



gD3.2 & gD3.3 Technical SRA

Technical scalability and replicability
analysis of relevant use cases.
Methodology and application



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Executive summary

This document portrays deliverables gD3.2 and gD3.3 and presents the work carried out during Year 3 for the technical scalability and replicability analysis (SRA) of the use cases tested in the Demos of the GRID4EU project. The objective of technical SRA is to assess how the outcomes of smart grid solutions and functionalities can be affected when implemented at a larger scope (scaling-up) or in a different location (replication). The work of Year 3 has focused on developing the methodological framework for the technical SRA of the GRID4EU use cases and on the analysis of the technical boundary conditions of the countries where the Demos are taking place.

The methodology proposed for technical SRA is presented in this document together with the selection of use cases relevant for technical SRA and the specific application of the technical SRA methodology to each of these use cases. The technical impact of the GRID4EU use cases will be assessed based on simulation of the implemented solutions on representative networks to compute a set of Key Performance Indicators and other metrics, under different technical boundary conditions¹.

The practical implementation of the technical SRA methodologies developed for the use cases is described in detail, introducing the models, assumptions and parameters that will be used and considered for simulation. For this purpose, use cases have been grouped into three categories: use cases that will be subject to reliability analysis, to steady-state analysis, and to time-domain analysis.

This document also provides an analysis of the technical boundary conditions to the use cases. Much effort has been put into gathering and processing the necessary input data to build the representative networks that will be used for simulation for each demo country. These data includes confidential information (not displayed in this document) provided by the Demo leaders and general, public data, to represent the actual networks in the Demo regions and countries. This document provides an overview of the different situations in relation to technical boundary conditions that may be found across the countries of the demos. Furthermore, the document presents a qualitative assessment of the effect that the variability of the context in these countries may have on the scaling-up and replication of the different use cases subject to technical SRA.

¹ Please refer to the document to section 6 for a definition of representative feeders for GRID4EU project.

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1 Introduction

1.1 Scope of the Document

The present document portrays deliverables gD3.2 and gD3.3 and presents the work carried out during Year 3 for the technical scalability and replicability analysis (SRA) of the use cases tested in the Demos of the GRID4EU project. Note that the contents programmed for the two deliverables, gD3.2 and gD3.3 have been included in one single document to convey an integral, coherent vision under the title “gD3.2 & gD3.3 Technical SRA: Technical scalability and replicability analysis of relevant use cases. Methodology and application”.

The technical impact of the GRID4EU use cases will be assessed based on simulation of the implemented solutions on model networks under different technical boundary conditions, to represent the effect of scaling-up and replication. The work of technical SRA comprises three main stages: (i) a first stage of methodological developments, (ii) gathering and analysis of input data to model the technical boundary conditions, including the model of distribution networks, and (iii) actually carrying out the simulations for the selected use cases and technical boundary conditions. These stages and tasks are inter-related and inter-dependent: the methodology sets the framework for technical SRA and determines the input data requirements to model technical boundary conditions that will be included in the analysis; building the model of the networks is a necessary task in preparation for simulations, but also enables a thorough analysis of the technical boundary conditions that may be found across Europe and requires the gathering of data, which is not always easily available and straight-forward to manage.

The work of Year 3 has focused on the methodological aspects and the analysis of the technical boundary conditions of the countries where the Demos are taking place. Much effort has been put into gathering and processing the necessary input data to build model networks that can represent the actual networks in the Demo regions and countries, both by Demo leaders in an internal deliberation to gather data and statistics of typical distribution assets and operation strategies and by the GWP3 team, to homogenize the information, compare the parameters and extract a model of distribution networks than can be used to simulate GRID4EU use cases, to model different aspects of the technical boundary conditions and compute the corresponding KPIs.

This document describes in detail the methodology proposed for technical SRA and presents the selection of use cases relevant for technical SRA, as well as the specific technical SRA methodologies developed for each of these use cases.

The document also provides an analysis of the technical boundary conditions to the use cases, describing the input data gathered from the Demo leaders and the representative networks built for each demo country are presented. The different situations in relation to technical boundary conditions that may be found across the countries of the demos are also compared, assessing qualitatively the effect that the variability of the context in these countries may have on the scaling-up and replication of different use cases. These conclusions will be further analyzed

during Year 4 through simulation using the developed network models to establish more qualitative relationships between the boundary conditions and the outcomes of the implementation of use cases.

1.2 Structure of the Document

The document is structured into eight sections and an annex. After this introductory section, section 2 describes the methodological developments of Year 3 of the project, presenting first the general methodology developed for SRA and then moving into the more detailed methodology designed for technical SRA. Then, section 3 presents the selection of use cases relevant for technical SRA and describes the specific technical SRA methodologies developed for each of these use cases. Section 4 goes into further detail to present the practical implementation of the technical SRA methodologies for the use cases grouped into three categories for simulation. Technical boundary conditions are addressed in section 5. First, the countries of the Demos are described through the input data provided by Demo leaders. Then, the impact of these boundary conditions on the outcome of implementing the use cases of the Demos is qualitatively analyzed. Section 6 describes the process to build representative networks with the input data described in the previous section. Finally, section 7 draws the main conclusions of the document and section 8 lists the references cited throughout the document.

1.3 Notations, abbreviations and acronyms

AGR	Automatic Grid Recovery
ASIDI	Average System Interruption Duration Index
ASIFI	Average System Interruption Frequency Index
CEER	Council of European Energy Regulators
DER	Distributed Energy Resources
DG	Distributed Generation
DSO	Distribution System Operator
ENS	Energy Non-Supplied
GWP	General Work Package
HV	High Voltage
KPI	Key performance indicator
LV	Low voltage
MV	Medium voltage
NRA	National Regulatory Authority
PV	Photovoltaics

SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SoC	State of Charge
SRA	Scalability and Replicability Analysis
WP	Work Package

Table 1: Acronyms

2 Scalability and replicability analysis

This section introduces the methodological developments of GWP3 for the scalability and replicability analysis (SRA) of the use cases implemented and tested in the Demos of the GRID4EU Project.

The SRA of GWP3 focuses on the technical and economic impacts of the implementation of smart grid solutions taking into consideration different aspects of the context of the implementation, namely technical, economic and regulatory boundary conditions and the perspective of the different groups of stakeholders involved. The general methodology developed for SRA throughout Year 2 of the project is described in detail in Deliverable gD3.1. SRA relies heavily on technical analyses that can identify and quantify the relationships between different contexts and the outcome of use case implementations. Therefore, the methodological developments for Year 3 include a methodology for technical SRA. This methodology is embedded in the general methodology for SRA and based on the use of simulation on representative networks to compute the KPIs and metrics that can assess the impact of the smart grid solutions implemented in use cases, building on the work carried out by GWP2 and the Demos to assess different metrics and determine the adequate KPIs for different impacts of the use cases.

First, subsection 2.1 describes briefly the general methodology for SRA briefly to contextualize the new methodology for technical SRA of smart grid use cases, which is then presented in subsection 2.2.

2.1 General methodology for SRA

The main goal of GWP3 is to evaluate under a common framework the solutions and functionalities that are demonstrated in the project in order to draw conclusions that can be useful for decision makers regarding the potential future large-scale deployment of smarter distribution grids.

The scaling-up and replication potential of the smart grid use cases tested in the Demos will be assessed following the methodology proposed and described in Deliverable gD3.1. Figure 1 represents the process for the scalability and replicability analysis (SRA), where the technical

analysis plays a key role to quantify the impact of smart grid solutions under different boundary conditions.

The approach selected for SRA is based on a technical, quantitative analysis based on simulation to compute the values of KPIs under different boundary conditions. This way, the effect of a different context to a smart grid implementation may be assessed. Then, economic, regulatory and stakeholder related issues are included to identify the drivers and barriers for the scaling-up and replication of smart grid use cases.

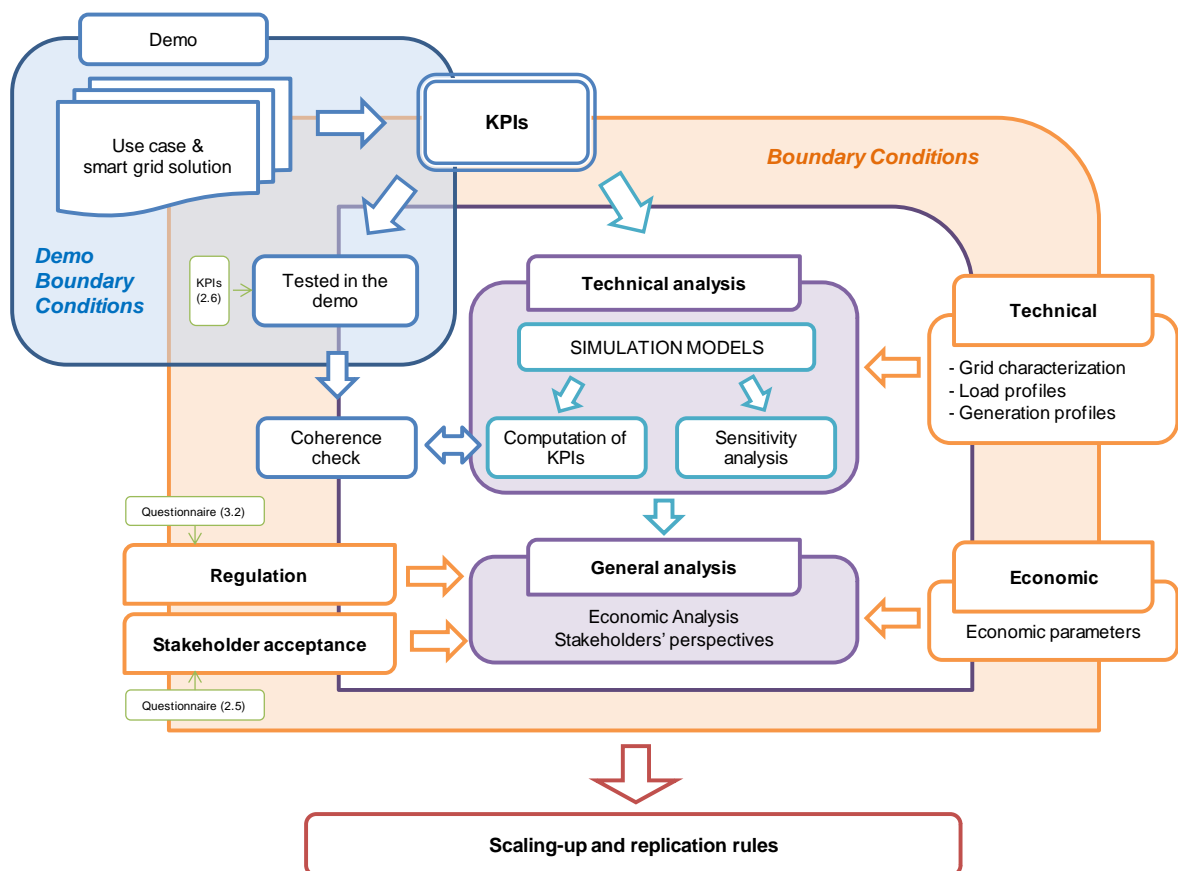


Figure 1: SRA general methodology.

This SRA methodology will be applied to carry out a process in accordance with the different dimensions of scalability and replicability defined in gD3.1, as illustrated in Figure 2. The use case will be first analyzed considering the boundary conditions of the Demo. Then, scaling-up in density will be studied by considering the variation of the degree of implementation of the solution. Replicability will be considered varying the boundary conditions, as would happen when changing the location of the implementation to a different region in the same country. Then the analysis would move on to consider the boundary conditions of other countries. Scaling-up is analyzed throughout the process by increasing the scope of the use case, which involves replication if boundary conditions vary within the area considered at each stage.

The methodology for technical SRA has also been designed accordingly, as will be explained in the following subsection.

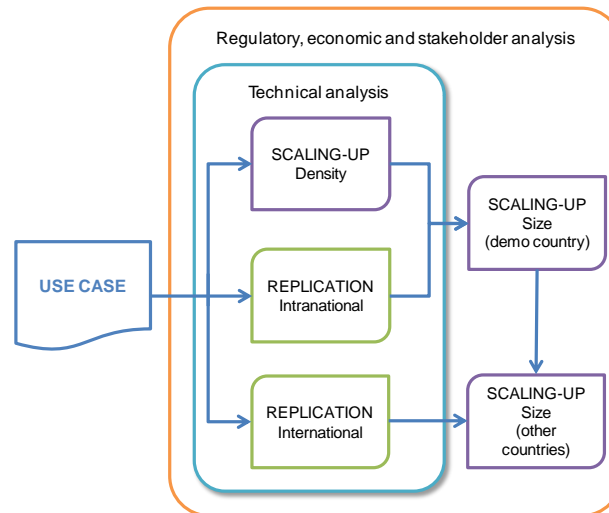


Figure 2: SRA process for the different dimensions of scaling-up and replication.

2.2 Methodology for technical SRA

As seen in the previous section, the approach and methodology designed for SRA relies mainly on the technical analysis of the use cases. This technical analysis is the core of the work of the Tasks of GWP3 for scaling-up and replication, and will be the quantitative basis to observe relationships and determine the scaling-up and replication rules.

The technical SRA is based on simulation of the system, with and without the implemented solution modeled. KPIs and other indicators will be quantified on both cases to compare and thus assess the impact of the use case. Then, the effect of different boundary conditions, related to scaling-up -considering a larger scope of the solution or a larger area for its implementation- and replication -changing the location of the implementation- will be also evaluated performing sensitivity analysis. Simulation tools and representative networks will be used.

The methodology for technical SRA will have to be adapted for each use case to determine the simulation to be performed, as well as the KPIs to compute and the parameters to analyze for each step of scalability and replicability. Therefore, before performing technical SRA, the following steps must be carried out:

- Define adequate metrics to quantify the impact of the use case
Given a use case, where certain functionalities are implemented to achieve a series of objectives, a set of metrics must be selected to quantify the degree of achievement of the pursued objectives. These metrics are the so-called Key Performance Indicators, defined by GWP2. GWP2 and Demo leaders have defined a set of general KPIs and some KPIs specific to a Demo. GWP3 will use the technical KPIs defined for each use

case in GWP2, but additional indicators may be considered for technical SRA to monitor other impacts of the use cases on the system. Non-technical KPIs, such as social and environmental KPIs will not be considered as an output of the technical SRA. Instead, these aspects will be incorporated implicitly in the analysis as boundary conditions (this is the case of KPIs such as recruitment and active participation, for instance) and considered for the subsequent economic, regulatory and stakeholder related analysis of the SRA.

Simulation tools for technical SRA will be able to model the performance of the system and compute the corresponding KPIs and metrics for each use case.

- Analyze boundary conditions

The technical boundary conditions involved in a use case will be characterized and analyzed, including voltage level, network architecture, operation of the network, strategies for voltage control, fault management procedures, characteristics of the elements in the network, demand patterns of consumers, loading of the network, DER connected to the grid, etc.

For different use cases, the parameters that are most relevant for technical SRA will differ. For instance, it will be very important to characterize fault management processes for the technical SRA of use cases aimed at improving continuity of supply, but not so important for use cases related to voltage control.

- Build representative networks and scenarios

Technical boundary conditions will be modeled through representative networks and simulation scenarios of generation and demand or operation state.

GWP3 will elaborate a set of representative networks for each Demo country, so that typical architectures, topologies and characteristics of the actual MV and LV distribution grid are represented. In general, a number of 2 to 4 types of networks per voltage level (MV and LV) will be sufficient to represent the distribution system of a country. The different networks will typically correspond to different types of areas in terms of population density and use of electricity: the different representative networks will correspond to rural or urban, industrial or residential areas. This classification is usually provided also by regulation to set different quality requirements and standards. Load density and quality requirements condition the type of network architecture and topology.

Simulation scenarios will be designed to consider the different situations where the impact of the smart grid use case must be assessed. Depending on the type of use case, these scenarios may focus on different aspects. For instance, for use cases aimed at improvement of continuity of supply, relevant simulation scenarios include the failure of different elements of the network, while for use cases for voltage control, scenarios to analyze will focus on generation and demand. For use cases where storage is involved, different scenarios of state of charge of the batteries will be considered.

Then, simulation is carried out to perform SRA. The methodology developed for the technical SRA of smart grid use cases is illustrated in Figure 3. This process is designed according to the different dimensions of scalability and replicability. The steps to perform are explained below:

- **Model of the system and use case**
First, the system is modeled, considering the technical boundary conditions that prevail in the demo. Simulation is carried out with the representative network to compute the parameters required for the KPIs for the different simulation scenarios. Then, the use case is also modeled and simulated on the representative network and the values of the KPIs are computed.
- **Scaling-up (density)**
Then, scaling-up will be analyzed to determine the effect that would be obtained if the use case were implemented in the same network, but at a larger scale regarding density aspects. Aspects considered at this stage would include larger penetration of DG in the network, higher demand in terms of contracted power or new consumers, higher degree of demand response in terms of number of engaged consumers or higher shares of “shiftable” or “shedtable” load and higher amounts of storage connected to the network. For this purpose, different values will be given to the technical input parameters related to these aspects and the new values of the relevant indicators will be computed with the simulation tools.
- **Replicability (intra-national)**
Then, replicability to different networks is studied, computing KPIs for different types of representative networks (urban / sub-urban / rural / industrial / ...). In order to represent the typical characteristics of such networks, the technical parameters that will have to be re-adjusted need to include network configuration (architecture, length of feeders, typical values of cables and lines parameters such as resistance, reactance and thermal limits), reliability levels (protection schemes, typical values of reliability indices) and density of demand (number of consumers per feeder length, amount of power contracted, number of substations per km², installed capacity of MV/LV transformer substations), typical consumption profiles and characterization of DG connected in the network (technologies, size, penetration degree). This analysis is focused on replication within the country, thus assuming the same boundary conditions of the demo regarding regulatory aspects and stakeholder acceptance.
- **Scaling-up (size)**
On a third step, the scaling-up of the use case will be analyzed, considering the implementation at a larger scale throughout the country to establish guidelines regarding its feasibility and advisability. The country will be characterized assuming the boundary conditions of the demo and assessing the share of areas of each type (urban / sub-urban / rural / ...).
- **Replicability (international)**
Finally, replicability will be analyzed to consider different boundary conditions to assess the potential effect of the use cases in other countries.

