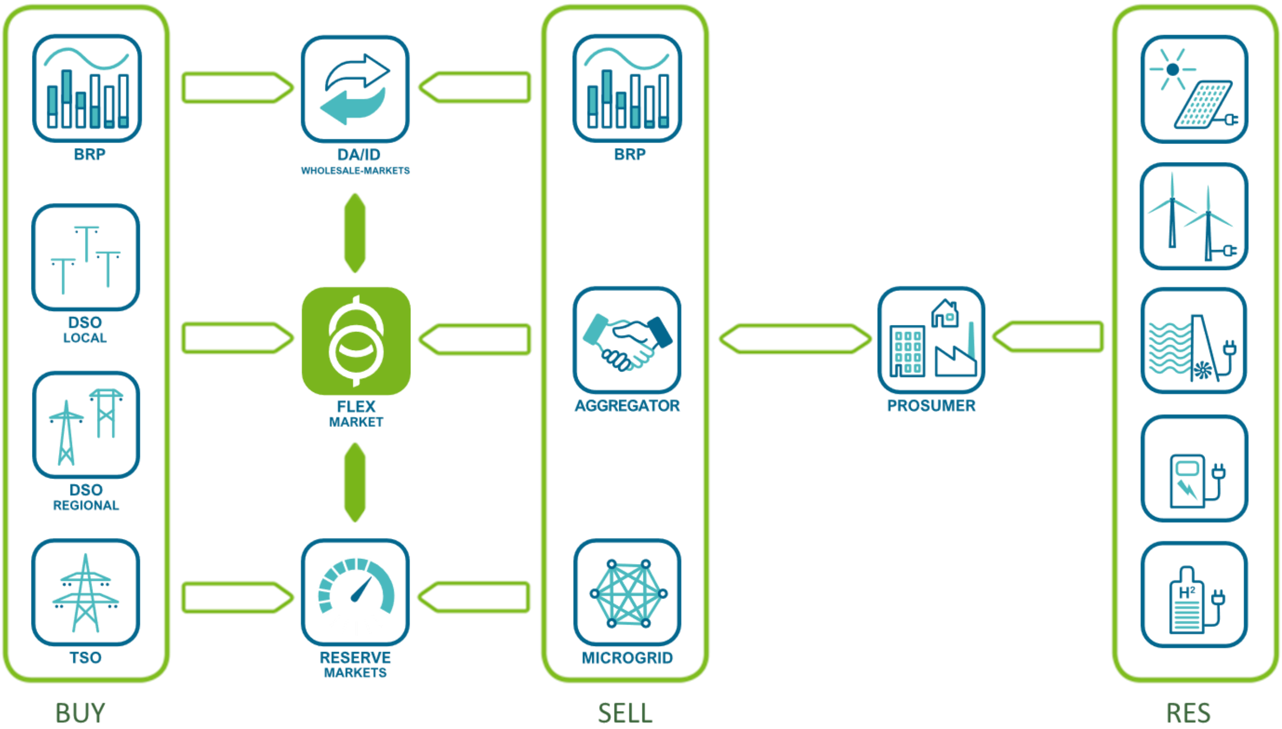

Figure 3.14 - Flexibility market stakeholders and link to other markets

NODES market design applies a continuous market clearing (pay-as-bid), where orders are matched continuously when a buy and sell order match each other's price and quantity limits.

The purchase of flexibility can be performed across different market horizons, i.e. the short-term and the long-term market (ShortFlex and LongFlex, according to the NODES terminology). ShortFlex products address an immediate need for flexibility by the grid operator, according to the respective short-term market characteristics that are defined in the demo-specific market design. LongFlex addresses products that can be reserved over a determined future time, enabling the grid operator to activate the reserved flexibility when needed or to buy a more appropriate flexibility solution in terms of quantity, location and price in the short-term market. LongFlex product prices are therefore composed of a reservation and an activation price.

However, the German demonstrator focuses on ShortFlex solutions for congestion management, using both active and reactive power. The market design defined for the German demonstrator determines the necessary timeline for market operation concerning Day-Ahead and Intraday processes, aligned with the wholesale market and the MNS internal iterative processes according to EU-SysFlex and Redispatch 2.0, which is shown in Figure A.2 in the appendix.

3.4 Connection through the UMEI

The UMEI as a standard communication interface aims to facilitate the connection of DSOs and other market parties to various market platforms to purchase local flexibility.

