INTERPLAN
INTEgrated opeRation PLAnning tool towards the Pan-European Network

Work Package 6

INTERPLAN model validation and testing

Deliverable 6.1

INTERPLAN scenarios which will be validated in the simulation

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Abbreviations

CANI	*Calculation of available & needed inertia*
CCS	*Carbon Capture and Storage*
DER	*Distributed Energy Resource*
DG	*Distributed generation*
DIRS	*Determination of inertia related setpoints*
DR	*Demand response*
DRES	*Distributed renewable energy sources*
DSO	*Distribution System Operator*
EAC	*Energy Authority of Cyprus*
EHV	*Extra High Voltage*
ENTSO-E	*European Network of Transmission System Operators for Electricity*
EU	*European Union*
EV	*Electric vehicle*
fFRC	*Fast Frequency Restoration Control*
HV	*High voltage*
IRSC	*Inertia related setpoints check*
KPI	*Key Performance Indicator*
LFG	*Load and Generation Forecaster*
LV	*Low voltage*
MQTT	*Message Queue Telemetry Transport*
MV	*Medium voltage*
NC RfG	*Network Code on Requirements for Generators*
OLTC	*On-Load Tap Changer*
OPF	*Optimal Power Flow*
RES	*Renewable energy sources*
RoCoF	*Rate of Change of Frequency*
SAIDI	*System Average Interruption Duration Index*
SAIFI	*System Average Interruption Frequency Index*
ToU	*Time of use*
TSO	*Transmission System Operator*
UC	*Use case*
WP	*Work Package*

Executive Summary

The goal of the INTERPLAN project is to provide an INTEgrated opeRation PLAnning tool towards the pan-European Network with a focus on the TSO-DSO interfaces to support the EU in reaching the expected low-carbon emission targets while maintaining the network security and reliability. The project involves six partners from five European countries.

INTERPLAN analysed national and European regulation and grid codes, and defined a number of use cases which are relevant for today's and future network operation and planning. Also, scenarios for the future electric energy system were looked up, namely for the years 2030 and 2050. In parallel, network models for all voltage levels were prepared.
Based on this work, five showcases were designed. The showcases put the use cases into a concrete technical setting, including a scenario, and network planning and operation criteria. They also define needed simulation types, time-series and grid model data. Controllers used for grid operation are currently under development. As soon as they are available, the showcases need to be tested in a simulation environment. This simulation is also an integral part of the proposed INTERPLAN tool.

The purpose of the deliverable at hand is to develop a plan for the implementation of said simulation. This is done based on an analysis of the five showcases as described in the deliverable D 5.1. The goal is to design a reference simulation scenario which would generally support validation of all showcases. Here for, this document contains an analysis of the showcase requirements in terms of validation, a summary about the current availability of grid models and time series, an introduction to the OpSim co-simulation platform, and finally a description of the reference validation scenario.

INTERPLAN developed a number of European energy scenarios (cp. deliverable D 3.2). The analysis documented here has shown that the showcases use two from these scenarios. The first such scenario is INTERPLAN-2: "Small and Local"; There, the energy provision system focuses on local and decentralized generation and storage, as well as smart grid solutions at transmission and mainly distribution level. The second scenario used by the showcases is INTERPLAN-3: "Large Scale RES". Here, the focus is on deployment of large-scale RES technologies and lower priority to decentralized RES is given. Since the most complete scenario data on electricity consumption and generation per type is available for 2050, this year was selected as target year for the reference simulation. The scenario parameters are used as inputs for the time series generation which is to be carried out during preparation of the simulations. Also, grid reinforcements proposed by the scenarios are considered as guideline for adapting the grid model selected for the simulation. The showcase analysis has furthermore shown that this grid model should contain at least one balancing zone or part thereof, and needs to span to all voltage levels, containing a total of 100 busbars or more. On-load tap changers, active- and reactive power-controllable generators, generators providing tertiary reserve, curtailable load, and ideally controllable storage (e.g. photovoltaic battery systems or electric vehicle charging stations) are needed as flexibilities for the controllers. Those flexibilities need to be placed throughout all voltage levels and cost needs to be attached to flexibility provision if applicable. Showcase 1 needs dynamic generator and load models with the ability of supporting the grid frequency. Hence, some of these models should be equipped with droop functions and/or synthetic inertia provision capability. Showcase 3 needs a radial 110 kV network section. Showcase 5 needs also reliability data for lines, transformers and loads. The main simulation environment for all showcases is Powerfactory, hence the grid model should be available in this format.

The analysis of available grid models has resulted in a number of options for the simulation grid model. Unfortunately, there is currently no grid model option which would ideally fulfil all requirements as-is. This problem needs to be solved in the work to come. The current intention is to use the balancing zone of the German TSO 50 Hertz – excluding the city of Hamburg – or part thereof as reference simulation case. Hence, the time series generation as documented in the deliverable at hand focuses on this network area. Since there is no openly re-distributable physical network model for that balancing zone available, a realistic benchmark MV/LV network was generated by using results from the SimBench[1] project.

For implementing the simulations, the OpSim co-simulation platform is available. It is intended for simulation of control strategies and aggregators in smart grids with very high share of renewable generation. It is a unique facility for the development of grid control strategies and their testing in realistic conditions. In INTERPLAN, the platform is planned to be used to combine a grid model and simulation which represents the physical network and is planned to run at a central server at IEE with remote controllers running at the project partner’s premises. This is enabled by using “OpSim As-A-Service”. Specific training material for this type of usage was developed and is provided to the project partners in the form of code examples and five instructional videos which explain the OpSim basic concepts and the implementation of remote DSO-level control algorithms using Python and Powerfactory, accessing the main service through a WebSocket interface.

The final chapter of the deliverable at hand summarizes a concrete plan for the standard validation scenario which will be put in action within the next months. Detailed plans are in place to develop the required scenario and have it available to be used to validate every showcase with small adaptations of time series and generator / load behaviour, but using the same grid model and basic generator and load layout. The next major step is to bring together grid models and time series such that load-flow analysis can be performed. Also, the simulation setup in the OpSim environment needs to be accordingly prepared, including generator and load models that would check operational limits and be able to be remotely configured by the external controllers.

[1] https://simbench.de/en/

1. Introduction

1.1 Purpose and scope of the Document

This document falls in scope of WP 6: “INTERPLAN model validation and testing”. It presents the results on preparing scenarios and relevant test networks for the validation of the integrated planning toolset, and also contains first results on setting up co-simulations and interfaces.

The main objective of this deliverable is to develop a concrete plan for the implementation of the validation actions to be carried out in WP 6 based on an analysis of the developed INTERPLAN showcases.

1.2 Structure of the Document

The report at hand presents the INTERPLAN scenarios which will be validated in the simulation. In addition, it includes a short description of the use cases, the simulated network and the time series which will characterize each of the validated scenarios. It is important to note that this information may be subject to change in the future, according to the outcomes arising from ongoing work especially on the development of the integrated planning toolset, as well as the results of the simulation and validation phases.

The deliverable consists of nine main chapters. The purpose and scope of the deliverable is described in the first chapter. Chapter 2 consists of a short description of the INTERPLAN project. In chapter 3, the methodology for the analysis of scenarios to be validated in the simulation is explained. Chapter 4 summarizes the analysis of the INTERPLAN showcases. Chapter 5 outlines the grid models relevant for validation and testing. Chapter 6 introduces the time series generation used in WP 6. Chapter 7 introduces the OpSim co-simulation platform. Based on all of this, a standard validation scenario is defined in chapter 8. Chapter 9 contains a brief summary and outlook.

References as well as the glossary of the terms and definitions used in the INTERPLAN project can be found in the Annex chapters.

2. INTERPLAN project in a nutshell

The European Union (EU) energy security policy faces significant challenges as we move towards a pan-European network based on the wide diversity of energy systems among EU members. In such a context, novel solutions are needed to support the future operation, resilience and reliability of the EU electricity system in order to increase the security of supply and also accounting for the increasing contribution of renewable energy sources (RES). The goal of INTERPLAN project is to provide an INTEgrated opeRation PLAnning tool towards the pan-European Network, with a focus on the interfaces between transmission system operators (TSO) and distribution system operators (DSO) to support the EU in reaching the expected low-carbon targets, while maintaining the network security and reliability. The project involves six partners from five European countries, namely ENEA (Italy), IEn (Poland), AIT (Austria), DERlab, Fraunhofer IEE (Germany), and FOSS (Cyprus). At the time of writing this report, the project is at Month 18 under the Grant Management phase.

A methodology for a proper representation of a “clustered” model of the pan-European network is provided, with the aim to generate grid equivalents as a growing library able to cover all relevant system connectivity possibilities occurring in the real grid, by addressing operation planning issues at all network levels (transmission, distribution and TSO-DSO interfaces). In this perspective, the chosen top-down approach leads to an “integrated” tool, both in terms of voltage levels, moving from high voltage level down to low voltage level and end consumer, as well as in terms of developing a bridge between static, long-term planning and operational issues considerations, by introducing controllers in the operation planning phase. In addition to the above, novel control strategies and operation planning approaches are investigated in order to ensure the security of supply and resilience of the interconnected EU electricity power networks, based on a close cooperation between TSOs and DSOs.

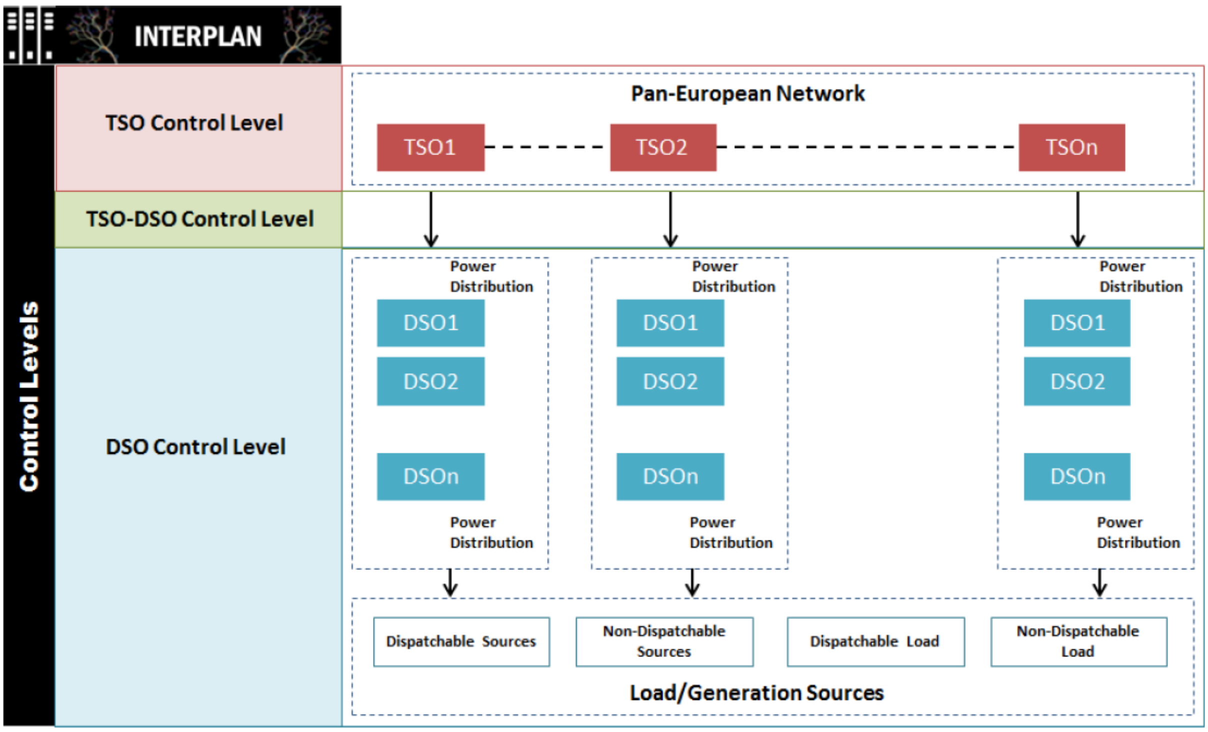

Figure 1: INTERPLAN concept

The basic idea of the INTERPLAN project is to cover the greater number of possible system connections and address interconnectivity issues and challenges that require a thorough assessment of existing grid codes and regulations at European and national level. Current shortcomings to integration of emerging technologies and services, such as renewables, storage, electric vehicles and demand response, as well as associated best practices are identified. Additionally, the developments and findings achieved through the INTERPLAN project are transformed into policy requirements to be addressed to the regulators and grid operators for possible amendments to the grid codes. Based on this analysis, use cases in addition to showcases for corresponding simulations are further developed. The use cases address the main challenges for network operation planning, considering the important role of emerging technologies, such as high share of RES and storage coupling, high integration of demand response services, and high share of electric vehicles. Examples of these technologies related challenges from the grid point of view are inertia management and voltage stability.