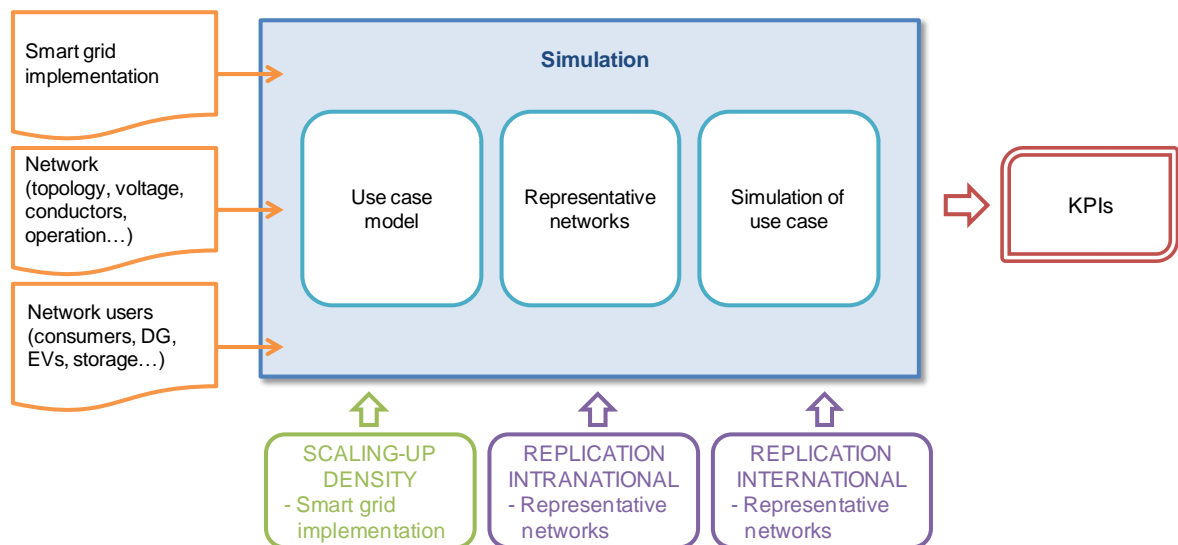


Figure 3: Methodology for technical SRA of smart grid use cases.

3 Application of SRA to GRID4EU Use Cases

This section presents the application of the technical scalability and replicability analysis in the context of the use cases of the GRID4EU Project.

The different use cases implemented in the Demos of GRID4EU are diverse, testing different smart grid solutions and enabling different functionalities in pursue of different objectives. The nature of the impacts of the use cases on the distribution system differs. For instance, use cases related where voltage control is involved have an impact on voltage profiles and energy losses, but automation for continuity of supply improvement has an impact on interruption occurrence and duration but not on voltage profiles or losses. Therefore, the methodology proposed for technical SRA and described in the previous section must be adapted for its application to the different use cases of the GRID4EU. Thus, the use cases of GRID4EU have been studied to select those relevant for technical SRA, and their specific technical SRA methodology has been designed.

This section is structured into two sub-sections. First, the use cases defined by the Demos are reviewed in subsection 3.1 to select the relevant use cases that will be considered for the technical SRA of GWP3. Then, subsection 3.2 will present the particularization of the methodology for technical SRA for each of the selected use cases. Herein, the type of simulation, the parameters that will be considered for sensitivity analysis and metrics to compute will be explained.

3.1 Selection of Use Cases for Technical SRA

GWP3 has reviewed the use cases identified by each Demo leader from the point of view of SRA to assess whether technical SRA is applicable. The selection of use cases that will be subject to technical SRA is gathered in Table 2.

Demo number	Country	Use Case	Technical SRA
1	Germany	Load control in MV	x
		Failure management in MV	x
2	Sweden	Outage detection in the LV grid	
		LV Network Monitoring and Control	x
3	Spain	Automatic grid recovery (AGR)	x
		Automatic outage detection (AOD)	
		Secondary substation node (SSN)	
		Customer engagement (CEN)	
		Improved grid estimations algorithm (GES)	
		Communications improvement (COM)	
4	Italy	Anti-islanding protection	x
		Voltage regulation in MV	x
		MV measurement acquisition	
		Demand response for MV consumers	
5	Czech Republic	Failure management in MV	x
		Failure management in LV	x
		Automated islanded operation	x
6	France	Maximize PV production in LV	x
		Islanding	x
		Power demand reduction	
		Consumer engagement	

Table 2: Selection of use cases for technical SRA.

Demo 1:

A Multi-Agent-System (MAS) comprised by switching and measuring agents will be implemented. The Demo comprises two use-cases, Load Control in MV networks, with an impact on voltage profiles and network hosting capacity, and Failure Management in MV networks, with an impact on continuity of supply in MV networks. Both use cases will be subject to technical SRA.

Demo 2:

A monitoring system has been implemented in the LV grid to enable future integration of DG and improve continuity of supply.

The use case of Power Outage Detection is based on the improved visibility of the LV network

to reduce the time to detect faults in the LV network. Thanks to the installation of RTUs in secondary substations, the fault is detected as soon as it occurs and the subsequent process of service restoration, which remains unchanged by the implementation of this use case, can start earlier. The actual time of supply interruptions for consumers is reduced. However, from the perspective of SRA, this use case does not involve direct action on the network where simulation to obtain the values of KPIs is applicable.

Therefore, the technical SRA of GWP3 will focus on the use case of LV Network Monitoring, to analyze how the connection of new DG and other DER to the LV network (especially PV panels and EVs) could cause voltage problems, overloads and congestions that could be observed by the monitoring system. The objective is to assess the conditions where monitoring equipment may be more useful or necessary in the future

Demo 3:

Demo 3 is focused on the monitoring and control of the LV and MV network, including smart meters, concentrators, LV and MV supervisors at secondary substations and telecontrol of protections.

The use case of AGR performs grid reconfiguration in the case of faults to reduce the number and power of consumers affected by interruptions caused by faults in the MV grid. SSN consists on providing secondary substation with MV and LV monitoring and telecontrolled switching equipment; GES is related to the estimation of the state of the grid using the data from the monitoring system; and COM is transversal to the other use cases, since communications are used by the monitoring and control systems. Consequently, from the perspective of the technical SRA, the use cases of SSN, COM and GES may be regarded as pre-requisites or enablers to achieve the functionalities of monitoring and control for the use case of AGR.

The AOD use case intends to test a wide range of functionalities related to the monitoring of the LV networks. However, it is not straightforward to infer specific indicators that may quantify the impact of its implementation. Consequently, this specific use case will not be considered as a prime objective of the technical SRA.

Regarding CEN, the objective of this use case is to enhance the information provided to consumers, so technical scalability and replicability are not applicable, but rather SRA of this use case should focus on regulatory aspects.

Therefore, technical SRA will focus on the use case of AGR.

Demo 4:

Demo 4 aims to improve the integration of DER based on the management of energy storage, controllable load (demand response) and participation of DG units in voltage control.

Technical SRA will be performed for the use cases of voltage control and anti-islanding protection. The use case of MV measurement acquisition can be considered as a pre-requisite for a more advanced grid operation that allows the implementation of the other use cases. The use case of demand response may be regarded as a specific case of the use case of voltage control, since controllable load is an additional source for voltage control. Hence, these two use cases are implicitly included in the technical SRA of voltage control in MV grids and Anti-islanding protection.

Demo 5:

The demo will test different solutions to improve reliability in MV and LV networks and to enable islanding of a section of the MV network. The three use cases defined will be subject to technical SRA.

Demo 6:

Demo 6 is focused on management of generation and demand balancing, testing the integration of PV generation and storage. Technical SRA will focus on the use cases of Islanding and Management of maximized PV production in LV. The use case of Reduction of power demand is more related to transmission and therefore has been discarded for technical SRA. Regarding the use case of Enhanced customer information, from the point of view of SRA, the effect of recruitment, demand response and amount of sheddable load will be implicitly studied for the other use cases as non-technical boundary conditions with an impact on the flexibility of the system and resulting KPIs and other indicators.

3.2 Application of Technical SRA Methodology to GRID4EU Use Cases

This section presents the particularization of the technical SRA methodology for each use case, providing a detailed description of the process to be carried out and the metrics computed to assess the impact of the use cases under different technical boundary conditions.

The section is structured into sub-sections for each Demo, with which in turn are sub-divided to present each relevant use case.

A summary of the main aspects of the application of the technical SRA methodology for the selected use cases of GRID4EU may be found in Annex A. The Annex displays a table with the metrics, simulation models and parameters for sensitivity analysis related to the technical SRA of each use case.

3.2.1 Demo 1

3.2.1.1 Use case 1.1: Load Control in MV Networks

The impact of this use case will be mainly observed on energy losses and improvement of quality of service (in terms of voltage profile, avoided overloads and therefore avoided disconnection of DG units). The KPIs and additional indicators that will be computed will be losses, voltage profile, overloads, disconnection of DG due to overload, network hosting capacity and number of switching operations performed.

The use case will be modeled and simulated. For this purpose, the demand and DG production forecasts and actual profiles will be generated. The distribution system will be modeled through a representative MV network.

The switching plan for network reconfiguration for the day-ahead will be designed. For this purpose, load flow analysis will be performed for the demand and DG forecasts, to determine the optimal switching at each period of the day-ahead, considering the presence of the MAS system. Then, the smoothing will be emulated to obtain the final switching plan.

Further load flow analysis will be performed for the actual generation and demand profiles to compute the KPIs and indicators mentioned above, first considering no switching plan and reconfiguration, and then considering that the designed switching plan is executed. Thus, the situation with the MAS without the MAS, where no reconfiguration is performed, can be compared qualitatively.

Forecasting errors will also be considered and their effect on the impact obtained by the MAS will be analyzed.

Scaling-up and replication

First, the scalability (in terms of density) of this use case will be analyzed by performing the simulation described above considering the variation of the following parameters:

- Density of the MAS: the number of M- and S- Agents will be increased to consider different scenarios of remote control and possibilities for reconfiguration of the grid
- Penetration of distributed generation (DG)

Considering these changes, different scenarios will be defined and the selected KPIs and additional indicators will be computed.

Intra-national replicability of the results will be studied with a special focus on the most important parameters:

- Type of network
This use case will be analyzed for other types of network with different types of grid architecture, which may correspond to different types of areas, varying aspects such as how meshed the networks are, length of feeders, load density, etc.
For this purpose, a set of different representative networks will be built, to represent the main architectures that may be found in Germany.
- Type of DG
The simulations and analysis will also be performed considering different types of DG, varying the size of DG units, the generation profiles for different technologies and the location of the DG units.

Then, the scope will be further broadened to consider international replicability. The parameters identified for Germany will differ for other countries. Therefore, the same parameters will be re-assessed to perform the previous steps of technical analysis:

- Type of network
Different networks representative for different countries will be included in the analysis. The networks in different countries may differ in architecture, voltage level, etc.
- Type of DG

The characteristics of the DG considered will be adapted to the situation of different countries (for instance, a higher number of small solar PV panels may be found in Germany, more scattered and evenly distributed, corresponding to domestic consumers with solar panels on their rooftops, while in Spain PV units will typically be more concentrated and have a larger size, corresponding to solar farms outside of population centers).

- Boundary conditions

The variations of the regulatory, economic and social context in each country will have an effect on the impact of the implementation of this use case. For instance, regulation regarding promotion of renewable energy sources may have a very important effect on the penetration of DG, installed technologies, typical size, etc. Furthermore, regulation towards losses may incentivize DSOs investment in reconfiguration to a different extent.

The diagram in Figure 4 summarizes the process of the technical analysis to be performed to evaluate the scaling-up and replication of the use case of load control in MV networks. The diagram shows the required inputs and tools for the analysis and the main outcomes of the process. Scaling-up and replication analyses will involve sensitivity analysis for the parameters listed in the green and purple boxes, respectively.

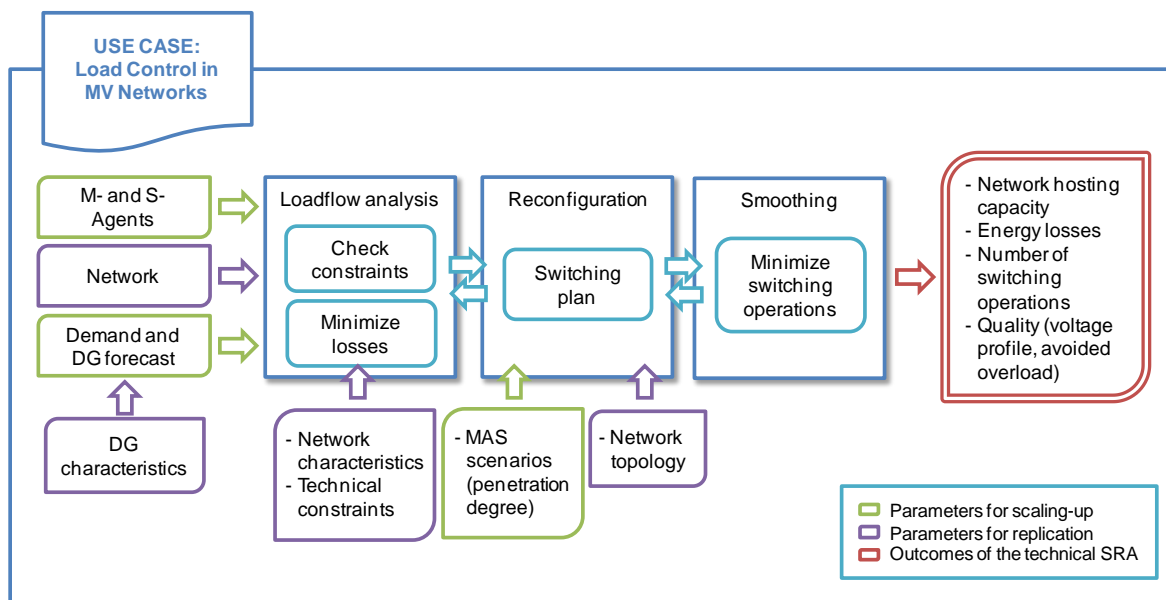


Figure 4: Technical analysis of scaling-up and replication for the use case of Load Control in MV Networks.

3.2.1.2 Use case 1.2: Failure Management in MV Networks

The impact of this use case will be mainly observed on the time required for service restoration when a permanent fault occurs in the MV network. Within the technical SRA, this use case will be simulated in order to quantify the impact of the MAS implemented and the resulting KPIs with and without the MAS.

For this purpose, the MV network will be modeled through a representative network comprising a few MV feeders. All possible faults that may occur in the MV network will be simulated. The process of service restoration will be simulated for each of these faults to compute the time required to restore service for each secondary substation considering the steps of fault localization, fault isolation and service restoration.

In the case with the MAS, the fault will be located taking the data provided by the M-agents into account and isolated among the two closest S-elements. A new reconfiguration for the network will be proposed to restore service to as much load as possible. Load flow analysis will be performed to check that the proposed configuration complies with all technical restrictions.

For the remaining secondary substations, or for all substations in the case without the MAS, the manual, sequential process for fault localization, isolation and service restoration will be simulated, considering the steps required for maintenance crews and computing the time required at each step to restore service for the corresponding secondary substations.

The number of interruptions and interruption time may be obtained for each consumer and power using the computed interruption time for each secondary substation at occurrence of each fault and considering the fault rates of the different elements to weigh all the different faults that have been simulated. Finally, overall reliability indices will be computed for the system, with and without the MAS, to compare both sets of values and thus determine the effect of implementing this use case.

Scaling-up and replication

The technical SRA analysis will be performed in a very similar way to the SRA for the use case of Load Control in MV Networks.

First, the scalability of this use case will be analyzed by performing the simulation described above considering the variation of the following parameters:

- Density of the MAS: the number of M- and S- Agents will be increased to consider different scenarios of degree of monitoring and remote control of the grid

Considering these changes, different scenarios will be defined and the selected KPIs will be computed.

Replicability of the results will be studied with a special focus on the most important parameters:

- Type of network
This use case will be analyzed for other types of network with different types of grid architecture, which may correspond to different types of areas, varying aspects such as how meshed the networks are, length of feeders, load density, etc.
- Reliability levels considering failure rates
Additionally, sensitivity to failure rates of the elements of the networks will be studied, including failure rate of MV feeders. The parameter of failure rate can account for the effect of age of the network (typically, older networks will suffer from

higher failure rates) and for the effect of different reliability levels due to different external conditions (typically, poorer reliability levels may be expected under very extreme weather conditions or in areas where there are street works in progress), etc.