The functionality required for FMO integration can broadly be divided into two categories:

- Category 1: Preregistration, prequalification, master data and other work performed initially or once in a while
- Category 2: Regular operations: Buying, selling, registering/submitting base lines and meter readings

For operations within category 1, the UMEI does not currently provide any API or guidelines. Participants are expected to use the FMO graphical user interface (web portal) or the FMO API, which will be specific to each FMO.

For operations within category 2, the UMEI will provide API specifications, which will be implemented on the server side by FMOs and on the client side by the other market participants (DSOs, FSPs) to ensure the correct connection and market operation between the two endpoints. These specifications will be outlined in detail in D2.6 - UMEI API management and documentation.

Daily operations:

- Communicating demand for flexibility: DSOs and other market participants communicate their demand for flexibility by posting buy orders. Each buy order is connected to a specific previously defined location in the grid.
- Communicating supply of flexibility: FSPs communicate their supply of flexibility by posting sell orders. Each sell order is connected to a portfolio and thus also to a specific previously defined location in the grid. The UMEI will support posting buy orders, fetching own orders, and deleting (deactivating) orders.
- Receiving notifications about trades: A trade (also referred to as a match or notification in other UMEI documents) describes an explicit trade between two or more partners, at least one buyer and at least one seller. The API will support fetching trade information relevant to an organization. Trade information is not directly modified, trades are created by the FMO when it matches sell orders and buy orders.
- Registering baselines for asset portfolios participating in the market: An asset portfolio in this context refers to one or more grid-connected assets that are treated as one single aggregated tradeable asset. Baselines represent planned/forecasted power consumption and/or production for the given portfolio during specified time intervals without activation of flexibility. The UMEI will support posting base lines, fetching its baselines, and updating/deleting its own base lines (subject to market rules).
- Registering meter readings for asset portfolios: Meter readings represent actual measured power consumption and/or production for the given portfolio during specified time intervals. The API will support posting meter readings, fetching own meter readings, and updating/deleting own meter readings (subject to market rules), which can be used for the settlement process.

Technical details about each operation will be published in the UMEI API management and documentation (D2.6).

3.5 Customer Aggregation

Centrica has the role of the FSP in the German demonstration and offers the flexibility services of one or multiple resource(s) through aggregation to system operators via market operators. In this demo, flexibility should be provided for the DSO (MNS), while NODES serves as Flexibility Market Operator (FMO). Figure 3.15 illustrates the connection between the different actors in the German demo.

Figure 3.15 - Actors in the German Demonstration

From the FSP's side, five different system use cases are defined: DER registration (SUC 16), Bidding aggregation (SUC 17), Resource dispatch and monitoring (SUC 18), Baselining (SUC 19), and Collecting and publishing metering data (SUC 20). All these system use cases apply to both the German and Portuguese demonstrators (cf. chapter 2.1).

The process starts with the registration of the flexible assets into the market platform, followed by the development of a physical model for each flexible asset. These processes are conducted by the FSP and are included in SUC 16. Different portfolios (clusters of resources) are defined in this same system use case, which depends on the grid nodes information received from the DSO. The FSPs need to solve an optimization problem to compute the optimal bids, which are then submitted to the market platform (SUC 17). The FSPs are also responsible for submitting the baselines at the same time that the bids are submitted, which is described in SUC 19.

After the market clearing, the FMO sends a notification to the FSP regarding the accepted bids. FSPs are responsible to dispatch the accepted offers via individual assets and make sure that the service is delivered in real-time (SUC 18).

Apart from the resources aggregation and disaggregation processes described above, SUC 20 describes the mechanisms to retrieve the metering data from the DER and share them with FSP, DSO and FMO for verification and settlement purposes.

Interacting with assets

To provide flexibility, the FSP needs to interact with each flexible asset. This interaction is done for two purposes:

1) The FSP can have access to the sub-metering data related to the flexible assets to calculate the available flexibility. This sub-metering data includes not only the energy consumption/generation of the asset but also the state of the flexible asset, if it is applicable (e.g., the state of the energy/charge of the battery). Another reason for the FSP to read sub-metering data is to calculate the baselines. It should be pointed out here that the metering requirements depend on the selected energy or flexibility products and their respective metering specifications in the market design. For instance, in the case of the reactive power product, metering for reactive power consumption/generation is needed.
2) After market clearing, the FMO sends the information regarding the accepted bids to the FSP. Then, it is the responsibility of the FSP to run the disaggregation algorithm to distribute the accepted bids among the available resources. After solving the disaggregation problem, the control signals need to be sent to the flexible asset to react upon the FSP's request. This signal control can include a binary message to turn on or turn off the flexible assets, like electrical heat pumps; or it can be a requested amount of energy to either charge or discharge a battery, for instance.