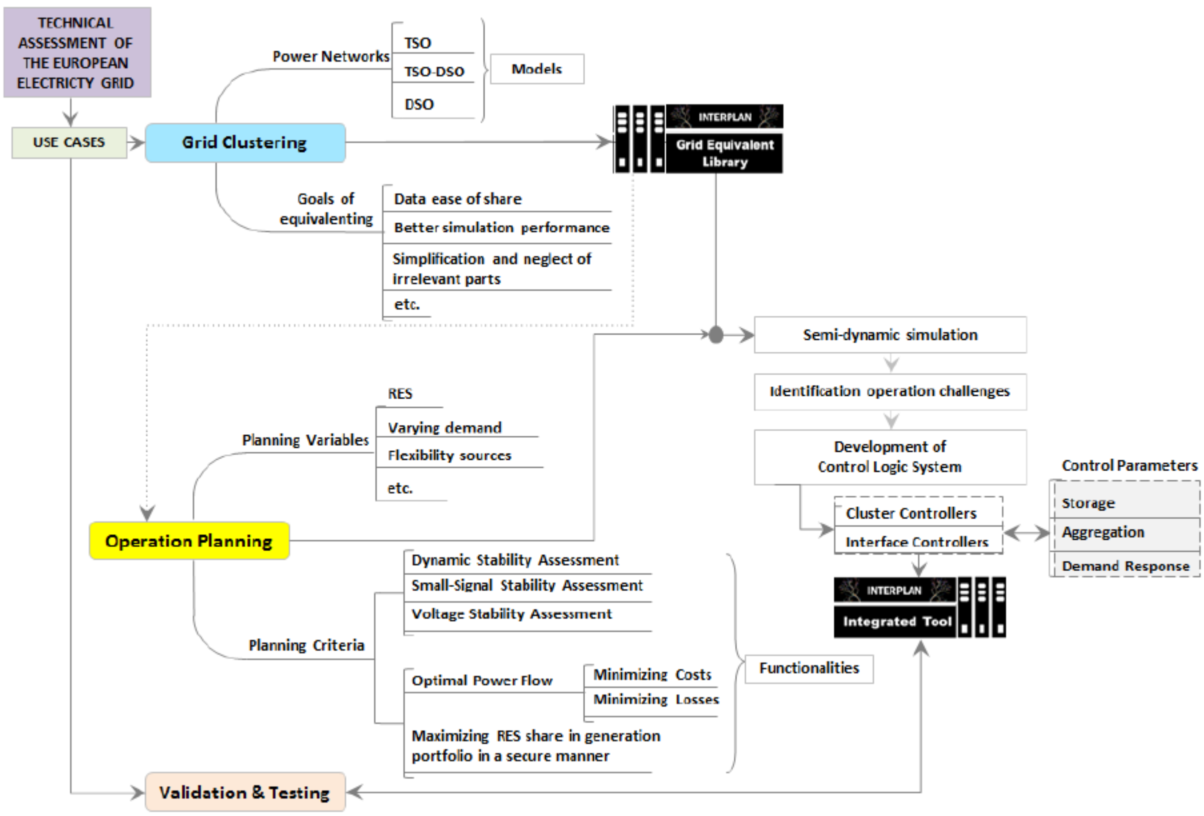

Figure 2: INTERPLAN MindMap

Based on the use cases and EU grid scenarios identified in WP 3 a series of showcases was developed which addresses issues such as resiliency of the interconnected grid with effective use of local resources. A “grid equivalenting” process is used to generate a grid equivalent model encompassing a large part of network substituted by a smaller counterpart, having the same dynamic and static properties. To this aim, the network models of previous use cases are designed in a computer based numerical power system simulation environment. Following this, a clustering methodology for transmission and distribution systems down to the end user level is identified, and a detailed approach for generating grid equivalents is developed for different use cases. Dynamic and semi-dynamic simulation scenarios of grid equivalents for each showcase enable analysis of the network behaviour, and eventual operational challenges as already mentioned i.e. stability, low inertia, line congestions etc. The post-processing or parallel-processing of the results allows to identify and address these operational challenges and shortcomings by developing novel control strategies. These strategies are developed in order to apply adequate intervention measures which are implemented by cluster and interface controllers. Finally, a validation process is applied through a computer based numerical simulation, to prove the validity of the proposed concept.

3. Methodology

Within INTERPLAN WP 6, the proposed use cases will be realized in a simulation environment and the developed grid models and the integrated planning toolset as well as the related simulation results will be validated, tested and verified.

INTERPLAN developed a set of specific use cases relevant for grid operation and planning. The use cases are documented in deliverable D 3.2, and are used as basis for the WP 6 verification. In order to demonstrate the concrete application of the INTERPLAN toolset, specific showcases have been developed, which are defined as “presentation of use case(s) in the frame of chosen scenario, simulation type, test model, time-series data and planning criteria”. These showcases are documented in deliverable D 5.1 and are used as a direct input for simulation scenarios.

From the INTERPLAN work on developing grid models and grid equivalenting methodologies a transmission grid model based on the ENTSO-E initial dynamic model of continental Europe as well as a number of distribution-level grid models are available (see also Deliverable D 4.1). A selection from these models is to be used as a basis for WP 6 simulation experiments. As foreseen by the project time plan, grid equivalenting methodologies are not yet available at the time of writing this document. The same is the case for tools that are being developed in WP 5, especially the controllers. However, simulation experiments can still be planned since sufficient technical information about the requirements is available.

Taking this into account, the following steps have been implemented with respect to the original project plan:

- *Identifying use cases which will be validated in the simulation.*
  This task was well prepared by the previous definition of showcases which basically include and detail the use cases. Hence in this document, we further relate to “validation of showcases” rather than “validation of use cases”. As to the question of identifying those showcases that will be validated in the simulation, it is obvious that only showcases can be verified for which there is a sufficient data basis in terms of grid models, time series data, and according mature tools, e.g. grid equivalenting methods and controllers. This document contains an analysis about the current availability of grid models and time series data. Currently we take the working assumption that all five showcases are subject to validation. Hence, the goal is to design the reference simulation scenario such as to generally support simulative validation of all showcases.

- *Define parameters and setting of the use cases so that they can be integrated in the simulation.*
  This task was again well prepared by showcase definition and is further detailed in chapter 4 of this document.

- *Identify (parts of) networks and (historical) time series of power generation and demand, as well as forecasts thereof, which will be the basis of the simulation.*
  As for the networks, results for this task are documented in chapter 5. As for the time series, it is pointed out that the task is not so much the “identification” of time series, because this implies that such time series would already be available. It was unfortunately found that this is not the case. Hence it would be more appropriate to talk about “development” or

"generation" of time series data specifically designed to match the INTERPLAN scenarios. Also, time series need to be defined such that they can be used in conjunction with the grid models, which may be again specific to individual showcases. All in all, the task of designing time series is substantially more complex than initially foreseen by the description of action, and is hence ongoing. Nevertheless, chapter 6 contains the current status about this task.

- *Prepare the test network(s) in a supported format*
  This task is again based on results of WP 4. The outcome of this work is summarized in chapter 5.

- *Prepare use case scenarios on the basis of time series or/and steady state data*
  This task basically combines use cases and scenarios, which is again a result already obtained by showcase definition. What is missing is the combination with time series or/and steady state data. This is again covered in chapter 6 of this document.

4. Analysis of showcases

4.1 Relevant INTERPLAN scenarios

This subsection contains a short summary of the two INTERPLAN scenarios which are relevant to the showcases:

- INTERPLAN-2: Small and Local and
- INTERPLAN-3: Large Scale RES.

More information about these scenarios can be found in deliverable D 3.2.

The WP 6 validation simulation is planned to use the balancing zone of the German TSO 50 Hertz, which mainly comprises Eastern Germany. The area includes the German states Mecklenburg-Vorpommern, Berlin, Brandenburg, Sachsen, Sachsen-Anhalt, and Thüringen. The city of Hamburg is included in the 50 Hertz balancing zone, but is not planned to be included in the standard validation scenario. Hence, the following section summarizes the key scenario parameters for today and the target year 2050 for INTERPLAN-2 and INTERPLAN-3 with special consideration of Germany and Eastern Germany. The parameters are needed for generation of time series data to be used in WP6.

Status quo

Table 1 summarizes the installed generation capacity [MW] in Eastern Germany and the whole country for the year 2019 [1].

Table 1: Installed generation capacity in Germany 2019 [MW]

Region	Nuclear	Fossil	Solar PV	Wind	Hydro	Other sources
Eastern Germany	1,410	10,908	8,701	16,609	68	2,333
Whole Germany	9,516	75,069	42,339	55,719	3,441	13,527

Table 2 summarizes the net electricity generation [GWh] in Germany for the year 2019 [2].

Table 2: Electricity generation Germany 2019 [GWh]

Year	Nuclear	Fossil	Solar PV	Wind	Hydro	Biomass
2019	72100	247000	45700	111400	17000	44800

The source used for the previous table does not state the electricity generation for Eastern Germany. Figures about this were obtained for the year 2016 online [3] for whole Germany and its states. The results are summarized in the following table.

Table 3: Electricity generation Germany and Eastern Germany 2016 [GWh]

Region	Total	Nuclear	Coal and Gas	Solar PV	Wind	Hydro	Biomass	Other sources
Eastern Germany	152,652[2]	0	96,154	8,740	25,711	584	13,420	8,043
Whole Germany	650,700	84,600	343,000	38,100	80,200	20,500	45,000	39,300

Table 4 summarizes the installed generation capacity [MW] in EU-28 for year 2016 [4].

Table 4: Installed generation capacity EU-28 in 2016 [MW]

Year	Nuclear	Fossil	Solar PV	Wind	Hydro	Other sources
2016	122,051	455,583	100,812	154,325	153,969	4,178

Table 5 summarizes the generation mix [GWh] in EU-28 for year 2016 [4].

Table 5: Electricity generation EU-28 in 2016 [GWh]

Year	Nuclear	Fossil	Solar	Wind	Hydro	Biomass	Other sources
2016	839,700	1,403,100	110,800	302,900	380,200	180,500	33,000

The gross electricity consumption is available for all regions in question only for 2014. In this year, it was 100 TWh for Eastern Germany, 504 TWh for whole Germany [5], and 3,234 TWh in the ENTSO-E area [6]. Notably, the 2016 gross electric energy generation in Eastern Germany summed up to well over 150 TWh, so the state most probably exported a part of its generation.

INTERPLAN-2: Small and Local is a scenario which assumes that European member states apply a strategy based on small-scale and local solutions, i.e. decentralized generation and storage, to reach the 80-95% green house gas reduction target. Smart grid solutions are applied mainly at the distribution, but also at the transmission level. Nuclear plants and carbon capture and storage (CCS) are not considered as options to reach the green house gas reduction target. Fossil-based generation, in particular gas-fired units, and biomass are considered main solutions to balance fluctuating RES production.

Table 6 summarizes the installed generation capacity for the scenario for two target years [MW].

Table 6: INTERPLAN-2 installed generation capacity Europe [MW]

Year	Nuclear	Fossil	Solar	Wind	Hydro	Biomass
2030	91,650	71,169	485,296	326,179	329,453	49,381
2050	48,000	126,650	583,900	387,753	257,179	107,750

[2] The total gross generation reported by this source adds up to 649,071 GWh

Table 7 summarizes the installed generation capacity [MW] in Germany for year 2050 for the INTERPLAN-2 scenario [7]. There are no numbers available for 2030.

Table 7: INTERPLAN-2 installed generation capacity Germany [MW]

Year	Nuclear	Fossil	Solar PV	Wind	Hydro	Biomass
2050	0	17,600	109,275	93,019	12,261	15,000

Table 8 summarizes the generation mix [GWh] in Europe.

Table 8: INTERPLAN-2 electricity generation in Europe [GWh]

Year	Nuclear	Fossil	Solar	Wind	Hydro	Biomass
2030	618,218	1,289,215	623,464	809,261	718,622	313,942
2050	313,261	135,406	721,449	900,714	574,756	593,442

The generation mix for Germany is not available from the source.

The yearly electricity demand, but also the demand flexibility will increase in this scenario. The peak electricity demand will decrease due to demand response to market prices. For 2050 the demand for Germany will be 466,152 GWh. For Europe excluding the UK it will be 3,186,980 GWh.

The following Table 9 summarizes the energy generation [MWh] in Germany for year 2050 from the perspective of the INTERPLAN-2 scenario [7]. There are no numbers for 2030 available.

Table 9: INTERPLAN-2 energy generation in Germany [MWh]

Year	Nuclear	Fossil	Solar	Wind	Hydro	Biomass
2050	0	19,289	109,192	204,641	24,324	86,088

The scenario assumes increased usage of battery and plug-in hybrid electric vehicles according to Table 10.

Table 10: INTERPLAN-2 usage of electric vehicles

Type of EV		**2030**	**2050**
BEV	Number of vehicles	40 Mio.	157 Mio.
	Energy demand	36,000 GWh/a	141,300 GWh/a
PHEV	Number of vehicles	10 Mio.	65 Mio.
	Energy demand	10,000 GWh/a	65,000 GWh/a

INTERPLAN-3: Large Scale RES: assumes that European member states apply a strategy based on deployment of large-scale RES technologies, e.g. large-scale offshore wind parks in the North Sea to reach the 80-95% green house gas reduction target. Similarly, a high priority is given to the development of centralized storage solutions (pumped hydro storage, compressed air, etc.) which accompanies the large-scale RES deployment. Electrification of transport, heating and industry is considered to occur both at centralized (large scale) and decentralized (domestic) level. However, the political focus is mainly on the supply side: large amount of fossil-free generation will make investments in energy efficiency solutions less attractive.

Table 11 summarizes the installed generation capacity for the scenario for two target years [MW].

Table 11: INTERPLAN-3 installed generation capacity Europe [MW]

Year	Nuclear	Fossil	Solar	Wind	Hydro	Biomass
2030	119491	32978	254054	319330	330956	62114
2050	157200	267850	256315	813469	376569	69750

Table 12 summarizes the installed generation capacity [MW] in Germany for year 2050 for the INTERPLAN-3 scenario [7]. There are no numbers available for 2030.

Table 12: INTERPLAN-3 installed generation capacity Germany

Year	Nuclear	Fossil	Solar PV	Wind	Hydro	Biomass
2050	0	45,000	54,428	118,677	14,899	9,000

Table 13 summarizes the generation mix [GWh] in Europe.

Table 13: INTERPLAN-3 electricity generation Europe

Year	Nuclear	Fossil	Solar	Wind	Hydro	Biomass
2030	827,880	1,356,045	325,211	757,941	690,053	214,883
2050	1,030,110	307,175	349,804	2,083,933	852,146	298,481

This scenario envisages the highest electricity demand to be supplied by large-scale centralized RES solutions. A low increase in energy efficient solutions is foreseen, including DSM and flexibility of electric vehicle (EV) use. Moreover, a clear shift towards ‘greener’ behaviours is expected compared to present practices. For INTERPLAN-3 2050, the demand for Germany is 815,155 GWh. For Europe excluding the UK it is 5,195,552 GWh.