The analysis previously introduced will enable the evaluation of scalability at a wider scope, even at a national level, considering the variability of the previously described aspects within the country and using the representative networks.

Then, the scope will be further broadened to consider international replicability. The parameters identified for Germany will differ for other countries. Therefore, the same parameters will be re-assessed to perform the previous steps of technical analysis:

- Type of network
Different networks representative for different countries will be included in the analysis.
- Demand and feed-in profiles
The characteristics of the DG considered will be adapted to the situation of different countries and characteristic generation and demand profiles will be considered for each type of distribution area of other countries.
- Boundary conditions
The variations of the regulatory, economic and social context in each country will have an effect on the impact of the implementation of the use case of failure management in MV networks. For instance, regulation regarding quality of supply will specifically have a very important effect on the focus of the MAS implemented by DSOs. Regulatory incentives for reliability improvement will affect on whether to invest on higher reliability in different types of areas or for different types of consumers (e.g. using load based indices such as ASIDI and ASIFI instead of consumer based indices such as SAIDI and SAIFI will probably drive the priorities for DSOs to invest on MAS in areas with large consumers, rather than on areas with a higher number of smaller consumers).

The diagram in Figure 5 summarizes the process of the technical analysis to be performed to evaluate the scaling-up and replication of the use case of failure management in MV networks. The diagram shows the required inputs and tools for the analysis and the main outcomes of the process. Scaling-up and replication analyses will involve sensitivity analysis for the parameters listed in the green and purple boxes, respectively.

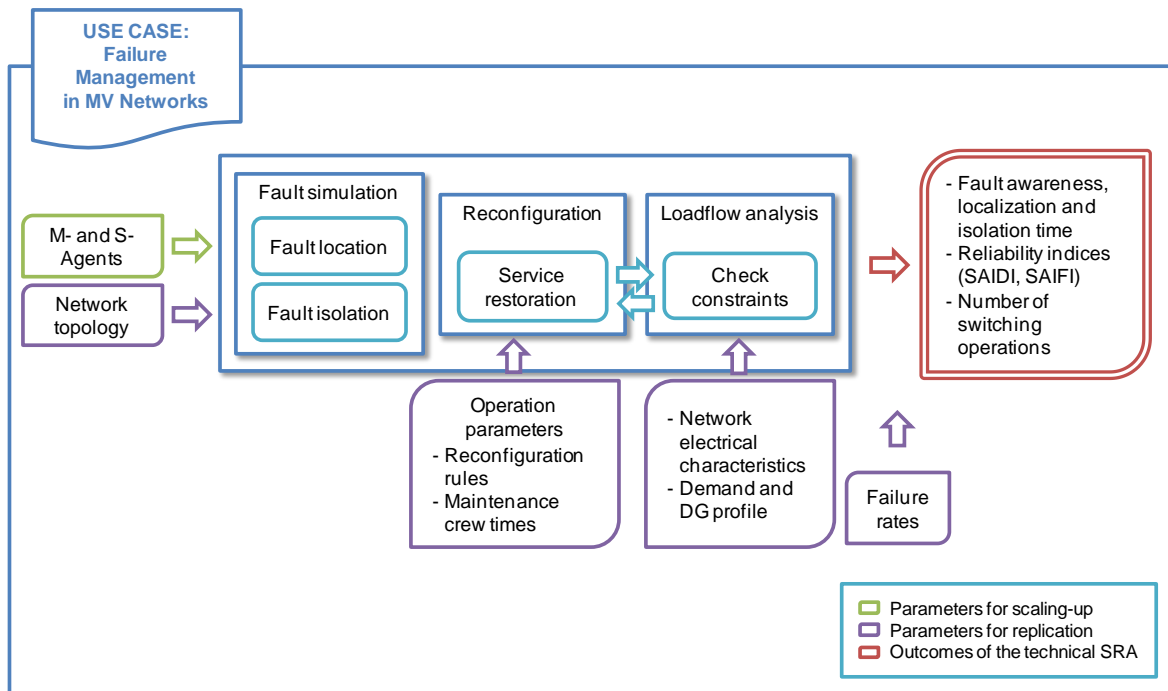


Figure 5: Technical analysis of scaling-up and replication for the use case of Failure Management in MV Networks.

3.2.2 Demo 2

3.2.2.1 Use case 2.1: Voltage Control in LV Networks

The technical SRA analysis of LV Network Monitoring and Control aims to determine the conditions and penetration degree of distributed resources connected to the LV grid that may cause operation problems and therefore would require monitoring the network.

Therefore, the indicators to be used for technical SRA are voltage profile and network loading, in order to detect overloads in conductors and transformers of secondary substation, disconnection of DG due to overload and network hosting capacity.

These indicators will be computed performing load flow analysis for a LV representative network, simulating different scenarios of distributed resources connected to the grid, mainly focusing on the penetration of PV panels and EVs in the LV network.

Scaling-up and replication

Scalability will be analyzed in terms of penetration of distributed resources connected to the grid, namely DG and EVs.

Replication will be addressed by further load flow analysis performed for different representative networks. For instance, for more rural areas, a representative LV network will have to feed larger areas under more extreme weather conditions, and DER connected to such

network may include larger DG units. Therefore, the analysis above described will be performed considering the variation of parameters including:

- Type of network
This use case will be analyzed for other types of network with different types of grid architecture, which may correspond to different types of areas, varying aspects such as how meshed the networks are, length of feeders, load density, etc.
For this purpose, a set of different representative networks will be built, to represent the main architectures that may be found in Sweden.
- DER characteristics
The simulations and analysis will also be performed considering different types of DG, varying the size of DG units, the generation profiles for different technologies and the location of the DG units. Moreover, the use of EVs may differ for different areas, where transportation habits and distances are different. Consequently, different generation and demand profiles will be analyzed.

Then, the scope will be further broadened to consider replicability from an international perspective. The parameters identified for Sweden will differ for other countries. Therefore, the same parameters will be re-assessed to perform the previous steps of technical analysis:

- Type of network
Different networks representative for different countries will be included in the analysis. The networks in different countries may differ in architecture, voltage level, etc.
- DER characteristics
The characteristics of the DG and uses of EVs considered will be adapted to the situation of different countries (for instance, the production of solar PV panels will be very different to those located in Spain).
- Boundary conditions
The variations of the regulatory, economic and social context in each country will have an effect on the impact of the implementation of this use case. For instance, regulation regarding promotion of renewable energy sources may have a very important effect on the penetration of DG, installed technologies, typical size, etc.

The diagram in Figure 6 illustrates the process of the technical analysis to be performed to evaluate the scaling-up and replication of the use case of LV monitoring and control of Demo 2. The diagram shows the required inputs and tools for the analysis and the main outcomes of the process. Scaling-up and replication analyses will involve sensitivity analysis for the parameters listed in the green and purple boxes, respectively.

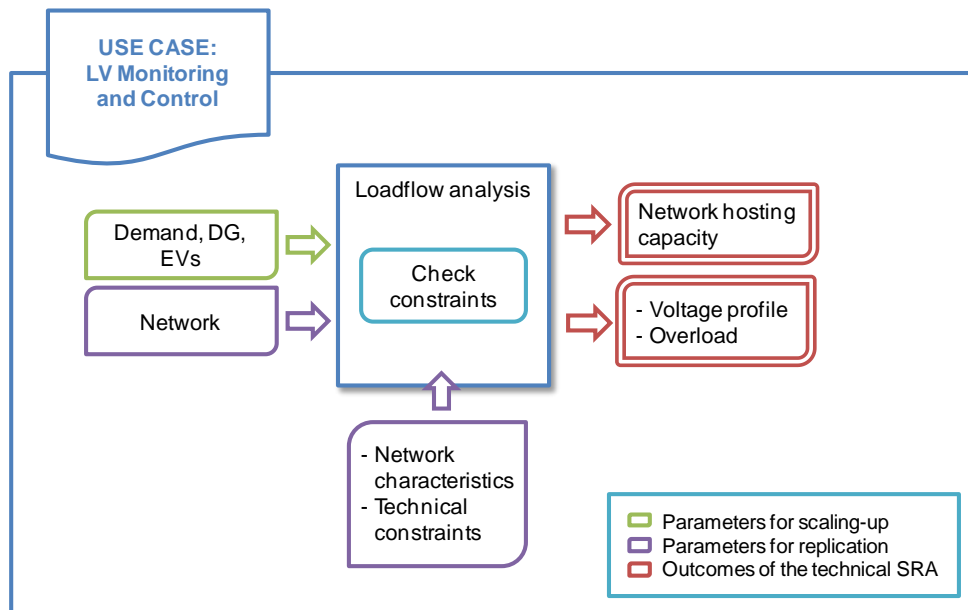


Figure 6: Diagram of technical SRA methodology for Demo 2.

3.2.3 Demo 3

3.2.3.1 Use case 3.1: Automatic Grid Recovery

The impact of this use case will be mainly on the time required for service restoration when a permanent fault occurs in the MV network. Consequently, the metrics selected for the technical SRA of this use case are related to continuity of supply, that is, number and duration of interruptions of supply.

Within the technical SRA, this use case will be simulated in order to quantify the impact of the AGR system implemented and the resulting KPIs with and without the AGR use case.

For this purpose, the MV network will be modeled through a representative network comprising a few MV feeders. All possible faults that may occur in the MV network will be simulated. The process of service restoration will be simulated for each of these faults to compute the time required to restore service for each secondary substation considering the steps of fault localization, fault isolation and service restoration.

In the case with the AGR system, the fault will be located and isolated among the two closest AGR elements. A new reconfiguration for the network will be proposed to restore service to as much load as possible. Load flow analysis will be performed to check that the proposed configuration complies with all technical restrictions.

For the remaining secondary substations, or for all substations in the case without the AGR system, the process for fault localization, isolation and service restoration that would be performed by maintenance crews will be simulated. The time required at each step will be computed, considering the sequences of the process, travelling, manual operation and reparation to be performed by maintenance crews. The number of interruptions and interruption

time may be obtained for each consumer and power using the computed interruption time for each secondary substation at occurrence of each fault and considering the fault rates of the different elements to weigh all the different faults that have been simulated. Finally, overall reliability indices will be computed for the system, with and without the AGR system, to compare both sets of values and thus determine the effect of implementing this use case.

Scaling-up and replication

First, the scalability of this use case will be analyzed from the perspective of scalability in density of the implemented solution. The simulation described above will be performed considering the variation of the following parameters:

- Implementation degree of the AGR system: the number of monitored and telecontrolled elements will be increased to consider different scenarios of degree of automation in the grid

Considering these changes, different scenarios will be defined and the selected KPIs will be computed.

Replicability of the results will be studied with a special focus on the most important parameters:

- Type of network
This use case will be analyzed for other types of network with different types of grid architecture, which may correspond to different types of areas, varying aspects such as how meshed the networks are, length of feeders, load density, etc.
- Reliability levels considering failure rates
Additionally, sensitivity to failure rates of the elements of the networks will be studied, including failure rate of MV feeders. The parameter of failure rate can account for the effect of age of the network (typically, older networks will suffer from higher failure rates) and for the effect of different reliability levels due to different external conditions (typically, poorer reliability levels may be expected under very extreme weather conditions or in areas where there are street works in progress), etc.

The analysis previously introduced will enable the evaluation of scalability at a wider scope, even at a national level, considering the variability of the previously described aspects within the country and using the representative networks.

Then, the scope will be further broadened to consider international replicability. The parameters identified for Spain will differ for other countries. Therefore, the same parameters will be re-assessed to perform the previous steps of technical analysis:

- Type of network
Different networks representative for different countries will be included in the analysis.
- Type of DG
The characteristics of the DG considered will be adapted to the situation of different countries.

- Boundary conditions

The variations of the regulatory, economic and social context in each country will have an effect on the impact of the implementation of the use case of failure management in MV networks. For instance, regulation regarding quality of supply will specifically have a very important effect on the focus of the AGR system implemented by DSOs. Regulatory incentives for reliability improvement will affect on whether to invest on higher reliability in different types of areas or for different types of consumers (e.g. using load based indices such as ASIDI and ASIFI instead of consumer based indices such as SAIDI and SAIFI will probably drive the priorities for DSOs to invest on MAS in areas with large consumers, rather than on areas with a higher number of smaller consumers).

The diagram in Figure 5 summarizes the process of the technical analysis to be performed to evaluate the scaling-up and replication of the use case of failure management in MV networks. The diagram shows the required inputs and tools for the analysis and the main outcomes of the process. Scaling-up and replication analyses will involve sensitivity analysis for the parameters listed in the green and purple boxes, respectively.

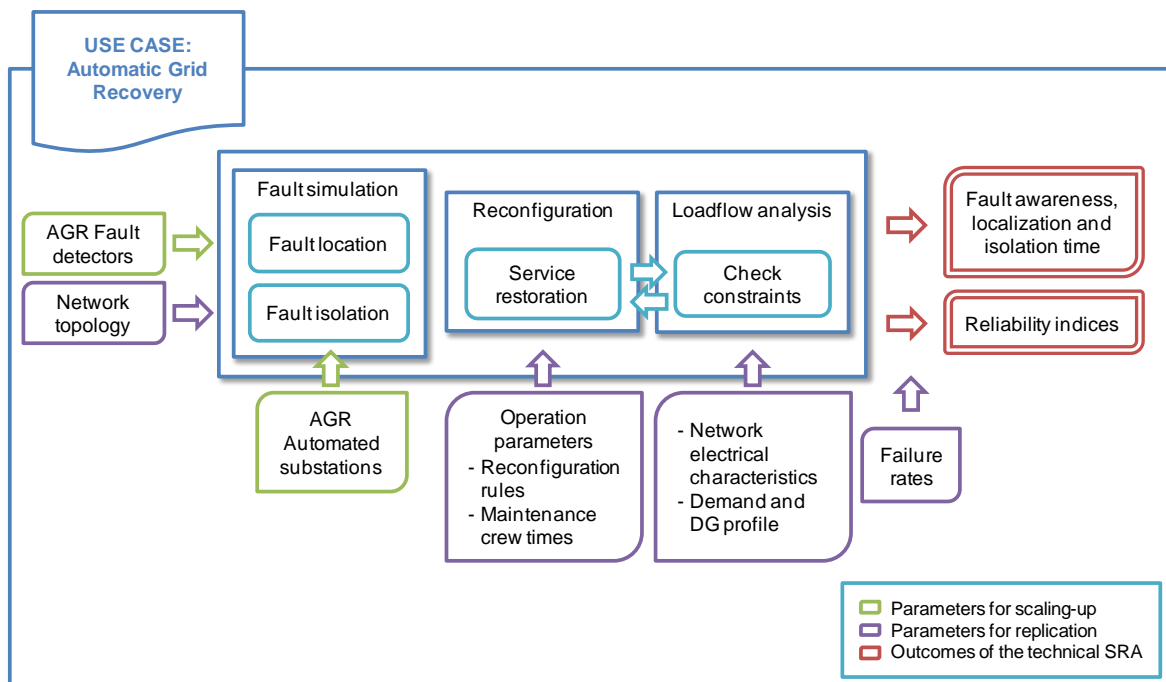


Figure 7: Technical analysis of scaling-up and replication for the use case of Automatic Grid Recovery.

3.2.4 Demo 4

3.2.4.1 Use case 4.1: Voltage Regulation in MV Networks

The impact of this use case will be mainly observed on voltage profile, energy losses and network hosting capacity. Network availability will be assessed in terms of curtailed active power generation from DG and load shifted and curtailed.

Therefore the KPIs and metrics that will be computed and compared for different simulation scenarios include energy losses, network hosting capacity, voltage profile, network availability, demand response, avoided overload, load curtailed and active DG power curtailed.

The MV network will be modeled by means of representative networks. A set of baseline scenarios will be defined, considering the characteristic load and generation profiles. Load flow analysis will be performed to compute voltage profiles, active and reactive power flows and energy losses in the system. Whenever violations of voltage constraints or overloads are identified, the adequate corrective actions will be determined by an OPF. In order to compare the situation where there is no smart grid use case implemented, first the corrective actions considered include only operating OLTC transformers of primary substations. Then, to model the cases where the use case is implemented, the corrective actions considered will also include, additionally to operating OLTC transformers of primary substations, changing DG reactive set-points, changing the storage charge or discharge rate and the curtailment of controllable loads will also be included. In both cases, the optimal voltage control strategy will be determined. The values of the KPIs energy losses and voltage line profile will be computed performing further load flow analysis for the scenarios where the designed strategies are put in place. The analysis will also consider and compare results obtained for different response rates of DG and consumers. Comparing no use case and use case results, avoided overvoltages and a quantification of the load and DG curtailed will also be obtained, as indicators of the impact of this use case. Network hosting capacity will be assessed by increasing the considered amount of DG to identify the level of DG that causes problems in the network.

Scaling-up and replication

First, the scalability (in terms of density) of this use case will be assessed considering different amounts of available flexibilities from load, DG and storage, different DG penetration degrees, etc. The variation of the following parameters will be considered:

- Volume of DG
Higher penetration degree of DG will also be considered, including different technologies, which will have different characteristics in terms of controllability and reactive margins. The effect of the location of DG will also be analyzed.
- Volume of storage
The number of batteries will be increased to assess higher volumes of storage. New locations will be considered for these batteries, to analyze effect of more disperse or concentrated storage capacity, locations near the head of the feeder or downstream, farther from the primary substation, etc.