According to Centrica's experience with different residential and industrial flexible assets, two ways of integrating devices are identified:

1) Cloud-to-cloud API integration (e.g. REST API, GRPC, Apache Kafka, etc.) between the cloud platform of the device and the FSP. The implementation of this option will be done based on the specific asset types and brands.
2) A local communication interface between the device and a home energy management gateway. Different wired and non-wired communication interfaces are available on the market.

Since in the German demo, no smart meter rollout has taken place on a wide-ranging basis and a broad variety of customers regarding the type and the brand of flexible assets can be assumed, the second option to build the interaction is more applicable. To this end, a home energy management system (HEMS) developed by E.ON Solutions and GridX has been selected for the German demo to make the connection between the FSP and the flexible assets installed at the end users' side. In that regard, all the flexible assets of the end-user will be connected to the HEMS and then Centrica as FSP is going to build the connection to the HEMS to receive data and control of the flexible assets through an API connection. This process is represented in a simplified manner in Figure 3.16.

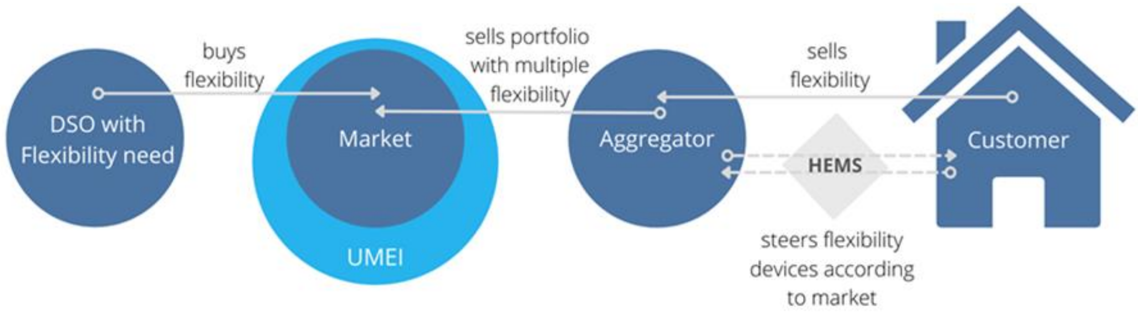

Figure 3.16 - Organisation of data flows and asset steering in the German Demo

4 Field test preparation

4.1 Measures implemented and planned structure of the field test

4.1.1 Grid selection

As a first step in preparing the field test, suitable grids were selected that represent the future supply task of the distribution grid operators. The aim was to consider the largest possible number and variety of flexible applications to enable different scenarios for the field test. First, all MNS low-voltage networks with existing flexible applications were analysed and evaluated. A scoring system was developed that takes into account the presence of different flexible assets, the total number of steerable appliances as well as past grid congestions. To take regional diversity into account and to compensate for a regional lack of interest, three pilot regions were ultimately selected in the grid regions of Brandenburg, West Saxony and South Saxony, in the area of operation of MNS. The following table characterises the selected pilot regions.

Table 4.1- Brief description of the selected low-voltage grids

Identifier	MLq0094	MFn4420	MIi0809
Grid region	Brandenburg	West-Saxony	South-Saxony
Town where the LV Grid is located	Falkenberg/Elster	Brandis	Frankenberg
Number of connected meters[2]	400	300	400
Number of customers with flexible devices	50	44	192
Specifics	• Mostly single-family houses • Partly still use of night storage heaters (historically grown) • MNS site in town	• Residential area with single-family houses from the 1990s/2000s • Radial grid structure	• Mixture of larger apartment buildings and single-family houses • No oil or gas heating allowed due to water protection rules • High spatial density of installed power

[2] Rounded values

The selected grids are among the MNS low-voltage grids with the highest densities of flexible resources and are representative of the possible usage of flexibility markets at the low-voltage level. In addition, a further increase of steerable systems is expected for the coming years, which makes the chosen regions an optimal use case for new grid solutions in congestion cases.

4.1.2 Customer acquisition

For the demonstration of the flexibility market, the acquisition of voluntary customers out of the selected grid areas is a central aspect. To participate in the field test, grid customers must fulfil two conditions:

1) The existence of flexible or steerable applications such as batteries, heat pumps, heat storage, electric vehicle (EV) chargers, PV converters
2) The willingness to participate actively in the local flexibility market as a test user.