Table 14 summarizes the energy production [MWh] in Germany for year 2050 for the INTERPLAN-3 scenario [7]. There are no numbers available for 2030.

Table 14: INTERPLAN-3 electricity generation Germany

Year	Nuclear	Fossil	Solar	Wind	Hydro	Biomass
2050	0	68,519	54,653	282,277	24,08	43479

The scenario assumes increased usage of battery and plug-in hybrid electric vehicles according to Table 15.

Table 15: INTERPLAN-3 usage of electric vehicles

Type of EV		2030	2050
BEV	Number of vehicles	21.5 Mio.	130 Mio.
	Energy demand	25800GWh/a	156000 GWh/a
PHEV	Number of vehicles	35.5 Mio.	120 Mio.
	Energy demand	42600 GWh/a	144000 GWh/a

Grid reinforcement in INTERPLAN 2 and 3 scenarios

The E-highway 2050 project has developed a cluster model for the Pan-European transmission network which balances complexity and applicability in order to efficiently identify the future EU grid scenarios [8]. The cluster model of the Pan-European transmission grid will serve as the basis for system simulations in order to define the initial transportation capacities as well as required grid reinforcement as indicators among the identified clusters. These indicators for grid reinforcement among EU countries as well as among different regions/clusters within countries are identified for both “Small and Local” and “Large Scale RES” scenarios for the time horizon 2050 [7] and can be used for building INTERPLAN grid models meant for simulation and validation of the developed controllers.

4.2 Showcase 1: Low Inertia Systems

4.2.1 Showcase summary

The first showcase is called “low inertia systems”. The main scope is to maintain frequency stability in systems with low share of synchronous generators, hence low classic inherent inertia. The showcase utilizes synthetic inertia, as well as fast frequency response provided by RES, distributed generation (DG), controllable loads and storage systems. Frequency is brought back to nominal values by optimal power flow (OPF)-based frequency restoration.

The sequence of actions for this showcase aims at carrying out an operational planning for a 24 hours period. The sequence is carried out for each data point of the available time series, and consists of the subsequent execution of sub-use cases 4.2 (”Fast frequency restoration control”) and 6.4 (”Inertia management”) as presented in Deliverable 3.2. This comprises the calculation of forecasted load and generation, the collection of available resources for frequency control, the calculation of available and needed inertia, and the determination of droop settings. The selection of inertia providing resources is based on an optimization function considering losses, and/or reliability. Cost is also considered if relevant data are available. The sub-use case 4.2 essentially results in frequency droop device setpoints while sub-use case 6.4 results in setpoints for RES or storage systems that are forecasted to be in operation and able to provide additional inertia needed by the system. The setpoints change the control mode or operating point of the device in question.

The designated simulation environment is DIgSILENT Powerfactory. The simulation type is semi-dynamic and dynamic.

4.2.2 Showcase requirements in terms of scenario

The showcase is intended to use the scenario INTERPLAN-3: Large Scale RES.

4.2.3 Showcase requirements in terms of grid models

Obviously, the grid model used for this showcase must contain a number of resources which can be used for frequency control, especially resources that can provide synthetic inertia or be operated according to droop functions. Such resources are typically inverter-coupled generators or battery storages, or generally inverter-coupled RES. Synthetic inertia can be defined as the reaction of a generator's active power output onto proportional to the rate of change of frequency (RoCoF) at its grid connection point [9]. Another option to provide inertia is fast frequency response, which can be defined as the rapid change of a generator's active power output in response to a frequency measurement at its grid connection point. A droop function is the mathematical formulation of the latter dependency. Both synthetic inertia and droop functions can be implemented by adapting the programming of inverter-coupled RES, e.g. wind power plants.

Dynamic models of such inertia providing RES must be available for validation of this show case. It should be noted that dynamic models used for frequency control need to be editable (meaning that their structure in Powerfactory can be changed) or at least have built-in frequency control for both over- and underfrequency. At the time of writing this document, dynamic models available in Powerfactory are used for this purpose.

INTERPLAN Deliverable D 5.1 explicitly mentions that the grid model must contain at least one balancing zone with at least one transmission and at least one distribution grid. All grid levels except the LV level are needed. The total number of terminals should be at least 100.

4.2.4 Showcase requirements in terms of time series data

Deliverable D 5.1 defines that real and/or synthetic data for generation and load profiles for 24 hours at a resolution of 15 minutes is needed. The RES generation profile may be based on real weather forecast data. Given the requirements for the grid model, it is obvious that such time series data must be attributable to RES resources and loads present in the grid under consideration. It is conceived that generators and loads situated in neighbouring networks, should they be modeled, could be equipped with static operation setpoints.

4.2.5 Plan for showcase validation

As will be outlined in chapter 5, the transmission and distribution grid models available generally overachieve the requirement of having at least 100 terminals. It is therefore feasible to select an area from this available network representing a single TSO balancing zone. Within this area, there needs to be a distribution grid modeled down to the medium voltage (MV) level. It is furthermore proposed to place a limited set of dynamic inertia providing inverter-coupled RES models within that grid, and to equip this specific set of RES with a 24 h 15-minute resolution time series. It is proposed to use photovoltaic (PV) systems as well as battery storage systems and wind farms for this. As for the generation devices and loads present in the rest of the TSO balancing zone which are not used for

inertia control, either time series (preferred option) or fixed operation setpoints could be provided, depending on which option is more practicable. As for generation devices and loads situated outside of the selected TSO balancing zone, it is proposed to not use them for frequency control, but to attribute fixed operational setpoints to them.
The validation of this showcase should consist in the simulation of the network according to 24-hours day-ahead operational planning data pre-calculated by the sequence of actions process. A part of the RES generator models must be equipped with real-time droop controllers which were configured according to the previously calculated setpoints. Another part of the models must be equipped with configurable synthetic inertia provision.
The validation test case should define an event which disturbs the frequency in order to calculate a frequency step response. Such event should be defined for at least one time step at the simulated day. The validation does not necessarily need to cover the complete 24 hour period since frequency stabilisation should actually take place within seconds.

4.3 Showcase 2: Effective DER operation planning through active and reactive power control

4.3.1 Showcase summary

The second showcase is called “Effective DER operation planning through active and reactive power control”. The main scope is to establish a control scheme to improve TSO-DSO coordination both in voltage stability management and solving congestion issues across all voltage levels. Active and reactive power resources including DSO flexibilities are subject of the control. The sequence of actions foresees the subsequent execution of sub-use case 2.3 (”Grid congestion management”) and 1.4 (”Coordinated voltage/reactive power control”) for each single time step in a planning time window. Considering the time series requirements, a typical time window would be one day, and the process would be executed as part of day-ahead operation planning. The process for sub-use case 2.3 uses TSO and DSO grid equivalents, and DG, RES and load forecasts to calculate active power setpoints for each busbar which solve expected congestion situations. This involves a congestion detection and an optimization which involves a DC load flow. The result is fed into sub-use case 1.4 execution, which uses reactive power and load forecast data, grid status and TSO reactive power asset status and employs TSO and DSO OPF calculations in order to determine optimal reactive power setpoints for TSO assets and DSO-level RES, DG and storages. Undesired voltage variations at each busbar are mitigated by this sub use-case.

The effectivity of the control may be validated by simulating a congestion event within the planning time scope.

4.3.2 Showcase requirements in terms of scenario

The showcase is intended to use the scenario INTERPLAN-2: Small and Local.

4.3.3 Showcase requirements in terms of grid models

The grid model must obviously contain DER which are controllable in terms of active and/or reactive power. According to INTERPLAN Deliverable 5.1, at least one transmission and one distribution grid must be included, spanning all voltage levels except the extra high voltage (EHV) level. The minimum number of terminals is 100. The main simulation tool is Powerfactory and the simulation is semi-dynamic.

The base showcase 2 uses remotely controllable on load tap changer (OLTC) transformers as the only means of voltage regulating tool for the DSO. Hence, the TSO/DSO transformer models must be able to receive and execute according remote control signals.

4.3.4 Showcase requirements in terms of time series data

Time series for this showcase must be designed such that, in at least one time step, a congestion event occurs either in the TSO or DSO network when this is not counteracted by controllable DER. A ‘congestion’ could be a line or transformer overload, which, depending on the grid impedance, may subsequently lead to voltage levels leaving permitted thresholds.

Deliverable D5.1 states that a time frame of 24 hours with a resolution of 15 minutes shall be covered. Generation and load profiles are needed. The RES generation profile may base on real weather forecast data. Given the requirements for the grid model, it is obvious that such time series data must be attributable to RES resources and loads present in the grid under consideration. It is conceived that generators and loads situated in neighbouring networks, should they be modeled, could be equipped with static operation setpoints.

4.3.5 Plan for showcase validation

Given the fact that the grid model requirements are very similar to showcase 1, it is proposed to use the same grid as in showcase 1 for validation. However, the DER models might need to be replaced by semi-dynamic models instead of dynamic ones, and additional active and reactive power controllability might need to be introduced. The showcase description does not define how many controllable DER resources are required. It is proposed to consider PV inverters and PV/battery systems and/or EV charging stations as flexible DER in the MV and eventually LV (low voltage) networks. Wind power plants could be considered at the MV or HV (high voltage) network. The DER models must be able to accept active and reactive power setpoints generated by cluster or interface controllers and change their power according to those setpoints within their permitted operational limits.

4.4 Showcase 3: TSO-DSO power flow optimization

4.4.1 Showcase summary

The third showcase is called “TSO-DSO power flow optimization”. The main focus of this showcase is to present an optimization strategy for energy flow management between transmission and distribution grid, ensuring the balance within a distribution network on one hand and on the other hand for participation of non-synchronous energy resources in the tertiary reserve market and supporting the TSO in keeping the whole network stable.

The sequence of actions foresees the subsequent execution of sub-use case 3.4 (”Frequency tertiary control based on optimal power flow calculations”) and 5.2 (”Power balancing at DSO level”) for each single time step in a planning time window. Considering the time series requirements, a typical time window would be one day, and the process would be executed as part of day-ahead operation planning.

The process in sub-use case 3.4 starts with gathering available flexibilities in the distribution grid based on required tertiary control reserve as well as forecasted load and generation. Using this information, an OPF for transmission grid is performed, providing setpoints for generation, loads and storages connected to the transmission grid, with regards to tertiary control reserve. In the next step, a tertiary control OPF at distribution level is calculated. Setpoints obtained from this OPF are sent to the grid assets available for tertiary reserve. These set points will serve as constraints for sub-use case 5.2, which is active power flow optimization at distribution level in order to ensure local usage of energy through minimization of power flow through the transformers connecting transmission/distribution grids. After TSO positive feedback on the results, the latter setpoints are sent to the remaining controllable generators and storages connected at distribution level.

4.4.2 Showcase requirements in terms of scenario

The showcase is intended to use the scenario INTERPLAN-2: Small and Local.

4.4.3 Showcase requirements in terms of grid models

The grid model must contain at least one balancing zone with one transmission and at least one detailed distribution grid. For the showcase calculation at the TSO side, the detailed transmission grid with the distribution grid equivalent is needed. For the DSO side, the detailed distribution grid with the transmission grid equivalent is considered. The grid model needs to include the EHV, HV, MV and LV levels for the operation areas of the grid operators. The model needs to be static and the sum of the number of nodes, busbars, terminal, cubicle and substations should be 100 or more in the transmission and distribution level. A special requirement applies to the 110 kV voltage level, which needs to be radial for this showcase because the current controller does not support other topologies.
The grid model must obviously contain DER and storage which are controllable in terms of active and/or reactive power. The main simulation tool is Powerfactory and the simulation is semi-dynamic.

4.4.4 Showcase requirements in terms of time series data

Deliverable 5.1 defines that a real and/or synthetic data for generation and load profiles for 24 hours at a resolution of 15 minutes is needed. The generation profile of the RES can be based on real weather forecast data. No event is considered for this showcase.

4.4.5 Plan for showcase validation

For show case validation, transmission and distribution grid models should be available. A portion of this available network will represent a single TSO balancing zone, in which the transmission and distribution grids will be modelled from EHV and HV down to the MV/LV level and the HV and MV parts should contain at least 100 terminals. The network models must include a suitable mixture of generating sources i.e. synchronous generators, RES and DG, loads i.e. dispatchable and non-dispatchable, and storage technologies according to the selected scenario. As for those generating sources and loads, which are present in the TSO balancing zone but not available for tertiary reserve, it is proposed to either provide time series or fixed operation setpoints, depending on which option is more practicable. As for generation devices and loads situated outside of the selected TSO

balancing zone, it is proposed to not use them for tertiary control, but to attribute fixed operational setpoints to them.
The validation of this showcase should consist in the simulation of the network according to 24 hours day-ahead operational planning data pre-calculated by the sequence of actions process. In the complete showcase, active power controllers will be included and a part of generators, loads and storages must be able to receive active power set points from cluster or interface controllers which change their control mode or operating point.

4.5 Showcase 4: Active and reactive power flow optimization at transmission and distribution networks

4.5.1 Showcase summary

Showcase number 4 is called “Active and reactive power flow optimization at transmission and distribution networks”. The main focus of this showcase is to present an optimization strategy for parallel control of active and reactive power at transmission and distribution grid, for maintaining the voltage quality at both network levels on one hand and on the other hand for participation in the tertiary reserve market and supporting the TSO in keeping the whole network stable. The control strategy must ensure an optimization of both active and reactive power of all available resources with no conflict in setpoints, considering the constraints.

The sequence of actions foresees the subsequent execution of sub-use case 1.4 (”Coordinated voltage/reactive power control”) and 3.4 (”Frequency tertiary control based on optimal power flow calculations”) for each single timestep in a planning time window. Considering the time series requirements, a typical time window would be one day, and the process would be executed as part of day-ahead operation planning.