Similarly, storage capacity will be increased by considering different charge and discharge rates, as well as different sizes of the storage units.

- Volume of controllable load
Different controllable loads will be considered, considering variations of size, number of consumers (or supply points) and different types of load (for instance, electric heating, smart appliances such as programmable washing machines, etc.)

Considering these changes, new sets of scenarios will be defined and the selected KPIs and additional indicators will be computed again.

Intra-national replicability of the results will be studied with a special focus on the most important parameters:

- Type of network
This use case will be analyzed for other types of network with different types of grid architecture, which may correspond to different types of areas, varying aspects such as how meshed the networks are, length of feeders, load density, etc.
For this purpose, a set of different representative networks will be built, to represent the main architectures that may be found in Italy.
- Type of DG
The simulations and analysis will also be performed considering different types of DG, varying the size of DG units, the generation profiles for different technologies and the location of the DG units, according to the different characteristic DG that may be found in different areas of the country.

Then, the scope will be further broadened to consider international replicability. The parameters identified for Italy will differ for other countries. Therefore, the same parameters will be re-assessed to perform the previous steps of technical analysis:

- Type of network
Different networks representative for different countries will be included in the analysis. The networks in different countries may differ in architecture, voltage level, etc.
- Type of DG
The characteristics of the DG considered will be adapted to the situation of different countries (for instance, solar PV panels in Germany or Sweden may produce less energy than PV panels in Italy).
- Boundary conditions
The variations of the regulatory, economic and social context in each country will have an effect on the impact of the implementation of this use case. For instance, regulation regarding promotion of renewable energy sources may have a very important effect on the penetration of DG, installed technologies, typical size, etc.

The diagram in Figure 4 summarizes the process of the technical analysis to be performed to evaluate the scaling-up and replication of the use case of failure management in MV networks. The diagram shows the required inputs and tools for the analysis and the main outcomes of the process. Scaling-up and replication analyses will involve sensitivity analysis for the parameters

listed in the green and purple boxes, respectively.

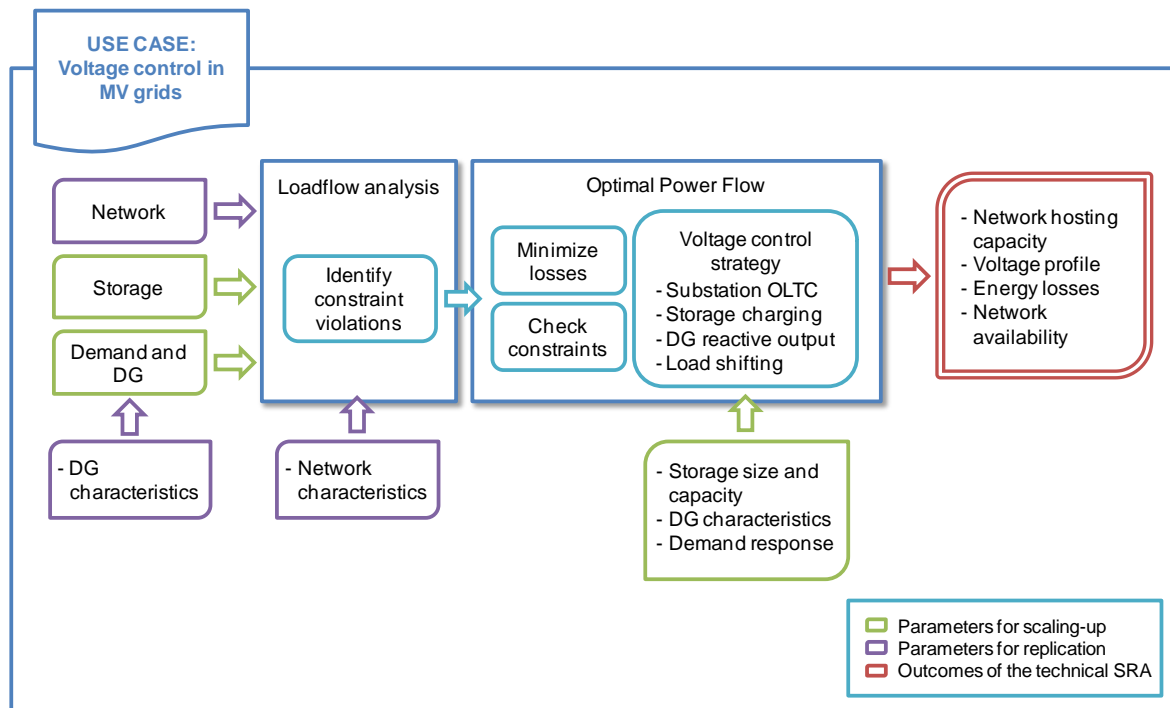


Figure 8: Technical analysis of scaling-up and replication for the use case of voltage control in MV grids.

3.2.4.2 Use case 4.2: Anti-islanding Protection

This use case consists in the implementation and testing of an advanced protection scheme through which DG units connected to the MV grid would be automatically disconnected in case the primary substation breaker trips. The technical analyses for scalability and replicability analyses will focus on the effects of a failure in such a scheme under different scenarios of load and generation. The purpose is to determine the conditions under which an island would be formed and identify excessive frequency and voltage deviations by studying the dynamics on the MV voltage grid after the tripping of the substation breaker that may cause safety hazards or cause damage to equipment.

The MV network will be modeled by means of a reference network. Dynamic simulation will be performed and the response of the system will be studied considering a very small time step to monitor voltage and frequency values, identifying cases where unintentional islands could be sustained over time and, in that case, the potential negative consequences. In order to do this, dynamic models of the batteries, loads and DG units will be used.

Scaling-up and replication

First, scalability (in terms of density) of the use case of anti-islanding protection will be

assessed by performing the simulation and analysis process described above considering the variation of the following parameters:

- Penetration level of DG
- Storage
 - Number of batteries connected to the MV network (considering new locations) and storage capacity of the batteries

Considering these changes, the probability of unintentional islanding will be re-assessed, to evaluate the conditions under which this undesirable situation could arise. Additionally, potentially damaging frequency and voltage deviations will be identified for all cases.

Then, similar analyses will be carried for other types of network, using other representative networks as for the previous use case. The different networks will have different technical characteristics, such as feeder length, characteristics of the conductors, load density, etc. This replicability analysis will determine whether the results obtained are expected to be significantly affected by the network characteristics.

Finally, different boundary conditions will be considered to assess replicability at an international level. The typical values of network, generation and demand parameters will be different for different countries. Replication analysis will deal with these issues performing the previous steps for different urban, sub-urban and rural networks.

The diagram in Figure 5 summarizes the process of the technical analysis to be performed to evaluate the scaling-up and replication of the anti-islanding protection use case. The diagram shows the main inputs and simulation tools required for the analyses together with the most relevant outputs. Scaling-up and replication analyses will involve sensitivity analysis for the parameters listed in the green and purple boxes, respectively.

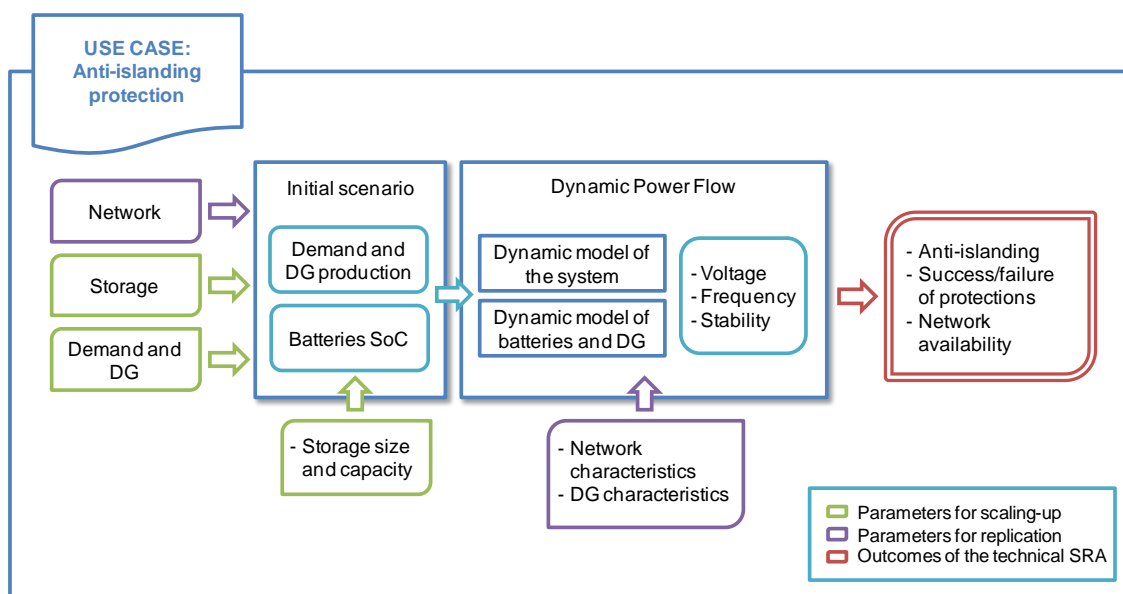


Figure 9: Technical analysis of scaling-up and replication for the use case of islanding.

3.2.5 Demo 5

3.2.5.1 Use case 5.1: MV Automation

The objective of this use case is to improve the fault management in MV networks so that interruptions of supply affect a lower number of consumers and interruption times are decreased. For this purpose, different elements are implemented in order to locate and isolate the fault and to achieve a reconfiguration of the network to restore service, including secondary substations equipped with fault detectors and remotely controlled load breakers and secondary substations at disconnection points with remotely controlled switches and IEDs.

The technical SRA for the use case of MV automation will be based on a model of the system where all possible faults in the MV line will be simulated and the corresponding KPIs will be computed, first in the case of no automation and then considering the implemented smart grid solution of MV automation.

For each fault, the time required to restore service for each consumer will be assessed, considering all automatic and manual actions required and available reconfiguration options. Load flow analysis is performed to check the validity of the reconfiguration. Finally, overall reliability indices SAIDI and SAIFI will be computed for the system considering fault rates of the different elements to weigh all the different faults that have been simulated.

Scaling-up and replication

First, the scalability (in terms of density) of this use case will be analyzed by performing the simulation described above considering the variation of the following parameters:

- Number of disconnection points
The number of secondary substations with disconnection points will be increased/decreased to assess the effect of a higher/lower implementation degree of the tested solution.
- Number of fault indicators
The number and location of fault indicators will also be varied to assess its impact.
- Automation degree
The implementation of the use case of MV automation in Demo 5 includes telecontrol in all secondary substations. In order to assess scalability, technical SRA will also consider scenarios where only some of the secondary substations allow telecontrol.

Considering these changes, different scenarios will be defined and the selected KPIs and additional indicators will be computed.

Intra-national replicability of the results will be studied with a special focus on the most important parameters:

- Type of network

This use case will be analyzed for other types of network with different types of grid architecture, which may correspond to different types of areas, varying aspects such as how meshed the networks are, elements that allow for switching and reconfiguration, length of feeders, load density, etc.

- Reliability levels

Sensitivity analyses will be performed considering different time requirements in the process of fault management. Additionally, sensitivity to failure rates of the elements of the networks will be studied, including failure rate of MV feeders. The parameter of failure rate can account for the effect of age of the network (typically, older networks will suffer from higher failure rates) and for the effect of different reliability levels due to different external conditions (typically, poorer reliability levels may be expected under very extreme weather conditions or in areas where there are street works in progress), etc.

The model of the network will be based on representative networks. A set of networks, each comprised by a few feeders will be built to represent the characteristics of actual networks. For instance, MV networks in the Czech Republic could be represented for the purpose of SRA in GWP3 of GRID4EU by two categories: urban and rural. Sensitivity will be performed changing the technical parameters of the different representative networks.

Then, the scope will be further broadened to consider international replicability. The parameters identified for the Czech Republic will differ for other countries. Therefore, the same parameters will be re-assessed to perform the previous steps of technical analysis:

- Type of network

Different networks representative for different countries will be included in the analysis. The networks in different countries may differ in architecture, voltage level, automation degree and level of protection and switching elements, etc.

- Boundary conditions

The variations of the regulatory, economic and social context in each country will have an effect on the impact of the implementation of this use case. For instance, regulation with strong incentives for continuity of supply improvement may have a very important effect on the penetration of automation technologies or may foster a more meshed network topology.

The diagram in Figure 4 summarizes the process of the technical analysis to be performed to evaluate the scaling-up and replication of the use case of MV automation. The diagram shows the simulation process, the required inputs and tools for the analysis, and the main outcomes of the process, which are the values of the KPIs, represented in the orange boxes. Scaling-up and replication analyses will involve sensitivity analysis for the parameters listed in the green and purple boxes, respectively.

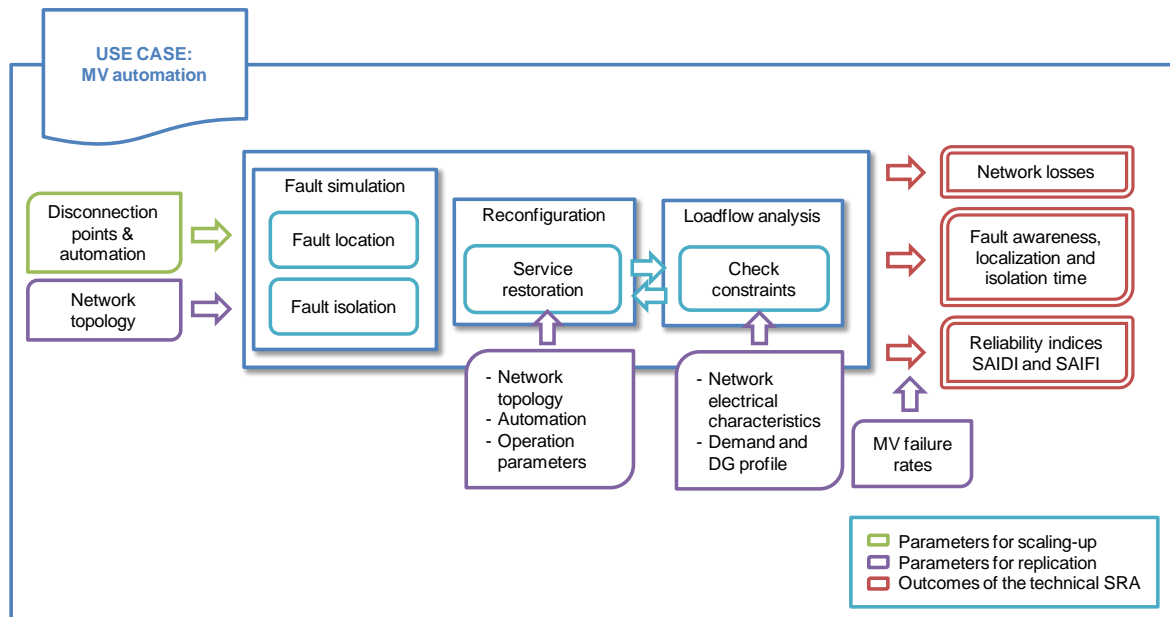


Figure 10: Technical analysis of scaling-up and replication for the use case of MV automation.

3.2.5.2 Use case 5.2: LV Automation

Similarly to the previous use case, the objective of this use case is to improve the fault management. However, this use case is focused on LV networks, where automated LV cabinets are implemented.

The methodology proposed for the use case of LV automation is very similar to the methodology for the use case of MV automation. The network will be modeled and faults will be simulated to compute values of KPIs: SAIDI, SAIFI and fault awareness, localization and isolation time.

Scaling-up and replication

First, the scalability (in terms of density) of this use case will be analyzed considering the variation of the degree of accessible cabinets and the degree of telecontrol in the LV network. Considering these changes, different scenarios will be defined and the selected KPIs and additional indicators will be computed.

In the same way as for the use case of MV automation, intra-national replicability of the results will be studied using LV representative networks. The parameters considered will include:

- Type of LV networks
Different types of LV networks may be found in different areas. These networks may differ in grid architecture (networks may be strictly radial or may have a different degree of meshing), length of feeders, load density, etc.
- Reliability levels
Again, sensitivity to failure rates of the LV lines and service and operation time for manual service restoration will be studied.

The analysis previously introduced will enable the evaluation of scalability at a wider scope, even at a national level, considering the variability of the previously described aspects within the country.

Then, the scope will be further broadened to consider international replicability. The parameters identified for the Czech Republic will differ for other countries. Therefore, the same parameters will be re-assessed to perform the previous steps of technical analysis:

- Type of network
Different networks representative for different countries included in the analysis.
- Boundary conditions
The variations of the regulatory, economic and social context in each country will have an effect on the impact of the implementation of the use case of failure management in LV networks. For instance, regulation regarding quality of supply will specifically have a very important effect on the focus of the solution implemented by DSOs. Regulatory incentives for reliability improvement will affect on whether failures at LV are included in the reliability indicators used in regulators and thus the incentives for DSOs of implementing such a solution.

The diagram in Figure 5 summarizes the process of the technical analysis to be performed to evaluate the scaling-up and replication of the use case of LV automation. The diagram shows the required inputs and tools for the analysis and the main outcomes of the process. Scaling-up and replication analyses will involve sensitivity analysis for the parameters listed in the green and purple boxes, respectively.