For this purpose, the customers should have as few restrictions as possible as well as easy access to information. Therefore, information events and talks were held with the mayors and offices in the pilot regions to discuss the organization of citizen events and to solicit support. An information video was created to explain the project goals in an easily understandable manner (see project website and link in Annex II). Every owner of flexible appliances in the designated low-voltage networks, in total more than 500 people, received a postal invitation to the events. Additionally, several articles in local newspapers and on the town websites were published to increase the reach and awareness of the project.

Figure 4.1 illustrates the distribution and contact type of interested persons as a consequence of those events, that were willing to participate or requested further information about the project.

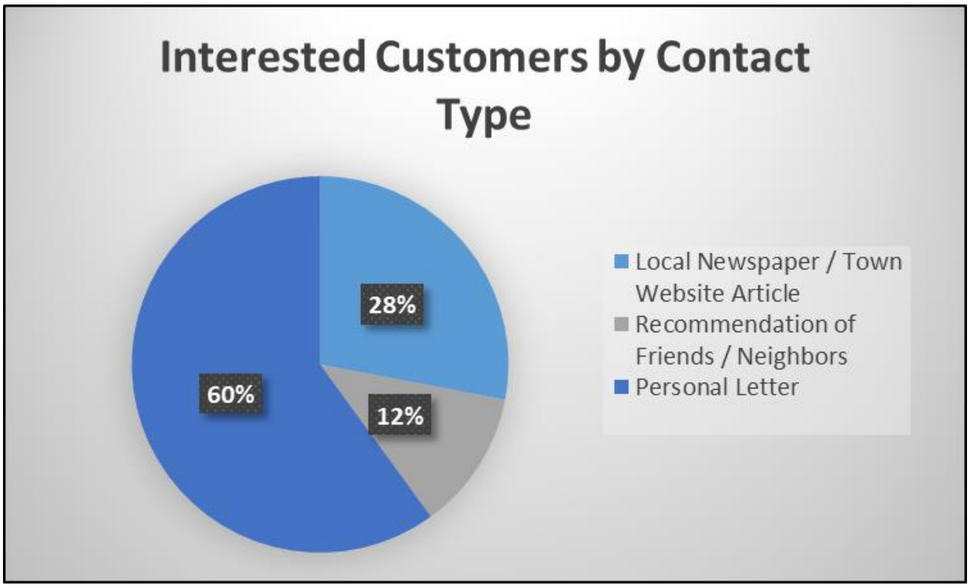

Figure 4.1 - Contact Channels for potential EUniversal customers

A citizens event was hosted in each of the pilot regions, describing the EUniversal project content and encouraging the participation of flexibility owners. In addition, digital meetings were organised as an alternative contact channel due to the tense COVID situation in the area of the demonstrator at the end of the year 2021. The interested volunteers were able to register via a separately set up mailbox for the German Demo of EUniversal and receive a contract to participate in the field test. The MNS legal department was included in the contract development to ensure compliance with current European GDPR and data sensitivity standards.

In total, at the completion date of this document, there are more than 30 interested people out of the three selected LV grids who have received and are currently reviewing the project contract.

To be able to react adequately to the previously unknown customer feedback, several scenarios were discussed in the project to minimize the risk of low customer participation for the planned investigations. These include sorted from least to highest impact:

(a) Extension of the aggregation area to the complete LV network (transformer level) instead of individual feeders to maintain the market character
(b) Virtual merging of participants from all regions to form a simulated LV network
(c) Test of effects with MNS assets (batteries) and generic simulation of customer behaviour

While option (a) only shifts the focus of aggregation from feeder-focussed local LV congestion to the provision of flexibility from LV for MV, which is also the potentially more common use case, the other options create an artificially extended aggregation and market area and thus reduce the evidence quality of the smart grid solutions for those local congestion cases.

Nevertheless, the pure amount of flexibility resources taking part in the field test does not have a large impact on the technical functioning of the smart grid tools and procedural scheme of the German demonstration. A lack of participation would however limit the significance of the cost-benefit analysis of the flexibility market approach.

Moreover, for all options, the demonstration of the UMEI approach is not compromised, since the developed interface works independently of number and type of flexibility. Additionally, the integration into the DSO and market system is examined. The objectives of WP8 (see section 1.2) can therefore be achieved.

Based on the customer feedback until now, the implementation of mitigation method (a) is the only method that could become relevant for the main part of the demonstration. However, by detailing among LV-feeders with above-average customer participation, the demonstration of all specifics for the demonstration is feasible. The addition of mitigation measures (b) and (c) can be considered if it adds value to the planned analyses.