The process in sub-use case 1.4 starts with gathering information on available flexibility in the distribution grid which is assessed based on required reactive power for voltage control as well as forecasted load and generation. Using this information, an OPF for the transmission grid is performed, resulting in reactive power setpoints for generation, loads and storages connected to the transmission grid. In the next step, an OPF at distribution level is calculated. Setpoints obtained from this OPF are sent to the relevant DSO assets, which are available for reactive power control. Then, all the reactive power setpoints serve as constraints for sub-use case 3.4 aiming in active power flow optimization at both transmission and distribution levels in order to provide required active power for frequency tertiary control. This optimization is performed with a similar sequence of actions as for the reactive power optimization. The final setpoints are sent to all resources which are available for tertiary reserve.

4.5.2 Showcase requirements in terms of scenario

The showcase is intended to use the scenario INTERPLAN-2: Small and Local.

4.5.3 Showcase requirements in terms of grid models

The grid model must contain at least one balancing zone with one transmission and at least one distribution grid. For the showcase calculation at the TSO side, the detailed transmission grid with the distribution grid equivalent is needed. For the DSO side, the detailed distribution grid with the transmission grid equivalent is considered. It needs to include at least the EHV, HV, MV and LV level

for the operation areas of the grid operators. The model needs to be static and the sum of the number of nodes, busbars, terminal, cubicle and substations should be 100 or more in the transmission and distribution level.
The grid model must obviously contain DER and storages which are controllable in terms of active and/or reactive power. The main simulation tool is Powerfactory and the simulation is semi-dynamic.

4.5.4 Showcase requirements in terms of time series data

Deliverable 5.1 defines that real and/or synthetic data for generation and load profiles for 24 hours at a resolution of 15 minutes is needed. The generation profile of the RES can be based on real weather forecast data. No event is considered for this showcase.

4.5.5 Plan for showcase validation

For show case validation, transmission and distribution grid models should be available. A portion of this available network will represent a single TSO balancing zone, in which the transmission and distribution grids will be modelled from HV down to the MV/LV level. The model should contain at least 100 terminals in total. The network model must include a suitable mixture of generating sources i.e synchronous generators, RES and DG, loads i.e. dispatchable and non-dispatchable, and storage technologies according to the INTERPLAN-2 scenario. As for those generating sources and loads, which are present in the TSO balancing zone but not available for tertiary reserve/voltage control, it is proposed to either provide time series or fixed operation setpoints, depending on which option is more practicable. As for generation devices and loads situated outside of the selected TSO balancing zone, it is proposed to not use them for tertiary/voltage control, but to attribute fixed operational setpoints to them.
The validation of this showcase should consist in the simulation of the network according to 24-hours day-ahead operational planning data pre-calculated by the sequence of actions process. In the complete show case, active and reactive power controllers should be included and a part of generators, loads and storages must be able to receive active/reactive power set points from cluster or interface controllers which change their control mode or operating point.

4.6 Showcase 5: Optimal energy interruption management

4.6.1 Showcase summary

Showcase number 5 is called “Optimal energy interruption management”. The main scope is to minimize the total energy interrupted during a contingency scenario. The flexibility provided by interrupt-able loads and re-dispatch of generation acts as control variables in achieving the objective. The sequence of actions starts with the contingency identification process. During this process, critical contingencies are defined based on the grid information, load and generation yearly profiles. The contingency identification employs load flow calculations to identify lines, generators and loads that are critical for contingencies, and results in a list of credible contingencies. The energy interruption planning considers one contingency at a time. For each contingency scenario, hosting capacity analysis of the network is performed in-order to define the maximum dispatch limits for the generators in the grid. The possible grid congestion, as a result of the contingency event, is identified and used to prioritize resources. Similarly, the sensitivity analysis of the critical buses with respect to the dis-patchable generation and interrupt-able loads is performed hence prioritizing assets which

can effectively counteract the contingency. These two analysis are used to prioritize the resources that on one hand aims to minimizes the energy interruption and also minimize the likelihood of a grid congestion scenario.
The controller of the showcase dispatches the generators and interrupt-able loads and identifies that whether all the grid constraints are satisfied. If the constraints are not satisfied, then a fall back strategy is activated that introduces further interruption of loads and emergency measures. The controller then optimizes again to reach a feasible result. The sequence of actions can be performed as a day ahead network planning task or on a longer time horizon based on the available data and forecasts accuracy.

4.6.2 Showcase requirements in terms of scenario

The showcase is intended to use the scenario INTERPLAN-2: Small and Local

4.6.3 Showcase requirements in terms of grid models

The grid model for this showcase must include a transmission and a distribution system. Controllable generators and interruptible loads should be present at HV and MV levels and preferably RES at LV level. There is no limitation on the network size however a large network will be beneficial to judge the scalability of the approach. A special requirement is that reliability data has to be available for lines, transformers, circuit breakers and loads. Stochastic generation models has to be defined for wind and dis-patchable generation. This data is used to evaluate the KPIs before and after the control action. It also help in the contingency identification process. The simulation tool is Powerfactory and the simulation is semi-dynamic. The optimal power flow from PowerFactory is used as part of the controller structure.

4.6.4 Showcase requirements in terms of time series data

Deliverable D 5.1 states that a time frame of at least 24 hours with a resolution of 15 minutes shall be covered by the time series. Real or synthetic load, PV and dispatchable generation profiles are needed. The generator active and reactive power capabilities must be known.

4.6.5 Plan for showcase validation

The requirements for this showcase are relatively low when it comes to the number of network nodes; hence, a grid which has suitable size for showcase 1 or 2 will be sufficient also for showcase 5. Stochastic generation models are needed for wind and dispatch-able generation In addition to the showcase 1 and 2 requirements, reliability data for lines, loads and transformers are needed; this could be addressed by using a limited set of standard lines, transformers, circuit breakers and loads for which reliability data can be obtained or estimated. Regarding the DER models, the requirements seem very similar to showcase 2, since the control subject is congestion in both cases. Hence, it can be assumed that the same DER models could be used for showcases 2 and 5. These models should allow for validating corrective actions which are calculated by a showcase 5 specific interface or cluster controller.

5. Grid models for simulation validation

Figure 3 shows a topographical map of the INTERPLAN network models documented in deliverable D 4.1.

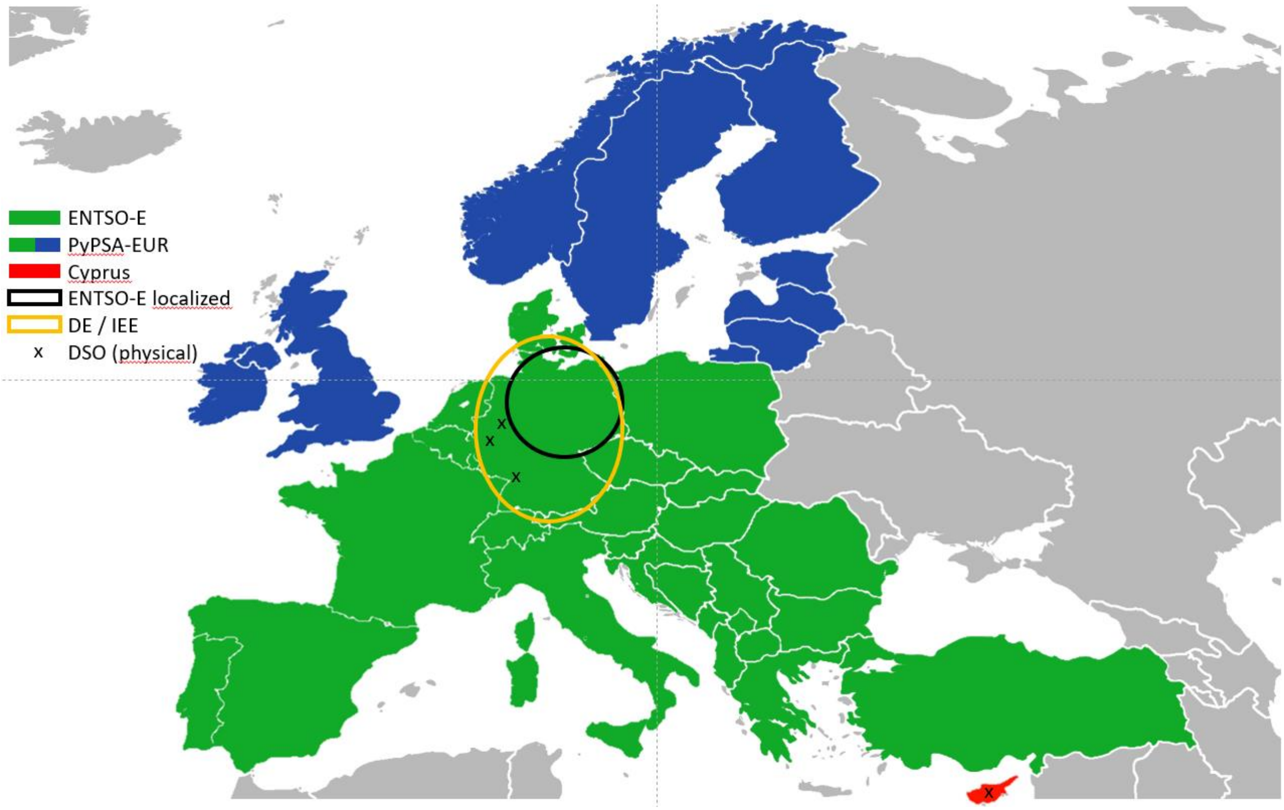

Figure 3: Grid models available to WP6 as resulting from T4.1

Notably, not all of the grid models are distributable amongst project partners because of confidentiality. The map indicates that different TSO grid models (full coloured countries and ellipses) are available for the Eastern Germany region. In addition, also time series were researched for this network area. However, there are no distribution grid models available for that area which would represent physical networks. Those grid models are marked in the map with an 'x', and are either not interchangeable amongst consortium partners at all or only with agreement of the DSO in question.

An extended and updated description of the grid models will be available in Deliverable D 4.1. The following sections summarize the key properties of the models that are relevant to WP 6 according to the current planning.

5.1 ENTSO-E geolocalized transmission system model

The approach for developing this grid model is detailed in INTERPLAN deliverable D4.1.
It is based on the ENTSO-E Initial Dynamic Model of Continental Europe which contains load flow data originating from electric utilities. It is expanded by ENTSO-E with standard models for generators and appropriate controller models in order to represent the dynamics of the

interconnected continental Europe power system. The model is available in the Powerfactory format, but does not contain any graphical data, and names of objects - usually relating to geographic names - are replaced by numbers. The only localization information that is left for the grid model assets is the European country which they're situated in. In Powerfactory, the assets are grouped into one folder per country. This lack of a fully geographically localized graphic model is a huge drawback for working with the grid model in Powerfactory.
On the other side, the model basic data is quite detailed and very extensive. There is a total of 18339 lines, 23253 buses, 7377 loads and 6147 generators. Each substation is typically modeled with several in-substation busbars. This property is a unique feature of the ENTSO-E model when compared to alternative models. The model contains focuses on EHV voltage levels, but at some points also includes lower voltages; however, there are no full distribution grids included.

In order to make the model better usable for the project, a partial rebuild of the ENTSO-E grid model was developed. The general approach for this was not to change the model itself, thus the resulting model has the following limitations introduced by the original model data:

- Initial load flow converges but gives warnings
- Several bus bars are isolated from the rest of the system
- RMS simulation related parameters of power plants seem to be equal for a country.
- Line lengths seem to be altered for countries.

The "rebuilding process" generally aimed at localizing the grid model nodes by assigning Powerfactory terminals to substation names without changing the reference model itself. The rebuilding process is semi automatized via object oriented Python scripts and resulting data is stored in an Excel workbook. It also includes an automated way to arrange and reduce the amount of visible data in Powerfactory, such that the resulting grid is much more clearly arranged.

The first process step is to manually geolocalize a portion of the German buses. A first approach for this was to identify generators with large nominal power. Usually nuclear power plants use very large synchronous generators (> 1 GVA) and, especially for Germany, there are not many of these kind of plants. The idea was to identify the generators of the German nuclear plants in the ENTSO-E grid and subsequentially start the further rebuilding process by identifying substations around these generators. However due to a large number of identified and unrealistically large generators (> 2 GVA) in the ENTSO-E grid this approach failed.

Hence, an alternative approach was taken by identification the cross border lines first and then starting the further rebuilding process from these lines on towards the center of a country, in our case Germany. This approach proved to be more successful. All cross border lines for Germany were identified and the rebuilding process was started for North-East Germany.

Starting from these elements and comparing to the ENTSO-E grid map [10], further elements towards the inner country could be identified, selected, automatically arranged as substations or plants, and finally automatically built into the Powerfactory Network Diagram Tool.

As an example result, Figure 4 shows the identified grid area of the German transmission system operator 50 Hertz Transmission GmbH. Voltage levels are 400 kV, 220 kV and 110 kV levels, major cities are Hamburg and Berlin and the cross border connections to Poland and Czech Republic are displayed. As an component example of this grid area, Figure 5 shows the German plant

“Jänschwalde”, featuring 6 generators with a nominal power 588 MVA each and 20 kV nominal generator terminal voltage.

Related to WP 6, the advantage of this model is that it bases on detailed official data, and can be shared between project partners since there was an NDA set up between ENTSO-E and the entire consortium. Two main disadvantages are the high complexity and that it is currently unknown if the load flow would converge for the time series in question for WP 6.