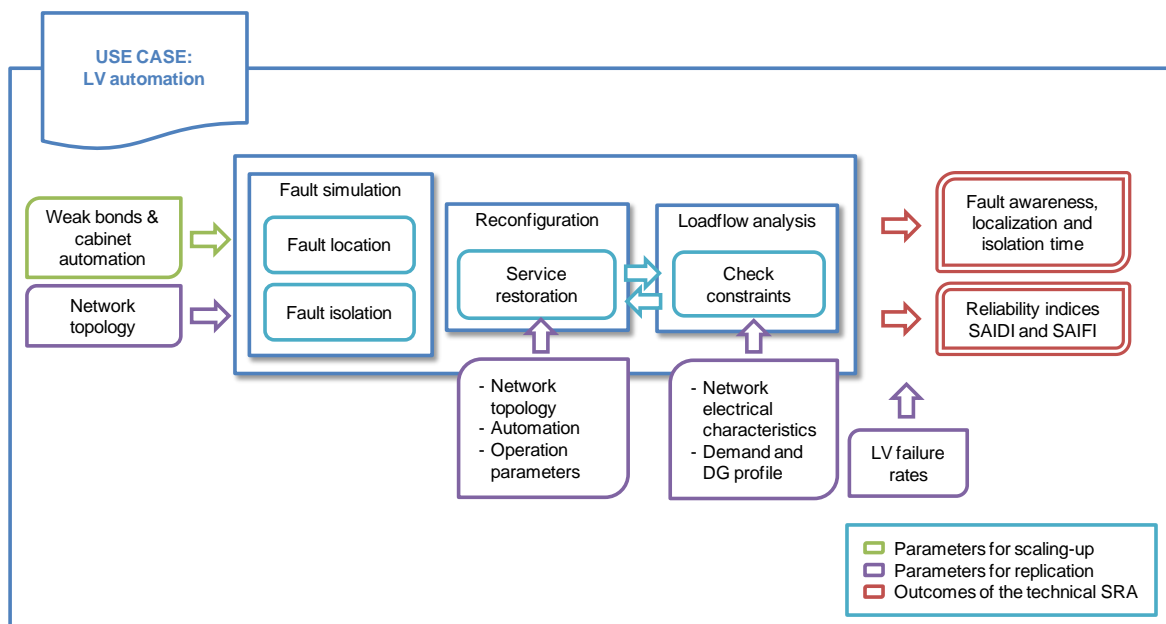


Figure 11: Technical analysis of scaling-up and replication for the use case of LV automation.

3.2.5.3 Use case 5.3: Islanded operation

In the demo, islanding will be tested in a portion of the MV network that can be disconnected from the grid and isolated by operating two automated disconnection points. The islanded operation will be triggered by the event of a fault in the MV that would supply the island area under normal operation conditions. Thanks to the activation of the islanded operation mode, the island is not affected by faults in segments of the MV feeder upstream or downstream the disconnection points. The activation of islanding will be performed only if conditions are favorable and balancing of generation and demand will be achieved through the control of the 1.6 MW CHP unit and controllable load of 200 kW. If necessary, load may be curtailed by disconnecting any of the LV feeders downstream the secondary substations of the island.

The MV network that constitutes the island will be modeled by means of a representative network and islanding will be simulated using a power flow tool to analyze the dynamics of the island. This way, balance is assessed in terms of frequency, stability, voltage profile and active and reactive power flows to check that no congestions or overloads appear in the network. The sequence of required balancing actions will be determined and simulated, including control of the active and reactive power output of the CHP, the connection/disconnection of the controllable load of electric boilers, and the disconnection of LV feeders in case of need.

Load and generation will also be modeled into different scenarios to account for the different conditions of the network, resulting in different actions required, which in turn, will be modeled by new generation and demand scenarios.

The simulation will assess the probability of success of islanding, computing the indicators voltage deviation during islanding, frequency deviation and volume of curtailed load.

Additionally, the expected improvement in reliability achieved by this use case will be evaluated. Thanks to islanding, consumers supplied by the island will not be affected in case of a fault in the section of the MV network that is out of the island area, so that the corresponding load will not be lost and the overall reliability indices of the MV network will be improved.

Scaling-up and replication

Scaling-up and replication will be based on sensitivity analyses of the KPIs and additional indicators computed by the simulation model to the relevant technical parameters that represent the variation of boundary conditions according to the different dimensions of scalability and replicability analyzed.

First, scalability of the use case of islanded operation will be considered in terms of density by considering an increasing degree of the two main sources of flexibility for balancing generation and demand:

- DG size and penetration degree
Simulation will be performed to assess the probability of successful islanding and the effect on the balancing actions required and values of the above mentioned indicators when having a different volume of DG to supply the demand within the island, considering DG with the ability to provide reactive power.
- Demand flexibility

Similarly to the case of DG, different volumes of controllable load will be considered

Scalability in terms of size will also be addressed by considering larger areas for islanding. Simulation will be performed to assess the effects of having more secondary substations included in the island, computing the selected KPIs and indicators to assess balancing requirements for successful islanding and reliability improvement.

Replicability of the results will be studied with a special focus on the most important parameters:

- **Type of network**
This use case will be analyzed for other types of network with different types of grid architecture and topology, which may correspond to different types of areas. The different architecture will directly affect the reliability improvement that may be achieved by activating the islanded operation. Furthermore, the effect of having different network characteristics within the islanded portion of the grid will be assessed, considering variations in aspects such as length of feeders, load density, etc. Additionally, load curtailment will be assessed considering different configurations of the downstream load for secondary substations.
- **Characteristics of DG**
Islanding will only be successful if the load can be supplied by DG production connected in the island. The effect of having DG units with different characteristics for aspects such as inertia and active and reactive output controllability will be assessed.

Different values for these parameters will be simulated and the new values for the KPIs and additional indicators will be computed to quantify the effect of the variation of these boundary conditions.

The analysis previously introduced will enable the evaluation of scalability at a wider scope, even at a national level, considering the variability of the previously described aspects within the country.

Then, the scope will be further broadened to consider international replicability. The parameters identified for the Czech Republic will differ for other countries. Therefore, the same parameters will be re-assessed to perform the previous steps of technical analysis:

- **Type of network**
Different networks representative for different countries included in the analysis.
- **Type of DG**
The characteristics of the DG considered will be adapted to the situation of different countries.
- **Boundary conditions**
The variations of the regulatory, economic and social context in each country will have an effect on the impact of the implementation of the use case of islanded operation.

The diagram in Figure 5 summarizes the process of the technical analysis to be performed to evaluate the scaling-up and replication of the use case of islanded operation. The diagram shows the required inputs and tools for the analysis, as well as the main outcomes of the process in orange. Scaling-up and replication analyses will involve sensitivity analysis for the parameters listed in the green and purple boxes, respectively.

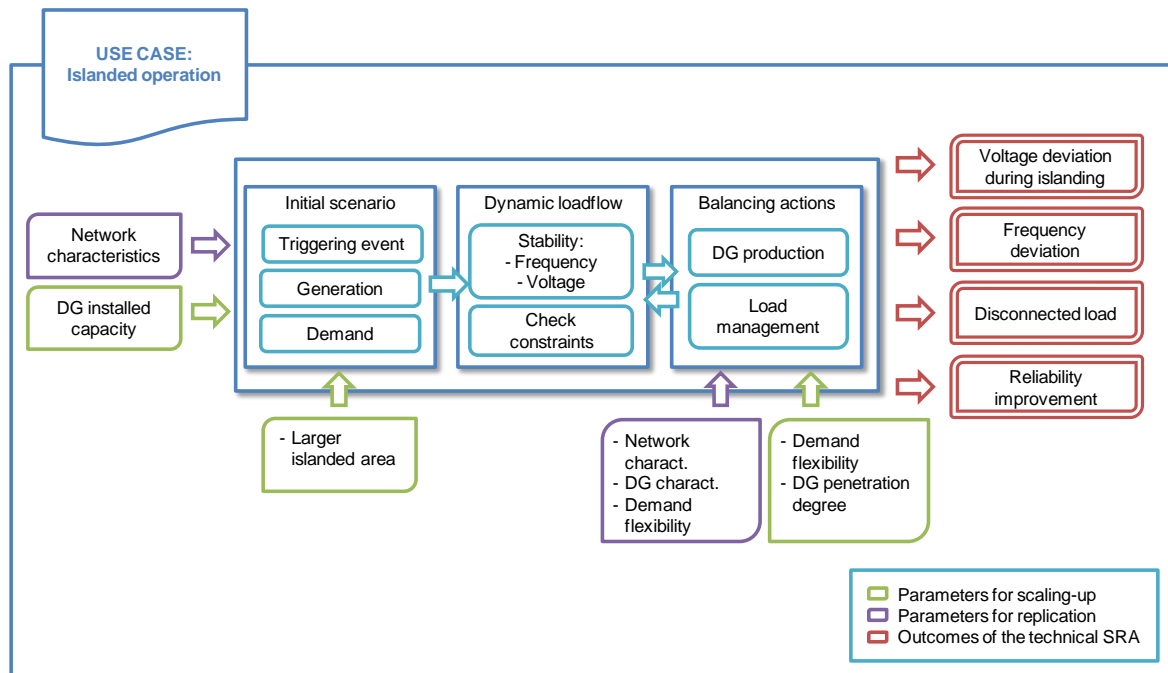


Figure 12: Technical analysis of scaling-up and replication for the use case of islanded operation.

3.2.6 Demo 6

3.2.6.1 Use case 6.1: Islanding

In the demo, islanding will be activated by disconnecting a MV/LV substation from the MV grid, so that the LV network downstream is supplied by local PV and storage during a period of a few hours. Then, the island will be re-connected, restoring normal operation.

For the technical SRA, the LV network will be modeled by means of a reference network. In order to simulate islanding of the LV representative network² and compute the indicators to assess the technical impact of this use case, load flow analysis will be performed to evaluate the voltage profile and the active and reactive power flows, checking whether congestions or overloads appear in the network, and dynamic load flow analysis will be used to evaluate the behavior during the connection and disconnection of the island to and from the MV grid, evaluating frequency and voltage stability. Load and generation will be modeled through a set of different scenarios that will be generated to account for the different conditions of the network, taking into account the possible values for SoC of batteries, demand from consumers and production of PV units.

² Please refer to section 6 for a definition of representative feeders for GRID4EU project

The process of technical analysis will be as follows. First, the initial scenarios of batteries SoC, demand and generation are analyzed. The NEM and NBA will be modeled to simulate the decision process of islanding (i.e. connection and disconnection from the grid) and the charging and discharging of batteries. Islanding is modeled by simulating the disconnection of the MV/LV substation and performing a dynamic load flow analysis to evaluate the stability of the system, considering the initial scenario and the dynamic behavior of the elements of the network (generation units, storage units, loads and the conductors). The response of the system will be studied considering a very small time step to control that voltage and frequency values remain within their admissible limits at all times, identifying cases of voltage sags or instability if any. Additionally, the dynamic simulation will focus on the reconnection of the island to the grid. This analysis will be necessary for the computation of the islanding KPI as well as reconnection success and frequency deviation.

During islanding in stationary, stable operation, load flow analysis will assess voltage profiles and power flows in the network. Whenever congestions or other restriction violations are detected, the NEM model will elaborate the strategy for triggering the required flexibilities, including management of the battery to reduce or increase demand and required load shedding or PV curtailment, if necessary.

A simplified model of the batteries will be developed to determine the SoC at all times, considering its electrical parameters: maximum charge/discharge rate, efficiency, losses, impact of temperature, lifecycle, etc. This information that may be obtained from manufacturers and approximate efficiency and loss functions may be developed.

Demand forecasting will be considered as an input data, and different rates of error may be considered to assess its impact on the operation of the system in real time. Additionally, PV production will be simulated, considering the forecast of PV and different error rates.

The load flow analysis performed for the corresponding scenarios will result in the computation of the islanding and load shedding KPIs. Additionally, the additional indicators successful duration of islanding, amount of load shed and avoided interruptions will be computed.

The analysis will consider islanding not only under programmed, favorable conditions, but also during network congestions, preventive and non-programmed corrective maintenance, etc.

Scaling-up and replication

First, scalability in terms of density of the use case of islanding will be assessed by performing the simulation and analysis process described above considering the variation of the following parameters:

- Storage
The number of batteries connected to the LV network (considering new locations) will be varied. Storage capacity of the batteries connected to the LV network and the battery in the MV/LV substation will be also increased.
- Higher penetration degree of PV
During islanding in the Demo, PV may be disconnected to avoid problems in the network. Nevertheless, SRA will consider different volumes of PV connected to the grid for simulation to understand the impact of having higher volumes of PV generation available to balance generation and demand.

Considering these changes, the values of the indicators will be re-assessed: the maximum duration of islanding will be computed, to check how much storage may be required to enable longer duration of islanding under different volumes of available DG production and demand flexibility. For all cases, the KPIs of islanding and load shedding will be computed, as well as the indicators amount of load shed and avoided interruptions. Additionally, as explained above, different error rates will be considered of the PV forecast and demand forecast to assess the effect of under/over-estimation of requirements of storage and demand response.

Then, the replicability of islanding will be assessed. For this purpose, the following parameters will be modified to perform sensitivity analysis:

- Type of network
The characteristics of the network will be modified to study variations in aspects such as length of feeders, load density, etc. Then, other types of network will be considered with different types of grid architecture and topology, which may correspond to different types of areas. This replicability analysis will determine whether the resulting values for the KPIs are expected to be significantly affected by the type of network.
- Storage technologies
Different types of batteries will be considered, additionally to the Lithium batteries that will be used in the demo, with different characteristics of charge/discharge processes and dynamic behavior.
- DG technologies
Additionally to PV, other technologies will be considered, such as for instance micro CHP or micro wind turbines that could be connected to the LV grid. Their generation profiles will be different, so that different flexibilities may be needed during islanding. Furthermore, their potential contribution will be simulated to assess the impact of their use for balancing generation and demand.
- Volume of flexible demand
Similarly to DG, the use of flexible demand during islanding will be simulated to assess the effect of this contribution.

Finally, different boundary conditions will be considered to assess replicability at an international level. The typical values of network, generation and demand parameters will be different for different countries. Replication analysis will deal with these issues performing the previous steps for different urban, sub-urban and rural networks.

Non-technical boundary conditions will also be considered and included within generation and demand scenarios. For instance, degrees of demand response (measured by the recruitment KPI) will be implicitly included in the analysis by performing sensitivity analysis to the volume of flexible demand.

The diagram in Figure 5 summarizes the process of the technical analysis to be performed to evaluate the scaling-up and replication of the use case of islanding. The diagram shows the required inputs and tools for the analysis and the main outcomes at each step of the process. Scaling-up and replication analyses will involve sensitivity analysis for the parameters listed in the green and purple boxes, respectively.

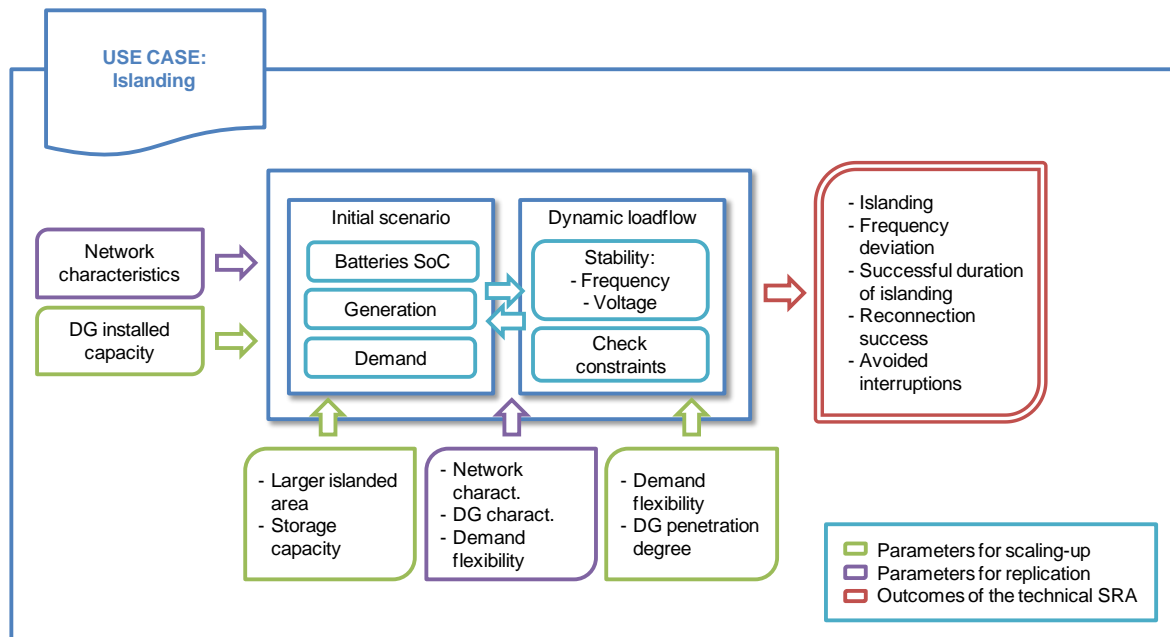


Figure 13: Technical analysis of scaling-up and replication for the use case of islanding.