4.1.3 Planned equipment of clients

Each participant will be provided with a Home Energy Management System (HEMS) of GridX to enable the proper execution of the pilot test. This is to ensure that control of flexible resources can be managed remotely (cf. Section 4.1.3) and that the interfaces for this control are harmonized. In addition, other grid state data are collected at the connection point of the flexible devices, which can be used to improve the forecasting and optimization tools. Details on the HEMS device can be found at [5].

The HEMS is compatible with the most common manufacturers of flexible assets like PV converters, batteries and EV charging. The compatibility of the customer devices is checked individually with each interested candidate before signing the contract for the pilot test. If the compatibility is not given and no upgrade solution can be implemented within a reasonable scope, the customer is excluded from the field test.

Figure 4.2 - Home Energy Management System

A visualization app is provided for displaying load profile data and feed-in forecasts. The participants thus can analyse their consumption in an easily understandable and detailed manner. Furthermore, compatible smart home applications can be controlled and informative data such as saved CO_2 emissions can be retrieved.

4.1.4 Installation of additional measurement technology in the grid

Because the roll-out of smart meters in the area of the German demonstrator was not far advanced at the start of EUniversal, alternative ways were sought to obtain suitable real values for the validation of the algorithms and the flexibility market concept. With the help of an adapted measurement setup, local grid stations and cable distribution cabinets were equipped with measurement bundles[3]. This has two advantages: On the one hand, these measurement points ensure the visibility of a large number of grid nodes in the network. On the other hand, they enable the equipment to be installed without extensive civil engineering work and supply interruptions.

[3] For regulatory reasons, the costs for this setup were implemented outside of the funded budget.

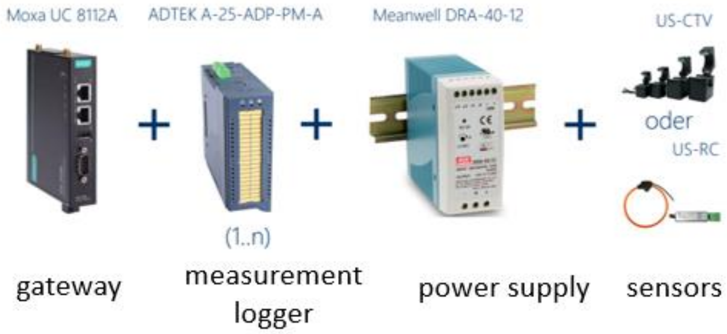

Figure 4.3 - Equipment of cable distribution cabinets

The bundles consist of current and power sensors, a gateway, a measurement logger and a power supply. In addition to current and voltage values, power and angle readings are also measured and can be used as input parameters of the grid tools. Via a telecommunication connection, the acquired electrical quantities are automatically transferred into the measured value database. These values can then be queried on request via a REST API.

4.2 Field test scenarios

The following section describes the outline of the field test schedule and possible research objectives to which a particular emphasis will be applied. The main objective of the test scenarios is to verify in complement with the WP6 defined KPIs [6], the functionality of the flexibility market value chain in the German demonstration and test the applicability of the overall process in different boundary conditions.

The scenarios will also form the framework for the field test simulations and measures, whose details and methodology will be explained in the upcoming deliverables of WP8. Furthermore, any characteristics and challenges to be expected in the future are analysed and classified based on this framework. In addition, the functionality of the UMEI will be demonstrated under different test cases.

The following scenarios will be examined:

1. *Tool precision*

   The data exchange between the systems and tools, the accuracy of the state estimation applications and the practicability of the optimization and market approaches will be tested in different grid topologies and load flow situations. For this purpose, research will be conducted in several test networks. If necessary, minor adjustments will be made in the foreseen process.

2. *Production/Asset Variation*

   The influence of different asset types in the flexibility market will be investigated. It will be analysed if there are potential variations in operation that need to be taken into account in the market set-up. An attempt will be made to gain insights into the question of how potential deviations need to be considered in (future) system management tasks.

3. *Load integration*

   The difference between the conventional congestion management in medium and low voltage with curtailment of renewable feed-in and the alternative use of flexible loads will be demonstrated and potential benefits of the latter for DSOs' voltage control and congestion management services will be analysed.

4. Market-based approach vs. Redispatch

   The connection of the flexibility market to the Redispatch 2.0 process, which is mandatory in Germany, will be attempted to enable a cascaded process. A recommendation for the possible interaction of the two approaches will be drafted.

Further considerations of aspects based on regional specificities or future scenarios are possible depending on the overall progress of the demo.

4.3 Applicability and limitations

The preparation and realization of the field test come along with numerous technical and operational challenges. In the following, the different limitations and challenges of the German Demonstrator will be outlined:

Technical

Technical applications and limitations are mainly related to the integration and interconnection of different system tools and APIs (mainly the UMEI and associated functional specifications). Furthermore, the HEMS have to be compatible with customers' resources to provide reliable control of flexibility activation, which may reduce the number of participants.