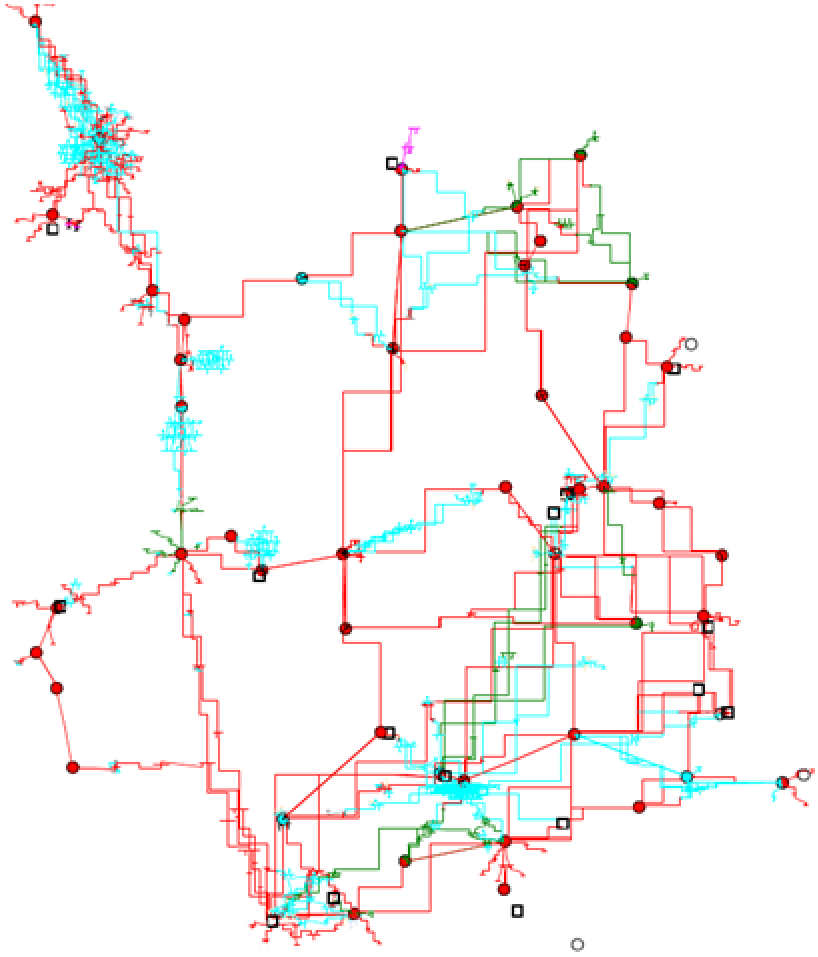

Figure 4: Resulting grid area of the German transmission system operator 50 Hertz Transmission GmbH

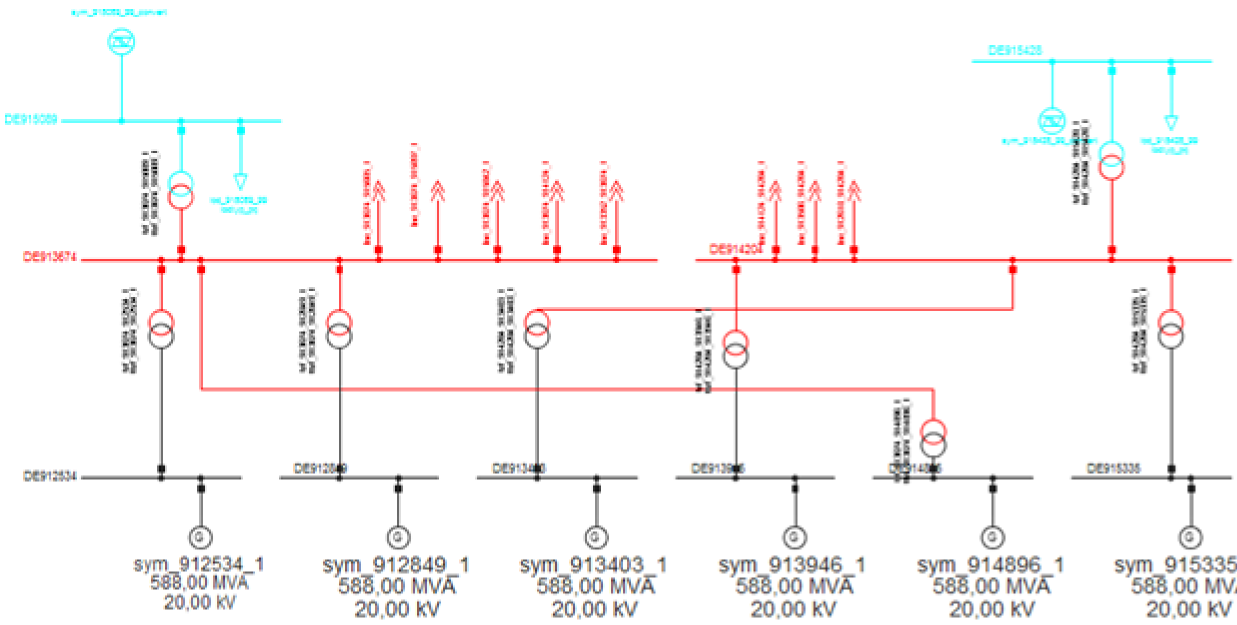

Figure 5: German plant "Jänschwalde" within in the ENTSO-E grid model

5.2 German transmission system

This model is based upon the German transmission system comprising the 380 kV and 220 kV voltage levels. It is confidential to Fraunhofer IEE, but could be used for validation of controllers in WP6 by serving as real physical grid model running on an OpSim component hosted at IEE (cp. Deliverable D 6.1). Public available data sets and grid maps of the four German transmission system operators as well as the public available power plant list from the German "Bundesnetzagentur" provide the basis for this model. It contains nearly 400 substations and more than 600 overhead lines and cables. One third of the substations and lines or cables is situated in the 220 kV voltage level and the remaining substations and cables or lines are in the 380 kV voltage level. In addition over 50 transformers between the two voltage levels are included in the model. The information about line and transformer parameters have been extracted from the data sets of the TSOs. Future grid development plans are not yet taken into account. The model is available in DigSilent Powerfactory including graphical representation.

The following Figure 6 shows a schematic plot of the currently available model. The part which is attributed to the states of Eastern Germany includes 75 grid nodes with one concentrated load at each node, over 300 generators and transformers with tap changers.

The advantage of this model is that is fully geolocalized and less complex than the ENTSO-E model. The main disadvantage is that it cannot be shared with project partners as-is for reasons of confidentiality. Also, the model was successfully used with time series provided by IEE, but time series in question for WP6 would still need to be tested with this model.

Figure 6: German transmission grid model

5.3 Cyprus transmission and distribution grid models

The following subsection summarizes grid models considered for usage in WP 5 and WP 6 by INTERPLAN project partner FOSS.

The considered transmission grid model is originating from the Cyprus transmission grid available at Electricity Authority Cyprus (EAC) and it is confidential. INTERPLAN partner FOSS has an agreement in place with EAC to use the transmission grid system for analyzing all development work of INTERPLAN under the direct control of personnel of EAC. The model represents the real physical grid area of the TSO of Cyprus in 2019. The model represents a synthetic benchmark grid. It comprises the voltage levels of 66 kV and 132 kV that are operational in Cyprus. The model contains a total of 324 lines (overhead/underground power lines), 3132 busbars, 167 2-winding transformers, 5 3-winding transformers, 169 loads, and 7 static generators (wind generators) and 30 synchronous machines. In addition, it provides 34 Shunts/Filters, 109 NEC/NER, protection elements and control models for synchronous generators. It is available in “pfd” format / DIgSILENT Powerfactory software. An interactive graphical representation is available with all the required notations/information about the power system elements and naming. The overhead power lines and transformer characteristics/parameters are set according to information provided by the manufacturer. The model assets are not attributed to geographic coordinates, but geographical information/ coordinates can be incorporated into the model in a future stage if this is required. The model does not include time-series profiles, but it includes min/max load conditions for performing operation scenarios. The model can be used in both steady state and RMS simulations which can provide results from per hour to per cycle resolution and which is suitable for steady state/dynamic studies and for appropriate control development.

The basic data for the distribution grid model considered for INTERLAN is originating to a part of the distribution grid of Cyprus provided by EAC. It is available at FOSS and the partners of INTERPLAN through a NDA and it is confidential for the public. The model represents the real physical grid area of Alambra transmission substation in Cyprus in the year of 2019. The model represents a synthetic benchmark grid. It comprises the voltage levels of 11 kV and 400 V line - line. The model contains a total of 964 lines, 1867 busbars (2423 terminals), 552 transformers, 551 loads, and 559 generators (558 PV systems, 34 of which active, and 1 biomass unit) and consequently 35 active generators. In addition, it provides 552 protection devices (552 fuses) and 372 breakers/switches. It is available in “pfd” format / DIgSILENT Powerfactory software. An interactive graphical representation is available with feeder noted by different color (7 representative feeders) and distribution substations either represented by a circle (overhead transformers) or rectangle (ground mounted transformers) at the top level of hierarchical graphical representation. Each distribution substation node includes a distribution transformer of a specific type depending on its nominal power, general/aggregated load, low/medium voltage busbars and/or aggregated PV system. The cable and transformer models are set according to information provided by the manufacturer for each specific type. It is readily available for performing both steady state and dynamic simulations. Steady state information of the network is already set properly therefore steady state simulations are feasible and can provide results of high credibility/accuracy. The distribution grid model can also be used for producing general results for dynamic studies. But, fine tuning of models based on technology type, control etc. is required to be performed in order to acquire results closer to reality. Storage is not included (as no storage is installed on the specific distribution network) neither provisioned in the model, but it can be incorporated at a later stage based on project requirements. The model assets are not attributed to geographic coordinates, but geographical information/ coordinates can be incorporated into the model in a future stage if this is required. The substation name, unique id and nominal power of each distribution substation is noted at the as well as the rating and type of cables at the top level of graphical hierarchy. The model does include time-series (per hour) for load consumption and PV power production for a single day which can be extended to a whole year or shorter time period of second resolution. The model can be used in both steady state and RMS simulations which can provide results from per hour to per cycle resolution and which is suitable for steady state/dynamic studies and for appropriate control development.

5.4 Alternative transmission grid models

Another transmission grid model is the PyPSA-EUR network [11]. It was possible to construct this network with public sources, but not possible to successfully perform a load flow calculation for the whole network. Since there were other alternatives available, the model was not investigated further; in particular it was not tried to perform a load flow calculation for a part of the network, e.g. Germany. Doing so would potentially be another alternative for WP 6 when the 50 Hertz balancing zone is considered as planned. The major advantages of this model would be that it could be freely distributed amongst partners.

5.5 SimBench benchmark datasets for transmission and distribution systems

SimBench is a project aimed at developing a public available benchmark dataset for grid models at all voltage levels. The project is running until April 2019. 13 basic grid models with different voltage levels can be created by this dataset until now. The following list shows the voltage levels that are included:

- one extra high voltage (EHV) grid

- two high voltage (HV) grids
- four medium voltage (MV) grids
- six low voltage (LV) grids

After finishing the project, each grid model is planned to have three different scenarios. At the time of writing the summary, only one such scenario is available. For the medium and low voltage levels, load and generator profiles are available at this time.
Until now these grid models can only be generated from the benchmark dataset by using the pandapower software. It is also possible to merge the grid models with each other if more than one voltage level is needed. Overall the SimBench project provides 246 possible grid model combinations.

In the next two subchapters a detailed description is given for a medium and a low voltage grid model. The combination of these models is an option for a distribution level network for WP6.

3.2.1.1 SimBench medium voltage grid semiurban

The basic data for this grid model is originating from the SimBench project. It is available at IEE and is confidential. The model represents a synthetic benchmark grid. It comprises the 20 kV voltage level with additional two transfer points into the 110 kV voltage level. The model contains a total of 124 lines, 118 busbars, two transformers, 120 loads, and 126 static generators. In addition, it provides ten switches to divide the network into subnets. It is available in the pandapower software format and is expected be also available in the Powerfactory software soon. A graphical representation is plottable using the pandapower software. The model provides detailed data for cables and transformers. The lines include parameters for length, resistance, reactance, capacity, and the maximum current. The transformers are modeled with parameters regarding tap-characteristics, transformer losses and relative short-circuit voltage. The grid model provides static model data for generators. The generators are assigned to energy sources: photovoltaic, wind power, biogas and hydro power. The model assets are not attributed to geographic coordinates or substation names. The model does include time series data for loads and generators for the scenario year 2016 in 15-minute resolution. This time series data was generated by a combination of real measurement data and synthetic data. For developing the synthetic data, a profile generator was used with multiple input data sources (weather data, location assumptions, etc.).

The given file format may be converted to pickle, excel, Json, SQL, PYPOWER, MATPOWER and Powerfactory by the pandapower software; however the Powerfactory conversion currently does not fully support all elements and does not take over the node coordinates, thus resulting in a generic Powerfactory network graph. Hence, the conversion result needs to be manually corrected.

At the time of writing this document, the grid model was used for load flow calculation with predefined data.

3.2.1.2 SimBench low voltage grid semiurban 4

The basic data for this grid model is originating from the SimBench Project. It is available at IEE and is confidential. The model represents a synthetic benchmark grid. It comprises the 0.4 kV voltage level with an additional transfer point into the 20 kV voltage level. The model contains a total of 42 lines, 44 busbars, one transformer, 41 loads, and one static generator. It is available in the pandapower software format and is expected to be also available in the Powerfactory software soon. An interactive graphical representation is not available at this time. The model provides detailed data for cables and transformers. The lines include parameters for length, resistance, reactance, capacity, and the maximum current. The transformer model includes parameters regarding tap-characteristics, transformer losses and relative short-circuit voltage. The grid model provides static model data for a photovoltaic generator. The model assets are not attributed to geographic coordinates / substation names. The model does include time series data for loads and the generator for the scenario year 2016 in 15-minute resolution. This time series data was generated by a combination of real measurement data and synthetic data. For developing the synthetic data a profile generator was used with multiple input data (Weather data, location assumptions, etc.).

The given file format may be converted to pickle, excel, Json, SQL, PYPOWER, MATPOWER and Powerfactory by the pandapower software.

At the time of writing this document, the grid model was used for load flow calculation with predefined data. Figure 7 shows the grid model as displayed in Powerfactory after such load-flow calculation. The blue area is the LV part and the green/red area is the MV part.