3.2.6.2 Use case 6.2: Manage maximized PV production in LV

The LV network will be modeled by means of a reference network³, as in the previous use case.

The NEM and NBA will also be modeled and similarly to the previous use cases voltage profiles, active and reactive power flows will be computed, identifying situations of local congestions/overvoltages/overloads, which would mean automatic disconnection of PV units in the area.

The technical analysis will consist of a first step of load flow analysis based on the PV generation and demand forecasts for the day-ahead. The power flow analysis will be performed to detect any violation of technical constraints in the system (overvoltages, congestion, overload, etc). Then, the model will compute the flexibilities to be triggered and use of storage to avoid these potential congestions, taking into account the SoC of the batteries. Then, load flow analysis will be performed for the actual scenarios of generation and demand and the flexibility plans designed. Comparing PV production with and without the use of the flexibilities and storage, the KPI of network hosting capacity will be computed. As a result of the load flow analysis network losses and avoided overvoltages and avoided overloads may also be obtained, as indicators of the success of this use case.

Scaling-up and replication

Similarly to the previous use cases, the scalability of this use case will be assessed considering

³ Please refer to section 6 for a definition of representative feeders for GRID4EU project

different amounts of flexible load and storage controlled by the DSO and different PV penetration degrees.

Then, replicability will be analyzed considering different types of networks and the same boundary conditions. This analysis will focus on the effect of the use case on the KPI of network hosting capacity and the indicators of network losses and avoided overvoltages. Additionally, different types of DG and storage will be included in the analysis.

Finally, international replicability will be analyzed to consider the different boundary conditions as in the previous use case.

The diagram in Figure 14 summarizes the process of the technical analysis to be performed to evaluate the scaling-up and replication of the use case management of maximized PV production in LV. Similarly to the diagram for the previous use case, this figure shows the required inputs and tools for the analysis and the main outcomes at each step of the process. First, an analysis based on forecasts is performed the day ahead in order to determine the demand reduction plans. Then, the analysis must be performed using the actual data of the real-time operation of the system. Scaling-up and replication analyses will involve sensitivity analysis for the parameters listed in the green and purple boxes, respectively.

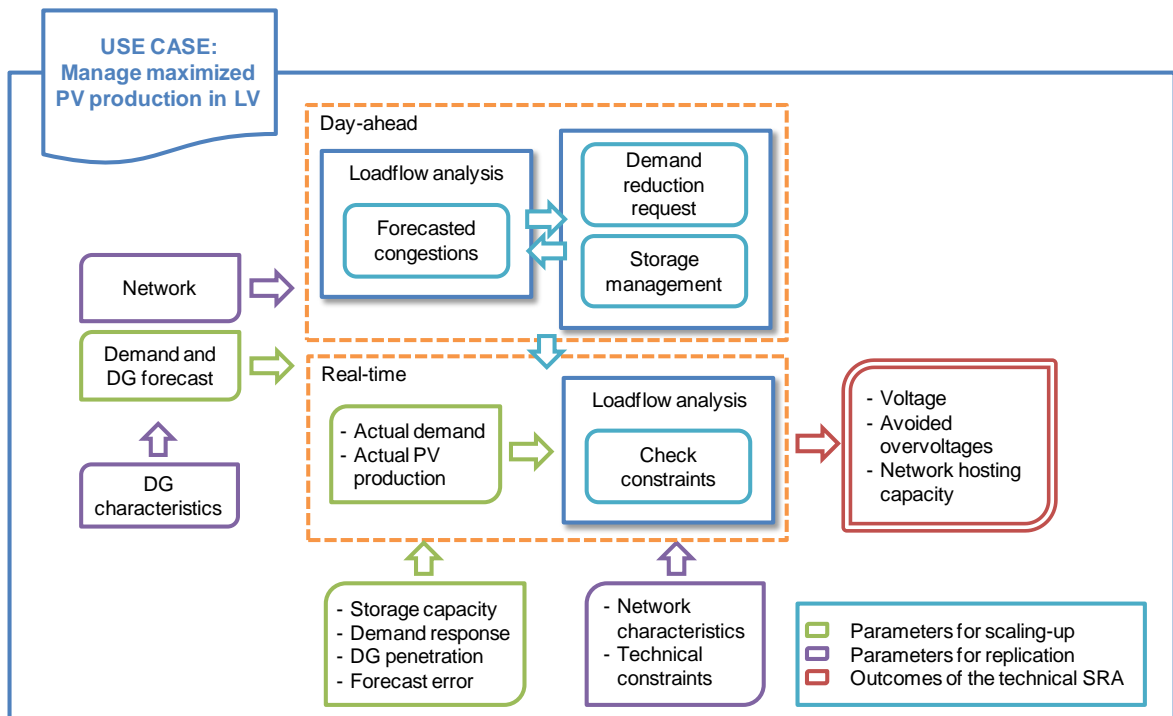


Figure 14: Technical analysis of scaling-up and replication for the use case of management of maximized PV production in LV.

4 Implementation of technical SRA of GRID4EU use cases

This section aims to provide further details on the actual work of simulation for technical SRA, describing simulation tools and models to be used and scenarios to consider.

The selected use cases for technical SRA have been analyzed one by one throughout section 3 and the similarities found among the different use cases have led to a classification for the practical implementation of the developed methodologies. Three different categories have been identified based on the pursued objective and the nature of the main impacts of the use cases in the system. These aspects determine the type of metrics to compute by technical SRA and thus the type of analysis and simulation required to quantify the corresponding KPIs.

Group	Use Case
Reliability analysis	Demo 1 - Failure management in MV
	Demo 3 - Automatic grid recovery (AGR)
	Demo 5 - Failure management in MV
	Demo 5 - Failure management in LV
Steady-state analysis	Demo 1 - Load control in MV
	Demo 2 - LV Network Monitoring and Control
	Demo 4 - Voltage regulation in MV
	Demo 6 - Maximize PV production in LV
Time-domain analysis	Demo 4 - Anti-islanding protection
	Demo 5 - Automated islanded operation
	Demo 6 - Islanding

Table 3: Categorization of GRID4EU use cases for technical SRA

- Reliability analysis

This category groups use cases that pursue the objective of improving continuity of supply. These use cases implement smart grid solutions based on automation, fault detection systems and remote control of switching elements, which help improve the process of failure management and service restoration.

The effect of these use cases is the reduction of consumers affected by supply interruptions as well as the decrease in the duration of these interruptions for affected consumers. Therefore, the main KPIs that will be used to measure the impact of these use cases are indices of continuity of supply, such as SAIDI and SAIFI, or ASIDI and ASIFI.

The use cases included in this category are all very similar. Failure management in MV (Demo 1), Automatic grid recovery (AGR) (Demo 3), and Failure management in MV (Demo 5) are focused on the implementation of failure management systems (the MAS system, the AGR system and a system based on automated disconnection points, respectively) in the MV network. The use case of Failure management in LV (Demo 5) is focused on a system that uses weak bonds and automated cabinets in the LV network.

The proposed technical SRA for this group of use cases will consist in computing the indices of continuity of supply if no use case is implemented and if the use case is implemented, so that the reliability improvement achieved by the use case can be determined.

- Steady-state analysis

This category groups use cases with the main objective of quality of supply improvement, enabling efficient DER integration and avoiding overloads and overvoltages in the networks. The use cases included in this category are Load control in MV (Demo 1), LV Network Monitoring and Control (Demo 2), Voltage regulation in MV (Demo 4) and Maximize PV production in LV (Demo 6).

These use cases implement smart grid solutions based on different elements (demand side management, use of storage, reactive power output of DG units or network reconfiguration), but all of them have a direct impact on voltage profiles, power flows and losses. Therefore, the proposed technical SRA for this group of use cases will consist in performing loadflow analysis for different scenarios that can account for the different strategies and solutions implemented in each use case to compute the KPIs of network hosting capacity, voltage profile, avoided overvoltages, avoided overloads, avoided disconnection of DG units and load shedding. Additionally, losses will also be computed to assess efficiency in the system.

- Time-domain analysis

This category groups use cases related to islanding operation and avoiding unintentional islanding. The use cases included in this category are Anti-islanding protection (Demo 4), Automated islanded operation (Demo 5) and Islanding (Demo 6).

The objective of the two islanding use cases (Demos 5 and 6) is to enable the autonomous operation of an area during unavailability of the grid due to faults or planned maintenance activities using storage, DG and flexible demand to balance generation and demand within the island. The impact of islanding use cases will be assessed in terms of availability of the network associated to the successful connection and disconnection of islanding mode and duration of the islanding operation.

The proposed technical SRA for this group of use cases will consist in performing time-domain analysis for different scenarios as starting points for the activation of islanding, in a dynamic simulation that models the behaviour of the system until during disconnection from the grid, islanding and re-connection to the grid. The compliance with technical constraints during islanded operation will be checked by monitoring frequency and voltage. Additionally, avoidance of load shedding and disconnection of DG units will also be monitored.

In the case of anti-islanding (Demo 4), the objective is to avoid uncontrolled situations of operation that could appear in the face of integration of DG in networks that were originally designed for unidirectional energy flows. The implemented smart grid solution comprises monitoring and new protection systems to ensure disconnection of DG units in the event of faults, etc. Although this use case clearly differs from the islanding use cases, it has been grouped together since it will also require a time-domain analysis to understand the dynamics of the system when a certain area is disconnected from the upstream network. Technical SRA will help identify situations where new protections systems should be a priority.

Technical SRA methodology is based on the simulation of the actual strategies and processes followed by DSOs in their Demos and the actual behaviour of the smart grid solutions implemented. The actual implementation of these simulations and models, as well as SRA assumptions, is discussed with each Demo leader to check their validity.

4.1 Reliability analysis for technical SRA

The use cases tagged for reliability analysis pursue the objective of improving continuity of supply. These use cases implement smart grid solutions based on automation for fault detection and remote control of switching elements, thus improving the different stages in the process of fault management.

The proposed technical SRA for this use cases will simulate the different faults that can occur in the MV and LV networks and compute for each consumer the number of interruptions suffered, according to the stochastic probability of each simulated fault, and the time required until service is restored for each fault that affects the consumer. This analysis will be carried out considering the base case, where no use case is implemented in the analyzed network, and considering the use case to be implemented.

Set of simulated faults

The faults considered will be those caused by failure of conductors, excluding the case of multiple failures at the same time or the failure of protection elements and substations

The process of service restoration is assessed for each segment of line of the MV or LV feeders of the representative networks developed for each Demo. The term 'segment' refers to the line between two MV/LV substations, in the case of MV networks, and the line between two LV supply points in the case of the LV network.

For each segment, the affected consumers will be identified, and the time required for the restoration of service will be computed for each of them.

The occurrence of faults will be considered deterministic: the occurrence rate will be estimated according to a certain failure rate of the conductor, which will differ for overhead lines and for underground cables, and in proportion to the length of the lines. The values for conductor fault rates will be taken from the values reported in the literature and may be re-adjusted to account for the different reliability levels, which may in turn be related to the age of installations.

Reliability assessment for each fault

For each segment, the affected consumers will be those among the two closest automatic switching elements identified

The process of service restoration depends on the topology of the network: the presence of protection elements, the meshing and structure of the network and whether the line is underground or overhead. In accordance to the network topology, this process will comprise a sequence of switching actions aimed at identifying the sub-section of the affected section where the fault has occurred (dichotomic search), visual inspection to check overhead lines and collect information from fault pass detectors, if any. At each step, as a result, service is restored for a certain group of consumers through reconfiguration or by operating switching elements that can further isolate the fault.

Service restoration will be assigned a deterministic time based on average values reported by distribution companies

The duration of the supply interruption will be for each consumer the sum of the following times for the different steps required until service is restored:

- times required for travelling of the maintenance crews to get to the points where switching operations and inspections are performed
- times for switching operations themselves to locate the fault in the case of underground cables
- times for inspection of lines in case of overhead lines to locate the fault
- times for switching operations for reconfiguration aimed at fault isolation and service restoration

At each step, once the fault is located in a section of the affected area, service is restored if possible, through reconfiguration. The reconfiguration schemes proposed will be checked through loadflow analysis, considering the corresponding demand and DG production to ensure compliance with technical constraints. In the case of a configuration causing overloads, the reconfiguration scheme will not be adopted.

Impact of the implementation of use cases

The presence of fault-pass indicators and other fault detection systems provide information so that the section of the network where the fault is known to have been originated is shorter. Therefore, the distances to cover and the elements to check by maintenance crews in the search for the origin of the fault are reduced and the total interruption time is decreased.

Telecontrol of switching elements enables remote operation avoiding physical travelling and accessing these elements. Therefore, the time required to perform switching operations to locate the fault among two switches and the time to reconfigure the network and restore service for non-faulty sections of the network, is drastically reduced.

Automation systems that feature monitoring of the network and selective and coordinated protections enable a very quick reconfiguration of the networks so that certain consumers may not experience an interruption⁴ at all.

Simulation tools

⁴ Automatic service restoration may be performed in a time of few seconds. Typically, only interruptions of supply with duration over 3 minutes are considered.

The simulation of faults and computation of reliability indices will be based on analytic computation using Matlab and Excel spreadsheets.

Metrics for technical SRA: indices of continuity of supply

Technical SRA will compute the number of interruptions suffered and the time until service is restored for each network user, for each fault that affects the user, both when no use case is implemented and when the use case is implemented. With this information, indices of continuity of supply may be obtained (or estimated in the case of ENS) if no use case is implemented ($I_{w/oUC}$) and if the use case is implemented (I_{wUC}) to determine the improvement achieved by the use case ($KPI_{reliability}$). The use of different indices may be established by regulation and can lead DSOs to take different approaches for improvement of continuity of supply, prioritizing networks supplying a certain type of users or loads, as will be discussed in section 5.2.3. Technical SRA of these use cases will compute different reliability indices to further investigate the repercussions of adopting a certain set of indices to measure the impact of these smart grid solutions to assess their potential implementation across different countries. The indices continuity of supply that will be considered are listed below:

$$KPI_{reliability} = I_{w/oUC} - I_{wUC}$$

- I SAIDI (System Average Interruption Duration Index)
- SAIFI (System Average Interruption Frequency Index)
- ASIDI (Average System Interruption Duration Index)
- ASIFI (Average System Interruption Duration Index)
- TIEPI (Equivalent interruption time related to the installed capacity)
- NIEPI (Equivalent number of interruptions related to the installed capacity)
- ENS (Energy not-supplied)
- Unavailability
- CAIDI (Customer Average Interruption Duration Index)
- CAIFI (Customer Average Interruption Frequency Index)

4.2 Steady-state analysis for technical SRA

The use cases that will be subject to steady-state analysis are aimed at enabling efficient DER integration and improving the quality of supply in terms of voltage profiles. Under increasing degrees of penetration of DG, EVs and other distributed resources, distribution networks face new challenges, with counter-flows that may exceed the technical limits of lines that were originally designed for traditional, uni-directional power flows. These use cases are intended to identify and avoid overloads and overvoltages in the MV and LV networks.

The smart grid solutions implemented in these use cases include monitoring, state estimation and strategies for voltage control to solve network constraints and facilitate integration of DG based on (i) management of the demand and generation profiles in the network and (ii) network

reconfiguration performed by the DSO. Management of demand and generation profiles may be performed using demand side management for flexible consumers, storage by charging and discharging batteries and power factor set-points for DG units. Table 4 indicates the strategies for voltage control used in the use cases grouped in this sub-section. In the case of Demo 2, the use cases will not implement voltage control strategies, so technical SRA will focus on the identification of situations where DG and EVs can cause voltage problems and overloads.

	Network config	Batteries (charge, P-Q)	DG (Q)	Flexible demand	EVs
Load control in MV (Demo 1)	✓				
LV Network Monitoring and Control ⁵ (Demo 2)			x ²		x ²
Voltage regulation in MV (Demo 4)		✓	✓	✓	
Maximize PV production in LV (Demo 6)		✓	✓	✓	

Table 4: Strategies for voltage control in use cases subject to loadflow analysis for SRA.

The activation of these use cases with different strategies for voltage control modifies power flows, voltage profiles and energy losses in the system. Technical SRA will therefore consist in performing loadflow analysis for different scenarios to compute the KPIs of network hosting capacity, voltage profiles, avoided overvoltages, avoided overloads, avoided disconnection of DG units, load shedding and energy losses. The different strategies implemented in each use case will be modelled to compute these KPIs for the analyzed scenarios and compare them to the values obtained when no use case is implemented.

Scenarios for simulation

Technical SRA will focus on two complementary approaches to address the different states of the system that correspond to generation and demand varying in time: simulation will consider (i) static scenarios or snapshots and (ii) time series scenarios or generation and demand curves.

First, static scenarios or snapshots will be simulated to analyze the specific impact of a use case at a period with a specific volume of generation and demand in the network. Such scenarios will help identify the most unfavourable situations where voltage problems and overloading may occur and to what extent the activation of the use cases can help solve them.

These scenarios will test:

- high generation and load demand, which could correspond, for instance, to mid-day in residential areas with high penetration of PV panels in houses, where consumers are not home and panels are producing energy, or night time in a more rural area with high penetration of wind power, when consumers are in bed and the wind is blowing

⁵ The use case of Demo 2 is based on the implementation of monitoring, Technical SRA for Demo 2 will analyze the impact expected from the presence of DG and EVs, but these elements will not be considered as part of the solution for voltage control.