The smart grid tools and the algorithms developed have to be correctly integrated into the MNS system, ensuring the well-functioning and hence a sufficient accuracy and precision of the results.

The parties acting on the market platform are requested to verify the compatibility of their system and APIs with the UMEI as a central interface to ensure all relevant processes related to the trading process.

Another technical limitation will be the strict separation of active and reactive power, BUC I and BUC II, respectively. The clear separation of both may not be realizable from a grid perspective, as converters, especially in LV, are generally designed to have an operating range that is fully or partially dependent on active power, e.g., in the case of a fixed cos(phi). Furthermore, the applied market clearing algorithms only consider active power. The latter is essentially important to bear in mind when interpreting the results: the algorithms of the smart grid tools do not distinguish between active and reactive power, since they are interdependent since LV grids are resistive and the separation from a technical perspective is thus difficult. Consequently, the estimation of the required amount of flexibility by the smart grid tools includes active and reactive power, whereas active and reactive power are traded separately on the market platform. This may cause a trade-off and hence affect the efficiency of the market.

Operational

From an operational perspective, the major uncertainty lies in the availability of necessary data in terms of amount, type and quality of data, as well as the required granularity, to correctly comply with German grid and energy market requirements. The input of this data directly affects the accuracy of the output of the smart grid tools and hence their applicability and reliability for the DSO. A major obstacle in this regard is the lack of active user participation, meter data and grid data: sufficient data is crucial for the Demonstrator to reliably evaluate the cost-effectiveness of the flexibility usage in the test locations. To test the set-up as well as the entire value chain, a series of simulations can be performed. However, it is important to note that a simulation will only serve as an operational test scenario, but does not reliably replicate a realistic situation.

Ultimately, the demonstrator aims at testing the practicability and feasibility of the combination of Redispatch 2.0 and flexibility markets in the Day-ahead and Intraday operational business. Similarly, the number of participants directly affects the reliability of this comparison, as the number and type of flexibility are crucial parameters to compete with the cost-based Redispatch.

At the same time, the pandemic situation made it particularly difficult to engage with customers in a face-to-face setting. Thus, the possibility to point out the importance of the project in discourse was reduced to alternative online appointments and small circle meetings with social distance.

Regulatory framework

The German Demo aims at testing the efficiency and effectiveness of smart grid solutions as well as the implementation of a flexibility market for the LV and MV grid in addition to the cost-based and mandatory Redispatch 2.0. Currently, the German regulation impedes the usage of demand-side response and the implementation of flexibility markets as an additional measure to the existing regulated solutions. There are several arguments for this, among them the potential risk of strategic bidding as well as the logistical challenge for system operators when coordinating the increased number of assets. However, adding flexibility markets as an official measure to the German energy system - as demanded by European legislation (Art. 32 Electricity Directive) - also bears the huge potential to prevent additional costs and time delay due to grid investments, to efficiently and effectively use existing resources and even to solve grid problems locally through smart up/down regulation of local or regional assets. Certainly, the realization would require an adaption of the German regulatory framework as well as adjustments of the grid tariff and tax schemes to incentivize the participation of flexibility providers for grid management. A detailed evaluation of the required adaptions has been elaborated by a forum of experts and presented to the German Ministry for Economic Affairs and Climate Action in June 2021[7].

The German Demo will test the different scenarios to evaluate the effective benefits in terms of resources and costs.

5 Conclusion and Outlook

This document outlines the framework in which the German demonstrator is taking place by explaining the project's internal and external drivers, influences from other projects, as well as regional conditions in the demonstration area. It also describes the system architecture and the developments made so far in and around the demonstrator.

A first impression of the tools, FSP systems as well as the market platform and the use of the UMEI is given. The selected low-voltage grids are presented and important preparatory activities for the field test, including the measures taken for the motivation of voluntary project participants, are described. Finally, important steps, limitations and scenarios for the field test are defined, which forms the basis for the demonstration of the use cases and their analyses planned in D8.2 and D8.3.

Further steps for automation and visualization of the results are planned for the next months until the actual start of the live demonstration phase. In addition, the installation of the HEMS needs to be performed, once the customers that have been won through the extensive acquisition activities have been contractually bound. In addition, the developed algorithms still need to be fine-tuned with appropriate forecasting and measurements to provide better results.