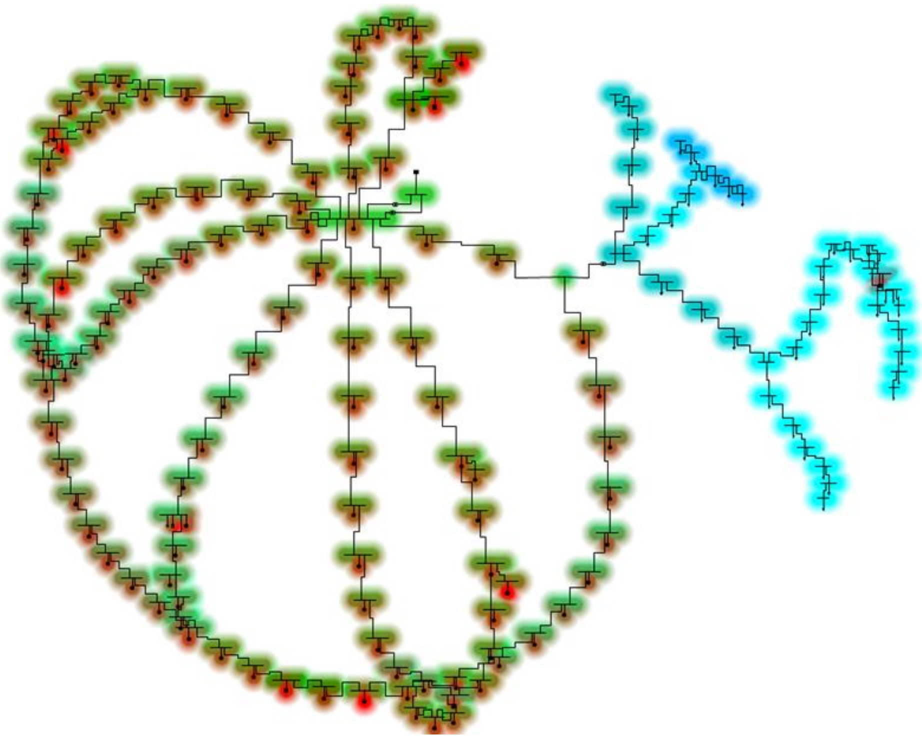

Figure 7: SimBench distribution grid model after load flow calculation

6. Time Series

For generation of time series for Eastern Germany, the following methodology was applied.

Data for wind (onshore and offshore) generation, PV and demand were extracted from 50Hertz and ENTSO-E databases that are available online and are given in p.u. which means that they can be scaled according to needs. Those data are for the part of the German network operated under 50Hertz and represent year 2018. Based on aforementioned data, 365 daily profiles were created with a time step of 15 min.
Profiles can be chosen by selecting a specific day in a year or through specifying one of a profile characteristic values, independently for each type of generation and load:

- mean
- minimum
- maximum
- range (min-max)

If profiles are selected through a set of characteristics then in a first step a group of profiles is found. Then, one profile is selected from this pre-selected group through a key parameter (by default 'mean' = 0,5) which can be also set for each type of generation and load. An additional component (Gauss distribution with a given standard deviation of normal distributed disturbance) can be added to the chosen profile. Moreover, for each object a profile with different parameters can be chosen by specifying a key parameter for a given object in an input file or by selecting a profile by hand from the profile database.

After choosing profiles from the initial model (at t=x) the base model is created (at t=0) in one or several steps, depending on the unbalanced power. Then from that model time series data are adjusted for each time step within a 24h period (including balancing). For each time step a load flow is performed to check convergence.

The time series generation poses several requirements to the grid model in question. In the following, requirements are listed and it is noted to which extent they are fulfilled by the grid models which are considered for WP6, specifically the ENTSO-E transmission model ("ENTSO-E TSO model"), the German transmission system model ("German TSO model)" and the eastern German benchmark distribution system ("DSO model"):

- For generator time series, the generation type (e.g. PV, onshore wind, offshore wind, coal, nuclear) should be indicated by plant category and subcategory in case of wind turbines.
  In the DSO model for WP6 and the German TSO model, this information is already available. In the ENTSO-E TSO model, it would have to be added since the model does not give information about generation types.

- Each generation type, including wind and PV generation, must be represented in the grid model by separate generators. Generator objects of specific type may not be combined with any other generator type or load. Separating wind and PV generation from loads (such units connected to MV/LV grid are usually modelled as integrated part of load) is recommended, otherwise they cannot be taken into account. The nominal power of the generators should be given. In the DSO model, these requirements are already met.

- The grid model should distinguish between onshore and offshore wind generation, otherwise they will be both treated as onshore wind generation.

- All loads are generally treated as scalable. If there are any non-scalable loads (e.g.: power station internal load), those should be indicated (as a parameter in model or as a list).

- Generation units used for providing balancing power should be distinguished from other generators. A standard operation point is needed (e.g. coal or nuclear plants which are running at e.g. 90% of their nominal power). Also, the minimum power of each balancing generator should be given (typically 40-60%), otherwise an assumption of typical minimum value will be made.
  This requirement is relevant to TSO models only.

- The above information should be provided in form of a list, (e.g. a text or excel file) or should be indicated in a grid model.

If all requirements are met, time series can be generated for loads and generators. The geographic locations of generation units are not relevant for this.

For neighbouring countries or grid areas, usually a time series for the power exchange over the interconnection lines is assumed. An approach to estimate this is to calculate the total power exchange between the grid area in consideration and the external grids by calculating the production/consumption balance. This total exchange power could be attributed to interconnection lines due to their relative transport capacity. Another approach is to use planned exchange powers according to day-ahead market clearing, if such data is available.

At the time of writing this document the preliminary version of the algorithm is available. In the evaluation and validation process the algorithm will be enhanced and optimized for the INTERPLAN usage.

7. The OpSim co-simulation environment

7.1 Introduction

Due to an increasing influence of power system control functions and a growing influence of market operations, holistic power system analysis typically requires the use of a combination of several simulation environments. This is needed especially in terms of the interaction between
multiple power system operators [12],[13].

A co-simulation is a hybrid simulation environment executing one simulation experiment by combining at least two models of distributed subsystems [14]. Each subsystem or component is solving a particular mathematical problem, such as algebraic or differential equations. The components are coupled to exchange state information. Co-Simulations are increasingly applied in the context of power system analysis. They present one way to cope with the increased complexity of simulation models and power system control behavior. Besides, co-Simulation does not only provides a combined simulation environments, furthermore, geographically distributed simulation tools can be easily integrated into joint experiments of more than one research infrastructure.

OpSim is a co-simulation and test environment and platform which was initially developed by Fraunhofer IEE in the German research projects OpSim and OpSimEval. It is intended for simulation of operation and control strategies and aggregators in smart grids with very high share of renewable generation. The simulation environment includes virtual power plants, distribution network control strategies, transmission system control strategies and energy management systems of distributed generators, storages and loads. Using the environment, co-simulations can be executed both in real time and accelerated.

The OpSim environment is a unique facility for the development of grid control strategies and their test in realistic conditions. Particularly noteworthy is the ability to analyze and optimize multiple control strategies in their interaction. OpSim applications are ranging from developing prototype controllers to testing operative control software in the smart grid domain. OpSim is maintained by Fraunhofer IEE and University of Kassel and enables users to connect their software to simulated power systems, or test it in conjunction with other software. The power grid simulator of OpSim is capable of emulating large power systems with multiple voltage levels and substantial amounts of generators, storages and loads.

The core of OpSim is a flexible message bus architecture; it allows arbitrary co-simulations in which power system simulators, controllers and operative control software can be coupled together. The message bus relies on Message Queue Telemetry Transport (MQTT) for transfer of simulation data and control flow between co-simulation subcomponents. The message bus forms the central part of distributing information among the simulation components. Every component is connected to this bus via a client which itself handles all communication, keeps track of simulation time and synchronizes the clock of physical separate systems.
For synchronization, the environment uses a so-called “conservative time synchronization method”: each simulator/controller is blocked until it confirms that all following events are after the last received one and it is safe to progress. This synchronization is implemented in generic “OpSim-clients”, while different simulation components are connected to OpSim via specific “proxies”. Amongst others, there are proxies available for interfacing to DigSilent Powerfactory and pandapower. The information exchange is organized by a central OpSim component “OpSim-Core”. For definition of a

specific simulation setup, a scenario file is used which is automatically generated from text files which define the input and output data of each simulation component. The according scenario file is read at the start of each simulation experiment. The simulation execution is controlled by a user interface component called “Master Control Program”. Figure 8 shows the OpSim architecture with an example subsystem configuration. The block to the left indicates possible external input data.

Typically, an OpSim co-simulation focuses on a single grid simulator featuring multiple voltage levels, which interacts with a multitude of (possibly conflicting) control strategies. Thus, different voltage levels are not separated into distinct simulation components, to ensure their physical interaction is accounted for correctly. Control strategies can be agent-based, but can also be global (say, a voltage optimizer which controls tap changers) or Energy Management Systems. In addition, "OpSim" focuses on the interaction between two or more control strategies (e.g. a Q-setpoint agreement scheme between DSO and TSO) and their effect on the power grid.

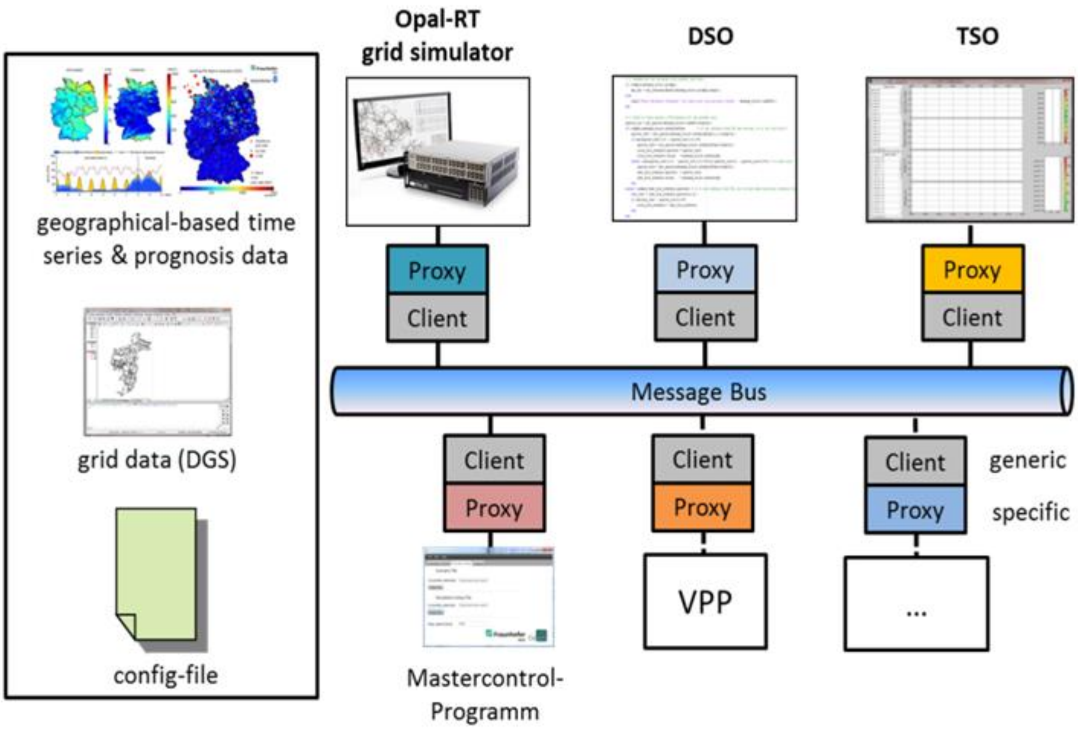

Figure 8: OpSim architecture overview (example)

A further extension of OpSim is a webservice component enabling remote co-simulation subcomponents that access the message bus over REST or WebSocket technology, enabling “OpSim as a service”. This functionality was already used in different previous projects, e.g. the German project “New 4.0”, and is planned to be used in INTERPLAN WP 6 for enabling co-simulation subcomponents representing controllers running at project partners, while the physical grid simulation runs at the OpSim server hosted by IEE.

7.2 Planned usage and training material

In order to support the usage of OpSim as a service in project INTERPLAN, a new demonstration and according training material was prepared in WP 6. The aim was not to present a complex simulation scenario, but a simple-as-possible simulation setup which could be used to explain basic OpSim as a service functions. The demonstration includes a very simple example for a co-simulation comprising three subcomponents:

1. A very small physical network simulation performed using pandapower, which is supposed to run at the OpSim server within the IEE IT network
2. A remote operation control which represents a first DSO. This component is using OpSim as a service and is supposed to run outside the IEE network. It is not using any grid model, but implements a simple local control. The control modifies the operation setpoint of a concentrated generator within the area of the first DSO. Also a load is present there.
3. A second remote control which represents a second DSO. This component is also using OpSim as a service and is supposed to run outside the IEE network. It is implementing a simple control scheme which makes use of an estimation of the grid status by utilizing an equivalent network model and Powerfactory. Powerfactory is interfaced to the OpSim component using a Python module which was developed in WP6. The control modifies the operation setpoint of a concentrated generator within the area of the second DSO. Again, also a load is present there.

The simulation experiments conducted in the demo consider a congestion situation in the simulated physical network, which occurs in form of a line overload for certain operation points of the generator active powers. Reactive power is generally disregarded in the demo. The simulation cases foreseen consist in a reference case, a DSO 1 - only control, a DSO 2 - only control, and finally the activation of both control schemes at once. In the reference case, the line overload situation occurs; in any of the other cases, the line overload is resolved by the control action.

The network model used for the demo is shown in Figure 9. The model is representing a purely fictive case solely used for training purposes; in reality, the shown configuration would not have been installed without grid reinforcements.