- peak demand with low generation, which could happen, going back to the first example, during the evening in residential areas, where all consumers are at home, but the sun is already down

Then, typical profiles for load and generation will be taken into account to create 24h scenarios and thus measure the impact on reduction of energy losses and avoided overvoltages or overloading in a day and in a year. These analyses will be useful to determine how often problems may occur and how often use cases will be able to solve them. Demand and generation profiles considered will include daily profiles for:

- weekdays and workdays
- summer, winter and spring/autumn
- different types of technologies for DG (solar, wind, CHP, biofuel/waste)
- different types of consumers, discriminating voltage level (LV and MV consumers) and use of electricity (residential, commercial, industrial and agriculture)

This discrimination will be considered where relevant, since, for instance, PV generation will vary from one season to another, but not between weekdays and weekends, while presumably the opposite will happen with CHP.

Simulation of the use cases

As previously explained, the use cases of Demos 1, 4 and 6 involve the activation of voltage control strategies that will be simulated to assess their impact. Actually, in the case of the use cases of Demos 4 and 6, the implementation of the use cases consists in managing demand, DG and storage. Therefore, the use cases will be modelled as the corresponding modifications of the generation and demand profiles due to the active and reactive power injected or absorbed at the nodes where the participating elements are connected. In the case of network reconfiguration in the use case of Demo 1, the corresponding generation and demand scenario will not be modified, but instead loadflow analysis will be performed for the different network configurations available. As the use case of Demo 2 implies no voltage control strategy, no modelling of the use case will be needed.

It must be borne in mind that the use of traditional voltage control systems will also be considered and simulated, based on tap changing in the transformers in the head of network and the use of reactances and capacitors connected to the network, according to the actual operation of the grid at each DSO.

In order to test the technical potential of using different voltage control strategies, loadflow analysis will be carried out for the snapshot analysis, considering the most unfavourable conditions for generation and demand and setting the network configuration, the batteries, the DG units and/or the flexible loads at their most favourable operation points. Then, the corresponding KPIs will be computed and compared to those obtained for the same snapshot scenarios, considering the so-called business-as-usual approach.

Then, in order to test actual behaviour of these use cases, the management and operation of these use cases will be simulated, that is, day-ahead strategies will be designed and then real-time operation will be simulated, taking into account possible forecasting errors, technical capability of voltage control elements to adapt to actual real-time conditions, etc.

The elements for voltage control of the use cases of Demos 1, 4 and 6 are managed according to a certain plan or strategy that is designed on a day-ahead basis: a daily switching plan for optimal configuration of the network, the curves for charging and discharging of batteries, load

shifting requests and/or DG reactive set points throughout the day are decided for the following day considering the available information from monitoring and forecasting systems.

Technical SRA will simulate this process: loadflow analysis will be performed for a certain forecast of generation and demand to assess the expected state of the network throughout the following day, detecting any violation of technical constraints.

Then, the optimal strategy for the day will be identified. For this purpose, the technical constraints of the elements participating in voltage control will be taken into account, such as for instance the state of charge of the batteries that must be coherent at every moment and must respect the maximum rates for charge and discharge or the number of switching actions to avoid excessive switching that can damage the equipment. This way, possible actions are determined. Then, the results of the load flow analysis of these possible strategies are compared to select the optimal strategy. Finally, a generation and demand is assumed and load flow analysis is carried out for the whole day considering the scheduled voltage control strategy, to assess the effect of forecasting error.

Scenarios for scaling-up in density

The penetration degree of DG, EVs and storage will be analyzed. For this purpose, the analyses carried out to compare results with and without the use of voltage control strategies will be repeated to consider the following set of scenarios:

- higher penetration degree of DG, considering (i) different technologies of DG, with the corresponding generation profiles; (ii) different size of the units, connected to the corresponding voltage levels; and (iii) different locations for the DG units
- larger volumes of storage, assuming a larger number of units, of different sizes and located at different nodes
- more flexibility of voltage control elements, considering higher degrees of flexible load, higher margins of reactive power for DG units, and different charge and discharge rates for batteries
- higher degree of implementation of switching elements, so that there are more options for reconfiguration

Simulation tools

Scenarios of generation and demand will be created using Excel spreadsheets that can integrate the information related to all network users, including forecasts for the production of each DG unit, actual production and reactive output, storage charging and discharging, flexible load, etc. Loadflow analysis will be performed using commercial software PSS/E.

Metrics for technical SRA

As already mentioned, the impact of these use cases will be assessed through a set of KPIs and other indicators, including (i) voltage profiles, (ii) overloading, (iii) network hosting capacity, and (iv) energy losses. The compliance with voltage limits will be checked by monitoring the voltage at all nodes. Different voltage limits will be considered, since there are different limits set by regulation at European level, in each country and also different operational practices adopted by DSOs.

4.3 Time-domain analysis for technical SRA

This category groups use cases related to islanding operation and avoiding unintentional islanding.

Simulation of islanding: disconnection from the grid and re-connection

These use cases will be analyzed through a time-domain simulation where voltage and frequency will be monitored. The control system implemented in the islanding use cases will be simulated, along with the dynamics of the loads, the network itself and the DG units.

Simulation will comprise the following operation points throughout the stages of connection and disconnection from the grid, as represented in Figure 15:

- Grid connected mode (start and final points in Figure 15)
- Transition from grid connected mode to islanded mode (points 1 and 2 in Figure 15)
- Islanded mode (points 3 and 4 in Figure 15)
- Transition from islanded to grid connected mode (points 5, 6 and 7 in Figure 15)

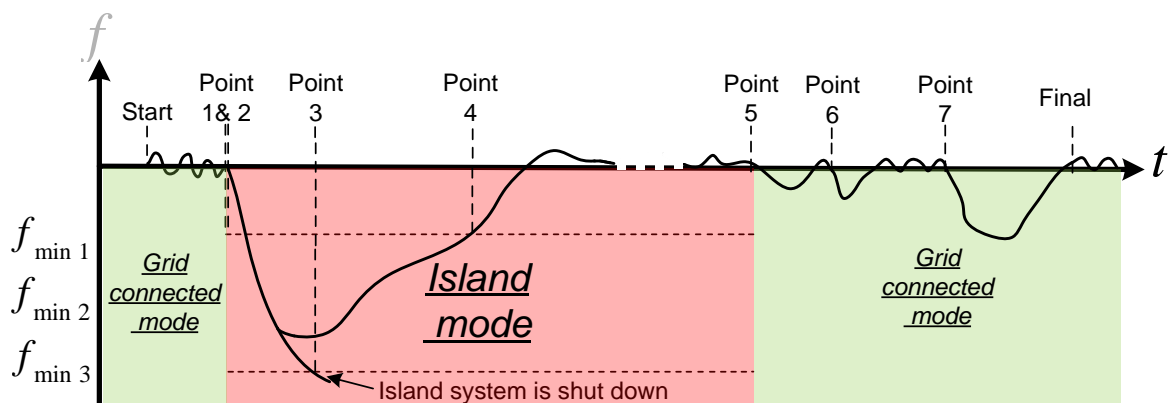


Figure 15. Typical frequency deviation in the stages of connection and disconnection of the island.

For this purpose, a Matlab-Simulink model has been developed. This model includes the dynamic model for DG units and loads and the control functions of the control systems implemented in the islanding use cases of Demos 5 and 6.

For instance, Figure 16 shows the scheme for the configuration of the island of Demo 5. The CHP unit will be modelled as a diesel generator. The model comprises a diesel generator, a governor, a synchronous generator and an excitation system with a power system stabilizer. The values of the parameters of these elements have been obtained from the literature. Figure 17 shows the control system modelled for the island. The connection and disconnection of loads is performed when frequency deviation surpasses certain limits.

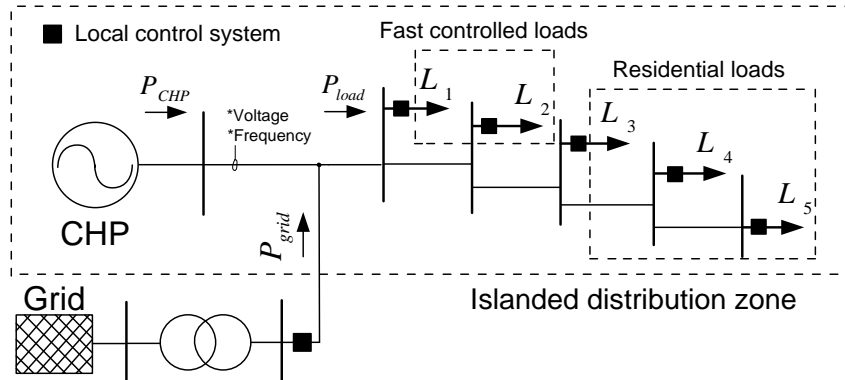


Figure 16: Distribution network configuration for islanding.

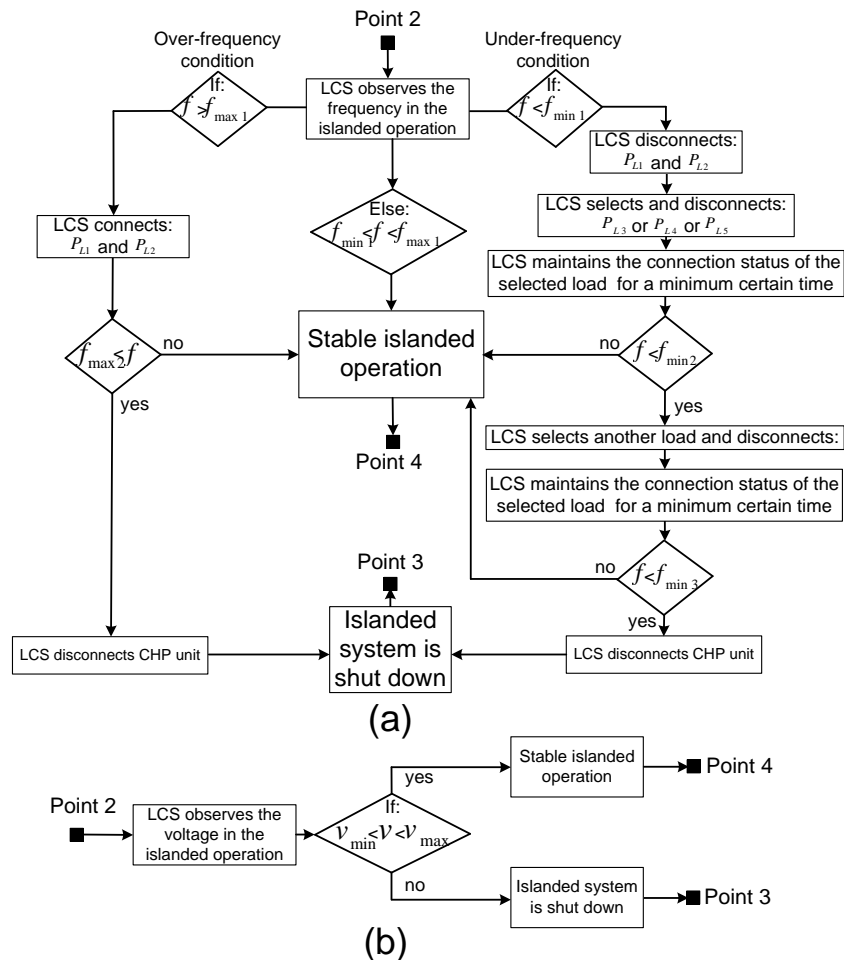


Figure 17. Control system in the transition from the grid connected to the islanded mode (a) frequency control, (b) voltage control.

Scenarios for simulation

Islanding use cases will be simulated for different scenarios of generation and demand as

starting point. Most unfavourable conditions will be the main focus of the simulations, where demand and generation are not coincident, to determine to what extent islanding can be performed.

Then, sensitivity analyses will be carried out to consider scenarios of different penetration degrees of DG that can help balance generation and demand in periods of high consumption during island, different types of DG with their corresponding dynamic models, different shares of demand flexibility and different volumes of available storage, both in terms of size of storage and in terms of charge and discharge rates of the storage.

The technical SRA of the anti-islanding use case (Demo 4) will analyze the situations where demand and generation are locally balanced, when the danger of unintentional islanding is higher. Additionally, a time-domain analysis will be performed to simulate faults in the MV networks when DG could remain connected to the grid and thus islands could appear in the network.

Metrics for technical SRA

The time-domain simulations performed will monitor frequency and voltage in the islanded area to determine the frequency and voltage deviations. The metrics that will be computed to assess the impact of this use case will also include the volume of load disconnected and the duration of successful islanding.

5 Technical boundary conditions for the GRID4EU Demos and Use Cases

Electricity distribution is very diverse across Europe and the technical boundary conditions, including distribution networks themselves, vary widely among the different countries. In order to analyze the technical scalability and replicability of GRID4EU use cases, the technical boundary conditions must be studied: the context where the Demos are carried out must be characterized and the range of different technical boundary conditions to consider for scaling-up and replication must be determined.

General information about distribution in Europe has been gathered and published by Eurelectric [1] and the CEER [2]. However, there is little data available to characterize actual distribution networks due to confidentiality issues. Furthermore, distribution infrastructure comprises a vast amount of elements, which complicates the process of characterization.

In order to model distribution systems, GWP3 proposes the use of a set of representative networks for each Demo to use for simulation. Additionally, in order to account for the different technical conditions and situations that may be found while scaling-up and replicating use cases in the Demo countries, GWP3 will define different simulation scenarios to perform sensitivity analysis to all relevant parameters. Representative networks and scenarios will be built based on data from the DSOs that lead the six Demos of GRID4EU.

This section describes the technical boundary conditions in the six countries of the Demos. In

an interactive process with the Demo leaders, input data has been gathered, homogenized and analyzed. First, the list of data requested from the demos is presented in subsection 5.1. Then, section 5.2 presents an overview of the six Demo countries and the effect of the different technical boundary conditions on scalability and replicability of the GRID4EU use cases is discussed from a qualitative point of view.

5.1 Input data requested from Demo leaders

Demo leaders have been asked to provide information on technical data to characterize distribution networks and the network users, i.e., consumers and DG. No specific format has been established, in order to allow for the information exchange to be easily adapted to information systems used by each DSO.

Representative distribution networks:

In general, a classification of distribution areas may be done according to the different size or dispersion of consumers, their different electricity needs and the according nature of the distribution networks that supply these consumers. Regulation typically acknowledges this fact and distinguishes different types of areas or networks to set different reliability standards, different efficiency criteria, etc.

DSOs have been asked to identify how many types of networks should be considered to be representative of their countries.

- How should MV networks be represented? (different MV network types could correspond to urban / sub-urban / rural / industrial / any other subdivision according to size or dispersion?)
- Should there be different types of LV networks? How many should there be considered to as representative? (urban / rural / any other subdivision according to size or dispersion?)

Information to characterize the distribution grid

DSOs have been asked to provide the following parameters to characterize distribution MV and LV networks and their operation:

- Typical voltage levels
- Size of HV/MV and MV/LV transformers
- Typical network architectures
Distribution planning determines different network configurations. DSOs have been asked to describe typical network architectures and to indicate typical network structures, number of feeders supplied by a primary substation and number of secondary substations in each feeder, and degree of meshing of the grid
- Typical length of feeders
- Parameters of conductors (R, X, thermal limits (I or S))
- Voltage control strategies
- Operation of the grid is characterized by the admissible voltage deviations (set by the

regulator and/or decided by DSO internal standards) and voltage control may be performed using different elements for voltage control (tap changers in transformers, capacitors, reactances, etc)

- Protection elements, reliability indices and strategies for fault detection, isolation and service restoration

This information should be broken down per type of network (urban/sub-urban/rural) and voltage level (MV and LV):

Network users

- Load density: number of consumers and consumption (contracted power or peak demand) per km of line, average size of consumers
- Load profiles for different types of consumers and different voltage levels (residential in urban/sub-urban and rural areas, commercial, industrial)
- Simultaneity factors at different levels (these can be obtained from aggregated load profiles)
- DG: Usual size (installed capacity) and technologies per voltage level and type of area
- Generation profiles per technology

Format of input data received from DSOs

Representative networks have been built using the input data received from Demo leaders in an interactive process, consulting the DSOs to check the validity of assumptions made and to check the representativity of the proposed networks. Each DSO has submitted input data in a free format. The two main approaches include (i) statistical data and (ii) actual networks. In the case of statistical data, the values reported for the different parameters may be presented in the form of average values or typical ranges. Some DSOs have selected a set of actual networks or designed a set of example networks that can be considered as (a) representative of the distribution networks operated by them at a general level, (b) representative for the regions where the Demos will be carried out, or (c) representative for the use cases that will be subject to SRA. The scope, perimeter and source of the different data gathered from the DSOs is described in further detail throughout the next section for the characterization of the network and network users.

5.2 Technical boundary conditions in Demo countries

This section analyzes the context that can be found in the different regions and countries where the GRID4EU Demos are carried out. The technical boundary conditions of each country are described and compared through a selection of technical parameters, addressing first the distribution networks in subsection 5.2.1 and then the network users in subsection 5.2.2.

Furthermore, the effect of these technical parameters on scalability and replicability of the GRID4EU use cases is discussed from a qualitative point of view in subsection 5.2.3. These

first qualitative relations will be deeply analyzed and developed in more detail through simulation during Year 4 of the project.