Nevertheless, the activities to date have laid the foundation for a successful proof of concept of the application chain. The first smart grid tools have already been tested and the data exchange has been established in an agile approach. Through the developed scenario framework, coordinated investigation objectives have been agreed upon between the involved partners, which will facilitate the further course of the planned tests.

6 External Documents

[1] Deliverable 2.2 - Business Use Cases to unlock flexibility service provision, 2021.https://euniversal.eu/wp-content/uploads/2021/05/EUniversal_D2.2.pdf
[2] Deliverable 6.7 - The German Demonstration- Flexibility of Active and Reactive Power from HV Distribution Grid to EHV Transmission Grid, 2022.https://eu-sysflex.com/documents/
[3] D. Engelbrecht et al., "Demonstration of a Market-based Congestion Management using a Flexibility Market in Distribution Networks," International ETG-Congress 2019; ETG Symposium, 2019, pp. 1-6.
[4] Docker, Inc., Use containers to Build, Share and Run your applications, 2022.https://www.docker.com/resources/what-container
[5] gridX, gridBox in detail, 2022. https://www.gridx.ai/edge-services#facts
[6] Deliverable 6.2 - Definition KPI for DEMOs, 2021.https://euniversal.eu/wp-content/uploads/2021/08/EUniversal_D6.2__Definition-KPI-for-DEMOs.pdf
[7] Land Brandenburg, Länder fordern bessere Rahmenbedingungen für flexible Verbraucher und Erzeuger im Stromnetz. 2021. https://mwae.brandenburg.de/de/l%C3%A4nder-fordern-bessere-rahmenbedingungen-f%C3%BCr-flexible-verbraucher-und-erzeuger-im-stromnetz/bb1.c.706108.de