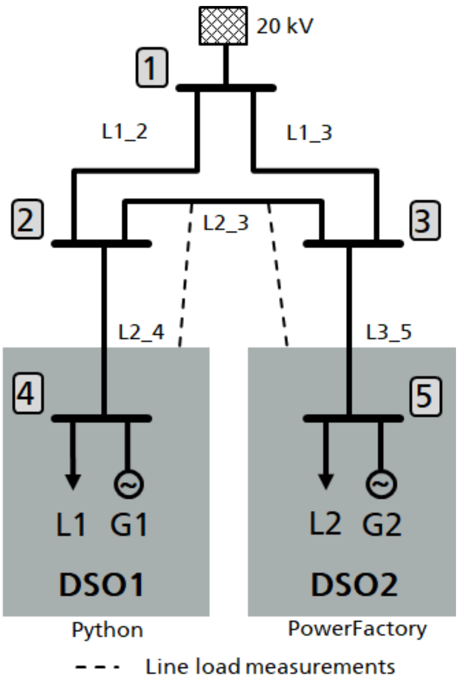

Figure 9: OpSim video demo network

All busbars have the same voltage level of 20 kV. The concentrated loads L1 and L2 are set to a fixed active power of 12 MW, whereas both generator G1 and G2 active powers can be continuously varied between 0 and 12 MW.

The following Table 16 shows the used line types.

Table 16: OpSim video demo line types

Line	Type	Length
L1_2	NA2XS2Y 1x240 RM	1000 m
L1_3	NA2XS2Y 1x240 RM	1000 m
L2_3	NA2XS2Y 1x70 RM	100 m
L2_4	NA2XS2Y 1x185 RM	200 m
L3_5	NA2XS2Y 1x185 RM	200 m

The line which is subject to overload is L2_3. The overload occurs when DSO 1 delivers a residual generation of 8 MW or more from busbar 4 to busbar 2, while at the same time DSO 2 has a residual load of 8 MW or more, or vice-versa. In this situation, the line current of L2_3 exceeds the maximum permitted limit of 200 A.

Both the two DSOs are assumed to measure the line L2_3 current. They individually apply the following control schemes to avoid the line overload:

- DSO 1 tries to balance generation G1 and load L1 in order to keep the line current below the 200 A limit. Here for, it changes the active power of G1 with a limited power gradient of 350 W per simulation step.

- DSO 2 tries to estimate the residual load of DSO 1 (L1-G1) using the line current and an equivalent network model in Powerfactory, and adapts its generation G2 to keep the line current in the allowed range.

The training material consists in five videos which contain a step-by-step explanation and walk through the Python sources provided for the components (2) and (3).

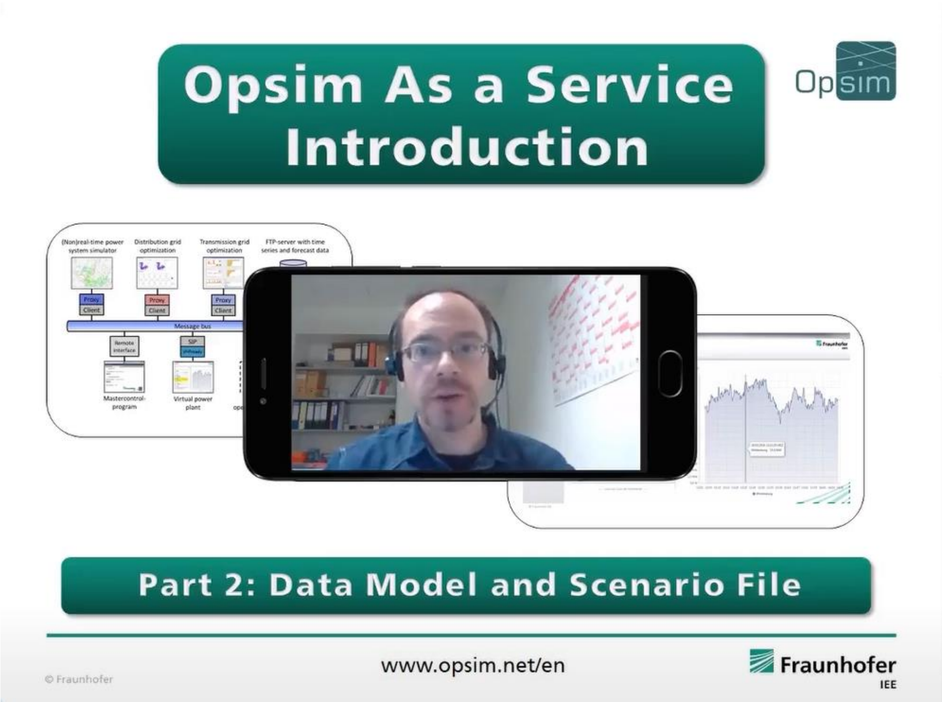

Figure 10: OpSim video part 2 as displayed in video player

8. Validation plan

8.1 Standard validation scenario

The following subsection defines a standard validation scenario which is designed to be applicable to most showcases.

8.1.1 Target area and year

The target scenario area is the balancing zone of the German TSO 50Hertz. It includes the states of Eastern Germany, i.e. Brandenburg, Mecklenburg-Vorpommern, Sachsen, Sachsen-Anhalt, Thüringen and Berlin. The considered target scenario year is 2030. This selection is made to avoid further significant changes to the installed generation powers because of the recent decision to opt out of coal-powered electricity production. This decision was made by the German government early 2019 and is thus not respected by the INTERPLAN scenarios which were previously developed in WP3. Grid reinforcements motivated by the coal power opt out which would have to be made after 2038 are not yet known. Hence, the target year 2030 is considered to result in a more realistic scenario for WP6.

8.1.2 Simulation type and environments

The simulation type for the standard scenario is semi-dynamic. It is intended to support quasi stationary simulations with simulation step-width of 1 to 15 minutes and a simulation time-scope of 24 hours.
The standard scenario uses grid models available to INTERPLAN in Powerfactory. However in order to simplify simulation system integration, conversion of the physical grid model to Pandapower is considered, since there are well tested tools available for interfacing Pandapower networks to the OpSim co-simulation platform.

8.1.3 Grid model

The idea for the standard scenario transmission grid model is to use the balancing zone of the German TSO 50Hertz as simulated system. Any network outside the 50Hertz area is considered outside the system boundary. As can be seen from Figure 3, there are several options for transmission grid models for that area, namely either the German transmission grid model, the ENTSO-E geolocalized model. Both those models have more than 50 grid nodes. The outside grid area may eventually be replaced by an equivalent network. It still needs to be tested if these network models would allow converging load flow calculation using the time series that are being in development. If not, time series data would have to be adapted. A third and backup option for the WP6 transmission grid model is to use the synthetic model from the SimBench dataset.

If the German transmission grid model is selected for the standard scenario, it should be considered if a simplified equivalent network for this model could be developed, which can be given to the project partners on a confidential basis for use in project INTERPLAN. This is needed since for performing the various optimization tasks defined by the showcases, the partners would need the transmission grid model.

With regards to the distribution grid model, WP 6 will resort to a synthetic grid generated from the

SimBench dataset since, from INTERPLAN itself, there are no publicly usable Eastern German distribution networks available. As discussed above, this network model has 118 busbars. The model is connected to a selected 110 kV busbar in the transmission network model.

8.1.4 Installed generation

The installed generation power in the resulting network model is to be selected according to the INTERPLAN-2 scenario which is used by all showcases except showcase 1. Since INTERPLAN-2 does detail the installed generation for Germany only, but not for Eastern Germany, the share of today's installed generation per generation type in Eastern Germany when compared to the whole country is assumed to stay constant until the scenario year 2030.

Every grid model taken into consideration the standard scenario already contains generation devices, but they will probably need to be adapted in order to match the installed generation defined by INTERPLAN-2. The according adaptation might include redefinition of generator types (e.g. replacing concentrated fossil fuelled generator by renewables), changing RES generator active nominal powers (representing e.g. retrofitting of wind power plants), removing of fossil fuelled power plants, or introduction of new renewable generators. For instance, the SimBench distribution grid model is currently equipped with four PV generators only, hence an increase of the PV generator count and introduction of MV wind generators is to be considered.

The modification needs to be done such that the requirements for the time series generation as outlined above are met; in particular, each generator type has to be modelled separately.

In order to support the various showcase's control actions, a selected portion of the generators within the HV, MV and LV networks needs to be equipped with control capability for active and reactive power. A selected subset of inverter coupled generators needs to be considered with droop control or system inertia provision capability. However, the WP 6 standard scenario does not foresee dynamic models for these generators. Nevertheless, it might be considered to replace the non-dynamic models for such selected generators by dynamic ones, leaving the rest of the system unchanged.

A part of the generators thus defined needs to be selected to be controllable by the grid operator in terms of their active and reactive power. Also, a part of the generators should be selected to act as tertiary reserve providers, i.e. being usually operated at lower than nominal power (e.g. 90%) in order to provide balancing power.

The aforementioned generators should cover a wide variety of types, ideally including conventional power plants at the EHV and HV level, wind power plants at the HV and MV level, PV plants at the MV and LV level, and storage systems at the MV and LV level.

When it comes control, the aforementioned selected generators need to be modelled such that their active and reactive powers can be adapted from one 15-minute time-step to another. For inverter coupled devices this time is usually sufficient for any power change; however, conventional power plants will not be able to arbitrarily change their output powers within that time, but be limited by a maximum rate of change. Also, operational limits of the generators need to be respected and accordingly modelled.

8.1.5 Installed load

In terms of load time series and loads contained in the grid models, similar things apply as for the generation. Concentrated loads are basically already available in the models; the load time series

need to be generated according to the relative consumption for Eastern Germany as given by the INTERPLAN-2 scenario.
Related to controllable loads it should eventually be considered to equip MV or LV connection points with derateable electric vehicle charging stations.
Introduction of derateable loads in the MV/HV grid could also be considered reviewing the types of loads according to the German Abschaltverordnung.

8.1.6 Additional controlled grid assets

One type of additional controllable grid asset relevant for some showcases are remotely controllable on-load tap changers for the EHV/HV and HV/MV transformers. MV/LV transformers are historically not equipped with this technology. Also, additional models for remotely controllable reactive power compensation units in the TSO network can be considered in case the selected transmission grid model does not include such units in the first place.

8.1.7 Time series

As stated above, the INTERPLAN-2 scenario together with today's ratios of installed power and generated energy between Eastern Germany and whole Germany should result in a basis for time series generation. The same is the case for the loads. This should result in available time series for the target year 2030.

8.1.8 Equivalent models and neighbouring grid areas

It is currently unknown which showcases would work with an equivalent distribution grid model. For showcases which need such, an equivalent model for the SimBench distribution grid already selected for WP 6 would need to be developed. Since this distribution grid has a MV and a LV part, two according equivalents may need to be selected using results from the related INTERPLAN tasks.

In terms of the transmission network, replacement of the networks outside the 50Hertz area by equivalent models has to be considered. Depending on the selection for the transmission grid, an equivalent model for the 50Hertz area itself eventually needs to be developed as well.

8.2 Application of standard validation scenario

In the following subsection, it is assumed that the consortium succeeds in developing a standard validation scenario as described above. In any other case, individual scenarios for validation of WP5 results need to be found.

The following Table 17 shows to which extent the standard validation scenario can be applied to the showcases and to which degree it covers different requirements of showcase validation. The green cell colour indicates that it fulfils the showcase requirement, yellow indicates that information has to be added in order to fulfil the requirements, and red indicates that the requirement cannot be fulfilled. It is assumed that WP 6 succeeds in finding a standard scenario grid model and base case time series which are usable by all partners, using one of the options outlined above.

Table 17: Showcase requirement coverage of standard validation scenario

Showcase / **Requirement**	**1**	**2**	**3**	**4**	**5**
Simulation type and environment					
Minimum number of grid nodes					
Needed voltage levels					
Controllable generators					
Generator information and models					
Controllable loads					
Load information and models					
Time series for validation					
Simulation time interval and timescope					

Related to the available TSO grid models as outlined in chapter 5, each of them only covers a subset of the requirements needed by WP 6 at the moment. A particular problem is that the model in question - or at least a part of it - must be freely distributable between partners since the individual showcase controllers need to perform optimization operations using the grid data. This situation is shown in Table x. A solution to this problem is to be found in the next step. The preferred option is to still model the Eastern Germany part of the 50 Hertz balancing zone, and to generate according time series. If this should not prove successful, a SimBench synthetic network could be used. Another alternative could be the public Nordic benchmark network, which is not included in the matrix.

Table 18:Requirement coverage of TSO grid models for WP6

Grid Model / **Property**	ENTSO-E	IEE	FOSS	PyPSA-EUR	Sim-Bench
Is non-confidential					
Calculates load flow					
Successfully used with time series					
Detailed generator information					
Represents physical grid area					

Notably, the base showcase definitions from D 5.1 would define a reference case for each simulated showcase, resulting in reference case KPIs. These can be compared to the KPIs obtained by simulating the situation with activated controllers for each showcase. For the latter simulation, adaptations of the standard validation scenario are needed for individual showcases as well as the planned simulation experiments. Those adaptations are listed as follows:

- Showcase 1: Non-dynamic generator models would have to be exchanged by dynamic models with droop control and synthetic inertia provision capability for selected generators. Also, other generators as well as time series might need to be changed in order to adapt the scenario to the INTERPLAN-3 scenario, which is exclusively used by showcase 1. Showcase

1 also needs forecasts for generation and load are needed which could be synthetically generated by applying a forecasting error to the time series of the target simulation day. The real-time simulation time scope and interval needs to be selected according to the showcase requirements. Within the target simulation day, an event causing a frequency deviation should be triggered. This can e.g. be achieved by a rapid power change of a load or generator.
The showcase validation would then consist in carrying out a day-ahead operation planning according to the showcase description, which would result in final time series and setpoints and configuration values for the droop functions and the synthetic inertia parameters of generating units providing inertia. This would be followed by a real-time simulation of the selected simulation timescope, and evaluation of the system frequency response onto the introduced trigger. The validation would be passed if the system frequency stabilizes after the trigger event within a predefined time.

- Showcase 2: This showcase needs a scenario which defines DER (e.g. PV, PV/storage, EV charging, controllable loads) that are controllable in terms of active and reactive power by the grid operator. The standard scenario already covers this. Like in showcase 1, forecasts for the active power infeed of all generators are needed. The time series for the target simulation day need to be designed such that a congestion and/or overvoltage situation would occur in the network if the controllable DER would operate at a standard operation point, which needs to be defined.
Validation of the showcase would then consist in a day-ahead planning, which would result in modification of the operation of the controllable DER in terms of active and/or reactive power, as well as a plan for operation of OLTC. The target simulation day then needs to be simulated using the operation plan. The according evaluation would include checking line and transformer loadings as well as busbar voltages. The validation would be passed if the loadings and voltages stay within permitted limits. As an extension of the base scenario, it could be considered to introduce a real-time event which would cause an unforeseen congestion or voltage limit violation, and to perform a re-optimization in real time for solving this. However, implementing this would probably need substantial additional efforts.

- Showcase 3: generator models which are controllable in terms of active power are needed for this showcase. Also, generators foreseen for provision of tertiary reserve need to be given. Both is covered by the standard scenario, but time series for latter generators might need to be adapted such as to provide more flexibility for tertiary reserve. Validation of the showcase would again consist in a day-ahead planning which would result in modified time series that define active power setpoints for the controllable and tertiary reserve providing generators. The target simulation day then needs to be simulated using the operation plan. The according evaluation would include checking generator operation and transformer loadings. The validation would be passed if the operation and loadings stay within foreseen limits. As an extension, it should be considered to add a real-time event which would actually trigger tertiary reserve provision, and eventually perform a re-optimization due to this.

- Showcase 4 is very similar to showcase 3 such that it requires generators which provide tertiary reserve. Also it requires generators with reactive power control capability. Validation would consist in day-ahead planning, which would result in modified timeseries for provision of tertiary reserve and adapted reactive power settings. The target simulation day then needs to be simulated using this operation plan. The according evaluation would include checking busbar voltages and generator operation. The validation would be passed if the voltages stay within permitted limits and the generators providing tertiary reserve would be operated such that this is possible at any time. An extended validation could consist in introducing actual tertiary reserve provision as in showcase 3.

- For showcase 5, reliability data has to be available for lines, transformers, circuit breakers and loads. It is the same case for generators and RES, stochastic models have to be defined. This data is not included in the grid models and load shedding information needs to be added. This could be addressed by using a limited set of standard lines, transformers, circuit breakers and loads for which reliability data can be obtained or estimated. With regards to validation, the day-ahead planning phase or planning based on a longer time horizon, depending on the available data, of the showcase will result in set-points for controllable generators and loads which enable to manage credible contingencies in an optimal way. The target simulation day can be simulated using the resulting operation plan in order to evaluate the KPIs mentioned in D5.1. Further validation depends on the question if a real-time controller for managing contingencies will be developed in WP5. If this is the case, then an event should be triggered which activates one of the identified credible contingencies. The evaluation would then consist in observing the system behaviour and according to the calculation of KPIs.

In terms of input parameters for the time series generation for Eastern Germany, the following tables summarize figures obtained from the data mentioned in chapter 4 and compares those with today's situation.

Table 19: Reference scenario installed generation capacity Eastern Germany [MW]

Scenario	Year	Nuclear	Fossil (Coal, Gas)	Solar PV	Wind	Hydro	Other (Biomass, Oil)
Today	2019	1410	10908	8701	16609	68	2333
INTERPLAN-2	2050	0	2557	22457	27728	242	2587
INTERPLAN-3	2050	0	6539	11185	35376	334	1552

Table 20: Reference scenario electricity generation Eastern Germany [GWh]

Scenario	Year	Total	Nu-clear	Fossil (Coal, Gas)	Solar PV	Wind	Hydro	Bio-mass	Other
Today	2016	152,652	0	96,154	8,740	25,711	584	13,42	8,043
INTERPLAN-2	2050	187,648	0	9,279	56,909	76,455	883	44,122	n.a.
INTERPLAN-3	2050	249,035	0	21,051	27,593	176,890	1,309	22,192	n.a.

Table 21: Reference scenario electricity consumption Eastern Germany [GWh]

Scenario	Year	Consumption

Today	2014	100,000
INTERPLAN-2	2050	92,500
INTERPLAN-3	2050	161,700

With regards to electric vehicle charging points, the INTERPLAN-2 and INTERPLAN-3 scenarios do not allow attribution to Eastern Germany. According to a recent study [15], the number of charging points for whole Germany in 2050 would be at least 37 Million, 31 Million of which situated at private households. The work based on the assumption that by 2050, all privately owned cars would be electric. The study [16] predicts the stock of electric vehicles in Germany 2050 to 32 Million, but this also includes fuel cell electric vehicles. According to statistical information [17], the ratio between the number of households in Eastern Germany to whole Germany for 2017 was 19,6 %. The total number of households in Eastern Germany sums up to 8.025 Million. Hence, the number of charging stations in the Eastern German LV networks could be conservatively estimated to at least 6.05 Million, and the number of private owned electric cars at least 6.27 Million. This means that 75% of the households connected to the LV networks would be equipped with a charging station. This percentage value again could be used as a guideline to place charging stations within the reference scenario LV network.

8.3 Next steps for OpSim based implementation of standard scenario

The standard scenario grid model should be provided as OpSim component representing the physical network, hosted at IEE. It should include controllable loads and generators able to receive external P/Q setpoints as well as (eventually) droop and synthetic inertia parameters. For each DER type, a control behaviour should be implemented which models the DER behaviour onto the external control signals according the permitted DER operation limits, e.g. limiting the rate of change of active/reactive power, limiting maximum permitted reactive power etc. Also local DER droop functions should be implemented here. The main role of external simulation subsystems would then be to represent operation control, and provide setpoints for the controllable DER for each timestep of the simulation timescope, as well as recording the simulation results. Specific result data needs to be defined for each individual showcase.
Individual showcases might alternatively use different means of validation in case those would be better suited than the standard validation model.

9. Summary and outlook

Based on a review of the previous INTERPLAN results, namely the five showcases and the available grid models, the deliverable at hand has provided a plan for a standard validation scenario which could, with appropriate modifications, be used to validate all INTERPLAN showcases. For implementation of this scenario, a method for generating time series was outlined. The validation scenario simulation will be set up using the OpSim platform as introduced by this document.

The work in the coming months will focus on implementation of the reference validation scenario. For this, time series have to be generated and brought together with one of the available grid models, and the physical network simulation needs to be setup at the Fraunhofer OpSim central server.

Furthermore, simulation experiments and validation test cases need to be specified in close collaboration with ongoing developments of INTERPLAN controllers for each showcase.

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Annex

10.1 List of Figures

10.2 List of Tables

10.3 Glossary of terms and definitions

10.3.1 Definition of project general terms

Term	Definition
Use Case	The specification of a set of actions performed by a system, which yields an observable result that is, typically, of value for one or more actors or other stakeholders of the system.
Sub Use Case	Description of a specific situation a use case is applied to. A Sub Use Case is always attributed to one (main) use case, but one use-case may have multiple sub use cases which detail the main use case in at least one aspect.
Base showcase	Presentation of base use case(s) with no controllers for emerging technologies, such as RES, DG, demand response or storages in the frame of chosen scenario, simulation type, test model, and time-series data. The base showcase allows to analyze the operation challenges of the related use case(s) and improvements achieved through the implementation of controllers in the associated showcase under specific planning criteria. These potential improvements are measured through KPI(s) evaluation.
Showcase	Presentation of use case(s) in the frame of chosen scenario, simulation type, test model, time-series data and planning criteria
INTERPLAN INTEgrated OpeRation PLANing tool	A methodology describing how to use a toolbox consisting of a set of tools (grid equivalents, controllers) for the operation planning of the Pan-European Network, by addressing a significant number of system operation planning challenges of the current and the future 2030+ EU power grid, from the perspective of the transmission system, the distribution system, and with a particular focus on the transmission-distribution interface. The INTERPLAN tool in essence, is a Python-based toolbox interfacing with PowerFactory, consisting of a library of grid equivalents and controllers for use cases and showcases aiming to address the related operation challenges under the selected scenario and operation planning criteria.
Scenario	Definition of a future situation applying to a well-defined time (most often year). A scenario can be fictional or predicted from the present situation. In INTERPLAN, scenarios describe the future situation of the European electric network, typically including grid topology, generation mix, loads and diffusion of EV, RES and storages.
Dynamic Simulation	A simulation experiment which considers the time dependent behaviour of a physical system, looking at events occurring in real-time operation, with a frequency of occurrence of less than one second of real time. The simulation may run faster or slower than real time, and may, despite the fast event frequency, span a total time interval of several hours real-time.

Semi-Dynamic Simulation (also: Quasi-Dynamic Simulation)	A medium- to long-term simulation experiment based on steady-state analysis, considering the state of a physical system at discrete steps of real time through user-defined time step sizes. The real time between the steps is at least one minute.
Test case	A specification of the inputs, execution conditions, testing procedure, and results that define a single test to be executed to achieve a particular testing objective.
Grid Cluster	A group of grids and parts of grids with similar characteristics
Grid Equivalent	A simplified network model, which approximately behaves like an associated complex physical network or a group of physical networks. The grid equivalent thus is a representation of the physical network(s), which is typically used for a simulation experiment.
Controller	A device, which implements an algorithm or methodology that is used for real-time grid operation. A controller may influence the operation state of distributed generators, loads or grid assets (e.g. tap changer, power switch, flexible AC transmission systems) based on information from different sources.
Interface	A means of transmitting information between two or more controllers or actors. It usually includes a specification about which information is to be transmitted, how this information is represented by data elements, and defines a physical means for transmission of those data elements.
Cluster Controller	A controller having the aggregated behavior of individual controller characteristic in a larger grid.
Interface Controller	A controller, which is intended to be installed in a specific "home" cluster, and uses information received through an interface from at least one other cluster data source outside the home cluster. This data source could e.g. be another cluster, but also e.g. an external weather forecast provider using an interface
Local Controller	A controller which is associated with a single specific generator, load or grid asset and which operation does not rely on remotely received information originating from any remote source. i.e. the operation only relies on information available within the local area network of the local controller's installation site.
Co-simulation	A simulation which consists of different parts that form a coupled problem and are modelled and simulated in a distributed manner (cp. Wikipedia). The parts are called "Co-simulation subsystems" and are exchanging data during the simulation. Different models and simulation means can be used in different subsystems. The Co-simulation (in the ideal case) is carried out by running the subsystems, which were individually tested and validated beforehand, in a black-box manner. In INTERPLAN, the data exchange between subsystems is done by the OpSim platform.

Co-simulation subsystem / Co-simulation subcomponents	A part of a Co-simulation which is developed, modelled and validated individually, while at the same time able to be integrated into the Co-simulation platform. In INTERPLAN, a subsystem might represent e.g. a DSO or TSO operation centre, a controller, or even the real physical network model.
Data model	An abstract model that represents a real-world entity, and defines, organizes and standardizes the description of the data elements related with that entity. Since real-world entities are typically consisting of other entities (e.g. an electric grid consists of lines, transformers etc.), a data model typically is hierarchically structured and also allows to define interrelations between entities.
V2G and G2V	Vehicle-to-grid (V2G) describes a system in which *plug-in electric vehicles* communicate with the *power grid* to sell *demand response* services by either returning electricity to the grid or by throttling their charging rate. When an EV is being charged, it's called G2V (Grid to Vehicle).
Allocation	With reference to the grid operation planning phase, it is the process deciding, which are the most suitable resources to commit and dispatch among *n* operating resources for a specific objective and under specific constraints.
Placement and sizing	With reference to the grid planning, it is the process deciding the most proper location (bus) and the size of a resource (active power) for a specific objective and under specific constraints.
Energy Not Supplied	Energy Not Supplied is defined as the amount of energy that would have been supplied to the customer if there had been no interruption.
Energy spillage	Energy spillage is the production (from Solar and Wind) that is unable to be accommodated due to demand being lower than production.

10.3.2 Definition of actors

Term	Definition
TSO - Transmission System Operator	Natural or legal person responsible for operating, ensuring the maintenance of the transmission system and, if necessary, developing the transmission system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the transmission of electricity. The term 'transmission' means the transport of electricity on the extra high-voltage and high-voltage interconnected system with a view to its delivery to final customers or to distributors, but does not include supply.
DSO - Distribution System	A natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems and for ensuring the long-term ability of the system to meet reasonable demands for the

Operator	distribution of electricity. The term 'distribution' means the transport of electricity on high-voltage, medium-voltage and low-voltage distribution systems with a view to its delivery to customers, but does not include supply.
ESCO	Electricity supply company (sometimes also: Electricity service company). General term for a company which supplies end users with electric energy. An ESCO may offer additional services, e.g. electricity generation, metering or supply with non-electric energy.
Prosumer	Active energy consumer who consumes and produces electricity. Various types of prosumers exist: residential prosumers who produce electricity at home - mainly through rooftop PV, citizen-led energy cooperatives, commercial prosumers whose main business activity is not electricity production, and public institutions.
Generator	A device which produces electricity.
Load	A device which consumes electricity.
Producer	A natural or legal person generating electricity.
Consumer	A natural or legal person consuming electricity.
Distributed Energy Resource (DER)	A source or sink of electric power that is located on the distribution system, any subsystem thereof, or behind a customer meter. DER may include distributed generation, electric storage, electric vehicles and demand response.
Aggregator	Company who grouping distinct agents in a power system (i.e. consumers, producers, prosumers, or any mix thereof) to act as a single entity when engaging in power system markets (both wholesale and retail) or selling services to the system operator(s).
Distributed generation (DG) unit	Any source of electric power of limited capacity, directly connected to the power system distribution network. DG can be powered by photovoltaic system, micro-turbines, combustion engines, fuel cells, wind turbines, geothermal, etc.
Flexible Loads	A load which consumption can be influenced in terms of power, time, or total energy consumed while still serving its intended purpose. The influence may be exerted by manual means (e.g. switching the load on or off at arbitrary times) or automatic means (e.g. external control signal).