Annex I - Further Illustrations

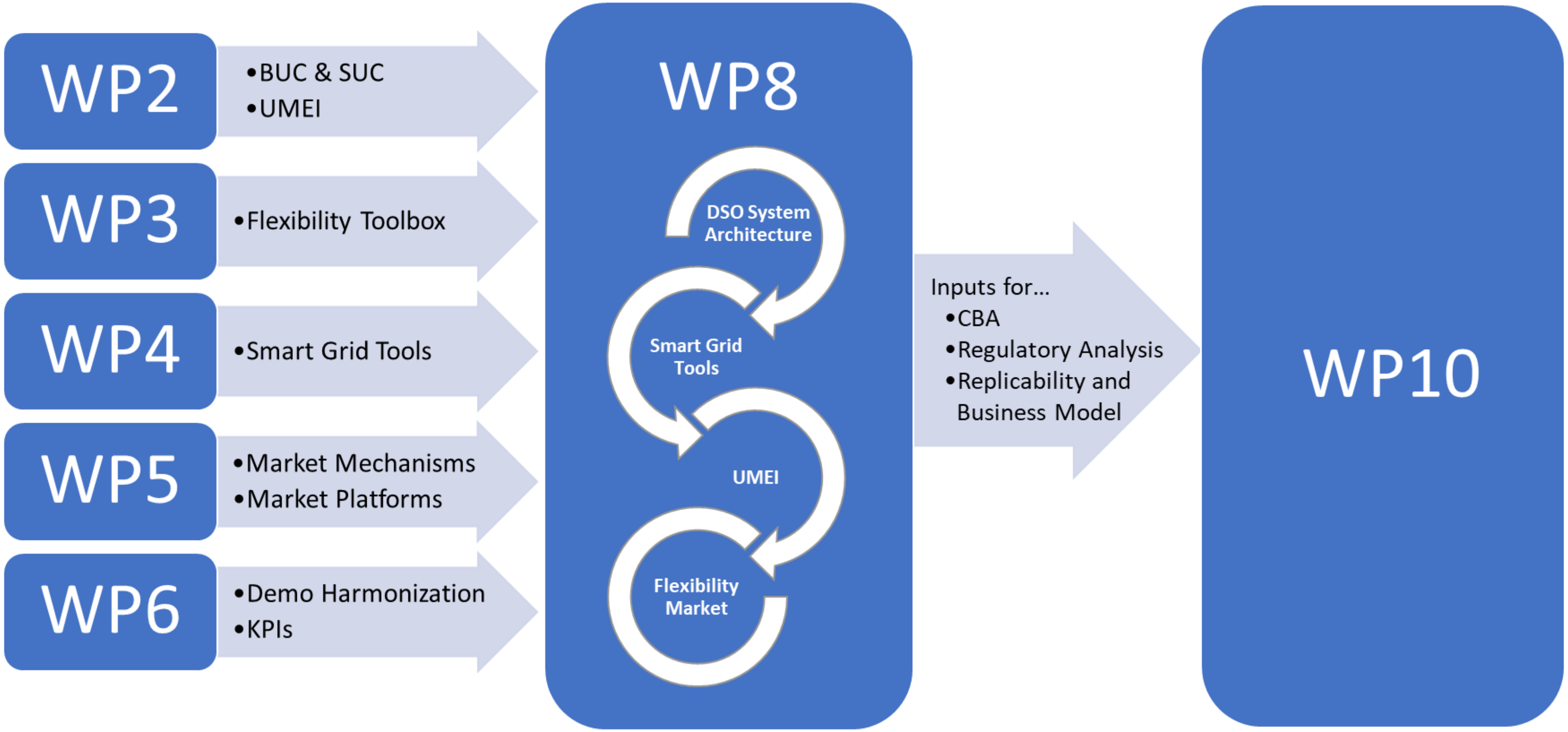

Figure A.1 – Relationship of WP8 with other WPs

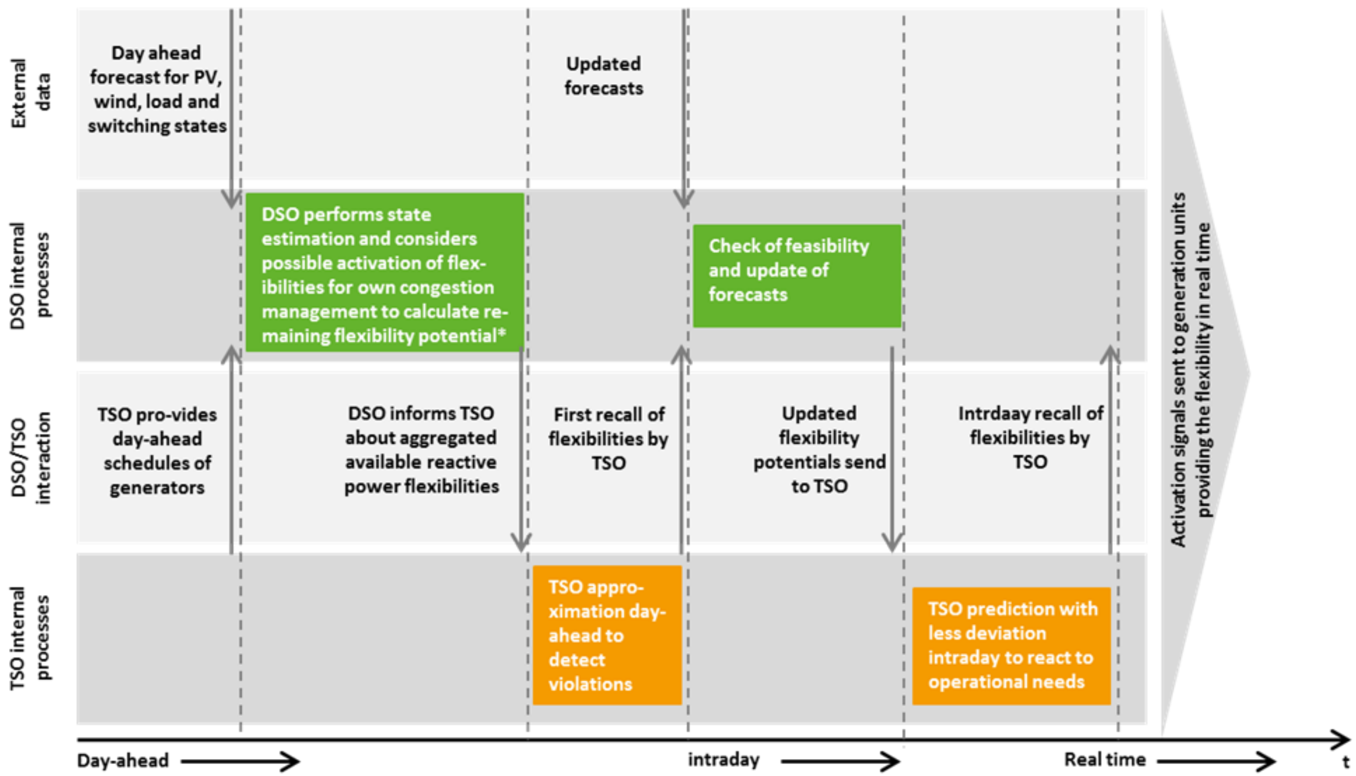

Figure A.2 – Process Chart EU-SysFlex

Annex II – Information video

https://euniversal.eu/german-demonstrator/

OR

https://www.youtube.com/watch?v=NBctCEnhTnA