The data requested has been collected by the Demo leaders within their companies for their region or country, and then gathered and analyzed by GWP3. Each Demo leader has followed a slightly different approach for the provision of input data, according to the availability of data:

- Some DSOs have focused on data for the region of the Demo, while some others have provided the data that corresponds to the whole country or the part of the country that they operate.
- Some DSOs have provided the data corresponding to
 - a set of example networks that can be representative,
 - actual data for real networks that can be taken as a reference for the use cases selected for SRA,
 - statistical data for a large group of networks, etc.

GWP3 considers this information to be the best representation possible for the technical boundary conditions of the countries where the Demos are carried out, although some of the data do not exactly correspond to the whole country. Many parameters are general and remain the same for the whole country, such as for instance regulation, voltage levels, standard equipment used by a DSO, etc. Some other parameters, such as for instance load density or penetration degree of DG, are more specific to each area, and can therefore vary when scaling-up from the Demo region to the Demo country. In order to tackle this problem, sensitivity analysis will be performed to the parameters that constitute the representative networks, as well as to different generation and demand scenarios. The ranges of values to analyze are such that can account for situations that have not been identified in the analyzed region but could be present in the rest of the country. For instance, given a set of three representative networks for a country based on the data of a province, simulations would be carried out using these representative networks, and would later be repeated considering higher and lower values for the length of the feeders. In the end, SRA rules aim to identify how technical boundary conditions impact the outcome of implementing use cases, in the context of distribution in the countries of the Demos.

Some of the information provided by DSOs is confidential and will be therefore only described at a high level. By contrast, some information is publicly available at the webpage of the corresponding DSOs or NRAs.

5.2.1 Distribution networks

Some of the main characteristics of the MV distribution networks in the Demo countries or regions are presented in this sub-section, according to the data provided by the Demo leaders. A first set of parameters is presented in Table 6 for the Demo countries, including (i) voltage levels, (ii) voltage limits, (iii) continuity of supply indices monitored by regulation, and (iv) continuity of supply levels. This information is monitored and published at a European level by the CEER.

Some other parameters are more specific and may vary for different areas within countries, especially in regions operated by different DSOs. Table 7 presents the following parameters included in this category: (i) feeder length, (ii) density of load, (iii) meshing and interconnection degree, (iv) automation degree, and (v) undergrounding level.

In order to elaborate Table 7, different sets of data provided by DSOs have been used. The values used represent areas of a different geographical scope and in some cases the values have been obtained under different approaches. The form of the data received from each Demo is explained in the first row of Table 7. Although based on areas of different size or scope, it is reasonable to use these data as the most representative data available for the technical SRA of the selected use cases.

In order to overcome the unavailability of information that can represent for the whole countries of the Demos, in the case of these more specific parameters, sensitivity analyses will be carried out to cover a wider range of technical boundary conditions. This way, different values from those reported by the DSOs can be considered into the SRA as well.

The information gathered in Table 7 has been split into urban and rural areas. Distribution networks are usually very different depending on the population density and the type of consumers supplied by the network. In fact, in European countries, distribution regulation often establishes different types of areas to set different requirements for reliability levels or network losses. Table 5 presents the example of Spain, Italy and France.

Spain		Italy		France	
Category	Inhabitants	Category	Inhabitants	Category	Inhabitants
Urban	>20,000	Urban: High concentration	>50,000	Urban	>100,000
Sub-urban	20,000-2,000	Sub-urban: Medium concentration	5,000-50,000	Sub-urban	10,000-100,000
Concentrated rural	200 -2,000	Rural: Low concentration	<50,000	Rural	<10,000
Scattered rural	< 200				

Table 5: Examples of segmentation in different countries.

Technical SRA has also included this distinction in the representative networks, establishing a certain number of representative networks, as explained in section 6.1. In the case of the information presented in Table 6, it must be noted that the information labeled as 'urban' may correspond to the information provided by DSOs for urban, high concentration and partly sub-urban, while the information referred to as 'rural' includes data for rural networks but also for concentrated rural, scattered rural and low concentration networks.

As explained, some design and operational parameters are sensitive for DSOs, so the actual data cannot be published or found in the literature. The high level information in Table 7 tackles some aspects that have not been previously discussed, such as for instance network length and loading of the networks. Due to the confidentiality of the parameters related to the topology and loading of the MV grid, their actual values cannot be shown in Table 7. Instead, it has been necessary to follow a more qualitative approach. For each parameter, the average of the values corresponding to each of the six columns has been computed and used as a reference, so that actual values have been substituted by the labels “below average”, “average” and “above average”. It must be borne in mind however, that the data for each column corresponds to a different scope, according to the first row of Table 7 itself, so that this categorization does not correspond to a comparison among countries.

Although the information in this table has been developed from values of different representativity, it reveals the differences between the networks in the different countries of the Demos. This information enables a first stage of qualitative SRA, giving an insight into the technical parameters across these countries and allowing the extraction of some very valuable conclusions prior to simulation for technical SRA.

All in all, the information presented in Table 7 provides a very good overview of distribution networks in the Demo regions, but the non-homogeneity of the data must be taken into account when interpreting and comparing the different columns corresponding to the different demos.

	DEMO 1 Germany	DEMO 2 Sweden	DEMO 3 Spain	DEMO 4 Italy	DEMO 5 Czech Republic	DEMO 6 France
Voltage levels⁶	<u>10</u> kV	<u>10</u> / 20kV	11 / 15 / <u>20</u> / 30kV	10 / <u>15</u> / 20kV	22 / <u>35</u> kV (6 /10kV past)	10 / <u>20</u> kV
Voltage limits	±10%	±10%	±7%	±10%	±10%	±5%
Continuity of supply levels	SAIDI⁷ 15,4 SAIFI⁷ 0,3	93,9 1,6	58,2 1,6	45,6 1,7	107,8 1,7	58,5 0,9
Continuity of supply monitored by regulation	SAIDI (LV), ASIDI (MV), SAIFI	SAIDI, SAIFI	TIEPI, NIEPI (≈ ASIDI, ASIFI)	SAIDI, SAIFI	SAIFI, SAIDI, CAIDI	SAIFI, SAIDI

Table 6: General characteristics of MV distribution networks in Demo countries.

⁶ The underlined values correspond to the voltage levels of the MV representative networks for SRA.

⁷ Average of annual SAIDI and SAIFI indices due to unplanned interruptions (t>3min), excluding exceptional events, for years 2010, 2011 and 2012. Source: CEER Benchmarking Report [2].

		DEMO 1 Germany	DEMO 2 Sweden	DEMO 3 Spain	DEMO 4 Italy	DEMO 5 Czech Republic	DEMO 6 France
Scope of information provided by DSOs to characterize MV networks and build set of representative networks for technical SRA		General data based on the North-West region and also for three representative networks (1-2 HV/MV subst and 6-30 feeders each)	Data based on one representative urban network (1 feeder)	Data based on networks in the whole country	Data based on the Forli-Cesena province	Data based on two representative networks (1 feeder each) for the part of the country operated by CEZ Distribuce	Data based on four real networks representative of the tested use cases (2 HV/MV subst and 4-6 feeders each)
Feeder length	Urban	below average	n/a	average	average	above average	above average
	Rural	below average	average	above average	average	above average	average
Density of load (number of subst/feeder)	Urban	average	n/a	average	average	above average	below average
	Rural	average	above average	average	below average	above average	below average
Density of load (number of cons/subst)	Urban	below average	n/a	average	below average	above average	below average
	Rural	below average	above average	average	below average	above average	below average
Density of load (inst capacity/feeder)	Urban	average	n/a	above average	below average	above average	below average
	Rural	average	below average	above average	below average	above average	below average
Meshing and interconnection degree	Urban	above average	n/a	average	average	average	average
	Rural	average	above average	below average	average	above average	above average
Automation degree	Urban	average	n/a	average	above average		
	Rural	average	above average	below average	above average		
Undergrounding level	Urban	average	average	average	below average	average	average
	Rural	above average	average	above average	below average	below average	below average

Table 7: Specific characteristics of MV distribution networks according to data provided by Demo leaders to build set of representative networks for technical SRA.

5.2.2 Network users

Network users have been characterized using the information provided by Demo leaders regarding demand and DG connected to the distribution grids.

The uses of electricity and the corresponding demand vary across regions and countries, in line with the local customs and usages, traditions and climate, among others. Domestic demand is strongly conditioned by the typical size of the dwellings, either family houses or flats in buildings (electricity consumption in larger houses is generally much higher), and whether electric heating and/or air conditioner is widespread (families in cold countries where electric heating is common will have in general a much higher electricity consumption). Tertiary demand is driven by commercial opening times, which also vary widely across countries and cities.

Demand is characterized by load profiles and peak demand or contracted power. In most countries, consumers pay for a certain amount of maximum power they are granted, which is the contracted power, but this concept does not exist in some other countries, such as for instance, Germany.

Table 8 presents a qualitative comparison for the data obtained from Demo leaders on average values of contracted power for LV consumers, peak demand and historical consumption data in the regions and/or countries of the Demos.

	DEMO 1 Germany	DEMO 2 Sweden	DEMO 3 Spain	DEMO 4 Italy	DEMO 5 Czech Republic	DEMO 6 France
Contracted power and peak demand for LV consumers	below average	above average	below average	below average	above average	above average

Table 8: Comparative of average values of contracted power and peak demand for LV consumers.

The generation connected to distribution grids in the six countries of the Demos comprises DG units that vary in size and technologies. The information collected from the DSOs is categorized following different approaches, per voltage level, considering technology, considering fuel, etc. As in the case of the network characterization, it must be considered that the information presented in this section is based on the data provided by the Demo leaders, which may correspond to the totality of the country, or to a certain region or area, as explained in Table 9. Therefore, when interpreting the tables and comparing the different countries, it must be borne in mind that the values used vary in their scope.

DEMO 1 Germany	DEMO 2 Sweden	DEMO 3 Spain	DEMO 4 Italy	DEMO 5 Czech Republic	DEMO 6 France
Data for the North-West region	Data for the whole country, including renewable generation connected to all voltage levels ⁸	Data for the whole country	Data based for the Forli-Cesena province Data for the whole country ⁹	Data for the part of the country operated by CEZ Distribuce	Data for the part of the country operated by ERDF

Table 9: Scope of information used to characterize distributed generation for technical SRA.

The technologies installed in the different regions and countries analyzed are presented in Table 10, in terms of the share of installed capacity that corresponds to each type of DG. These values show the general predominance of solar and wind, but also the difference among the countries. For instance, wind plays a key role in Spain and France, while the predominant technology in the Czech Republic is CHP.

	DEMO 1 Germany	DEMO 2 Sweden	DEMO 3 Spain	DEMO 4 Italy	DEMO 5 Czech Republic	DEMO 6 France
Scope of data	Regional	National	National	Regional	National	Regional
Solar PV	40%	12%	12%	78%	35%	23%
Solar CSP			5%			
Wind	52%	33%	61%		17%	49%
CHP			16%	13%	38%	12%
Hydro < 10 MW		8%	4%		6%	10%
Hydro > 10 MW			2%	1%	32%	8%
Biogas				3%	3%	2%
Biomass & waste	9%	47%		5%	3%	4%
Others					4%	

Table 10: Technologies of DG in the Demo regions or countries (% of total DG installed capacity)

⁸ Source: Swedish Energy Agency, The electricity certificate system, 2012. Information on the number of units, installed capacity and energy production per technology for the generation that has been awarded at least one certificate for renewable production.

<http://www.energimyndigheten.se/en/Facts-and-figures1/Publications/>

⁹ Source: GSE Report 2012. www.gse.it

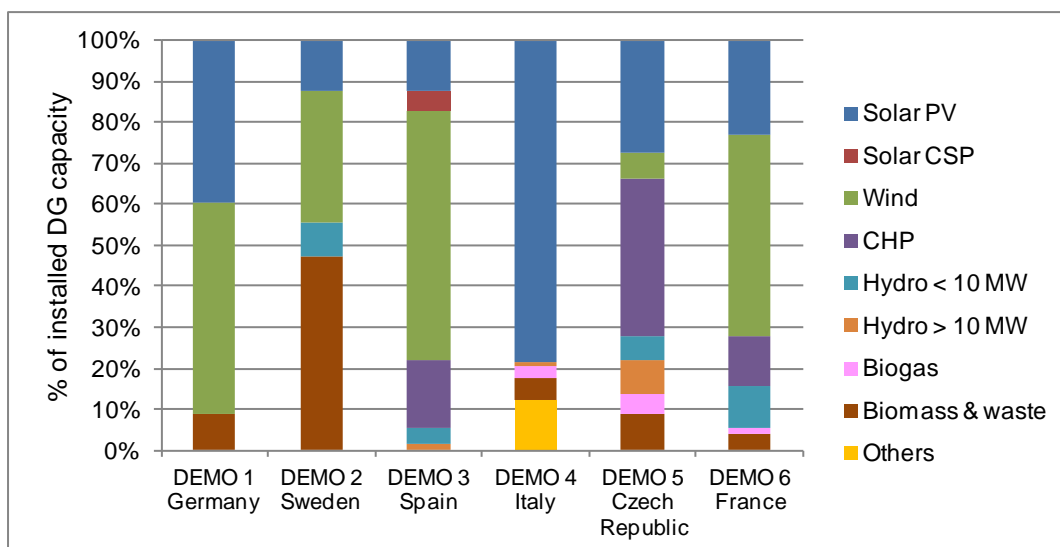


Figure 18: Technologies of DG in the Demo regions or countries (% of total DG installed capacity)

The size of the DG units determines the level of voltage it is connected to. Larger units are connected to the HV or MV voltage networks, while smaller units are typically connected to LV networks. Actually, in some countries, like France and Italy, HV grids are not operated by DSOs, and therefore any generation unit connected at HV level is not considered to be DG. Table 11 presents for each technology, the share of installed capacity connected to each voltage level, which signals the usual size of DG units. For instance, most PV connected in the region of North-West in Germany is connected to the LV network, which typically corresponds to PV panels in houses and buildings. By contrast, the share of PV connected to MV and HV networks in Spain is much higher because there are many big solar plants, both based on PV panels and also thermal solar power.

	DEMO 1 Germany			DEMO 3 Spain			DEMO 5 Czech Republic		
	<i>Regional data</i>			<i>National data</i>			<i>Regional data</i>		
	LV	MV	HV	LV	MV	HV	LV	MV	HV
Solar PV	70%	30%	0%	36%	48%	17%	14%	76%	9%
Solar CSP				0%	12%	88%			
Wind	0%	70%	30%	1%	4%	95%	0%	68%	32%
CHP				1%	41%	58%	0%	13%	87%
Hydro < 10 MW				2%	58%	40%	22%	78%	0%
Hydro > 10 MW				0%	5%	95%	0%	10%	90%
Biogas							0%	100%	0%
Biomass & waste	3%	92%	4%				0%	8%	92%

Table 11: Installed capacity connected to the different voltage levels in the Demo regions or countries per technology

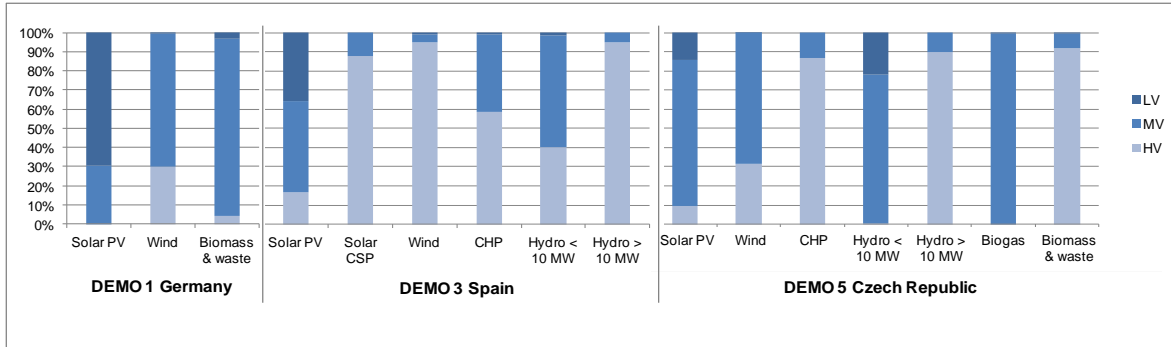


Figure 19: Installed capacity connected to the different voltage levels in the Demo regions or countries per technology

5.2.3 Impact of technical boundary conditions on SRA

The impact of the implementation of the different GRID4EU use cases is subject to the technical boundary conditions that frame the implementation. Depending on the functionalities implemented and the objectives pursued, the parameters that have a stronger effect on the outcomes of the use cases differ.

Use cases subject to reliability analysis

The use cases aimed at the improvement of continuity of supply modify the fault management processes of the DSOs so that faults in the system result in shorter times of interruptions and affect a lower number of consumers. Distribution networks differ across Europe, and the main parameters that condition the improvement that can be achieved by the implementation of these use cases are the configuration of the network, in terms of meshing, undergrounding, protections and automation, and the actual reliability levels in the system, which are in turn related to the configuration of the network, but also the conditions of the infrastructure, in terms of age, fault rates, undergrounding, etc.

- Reliability levels

In general, the implementation of automation use cases in networks with poorer reliability levels will have a deeper impact, since there are wider margins for improvement. For instance, older conductors in lines will typically have higher fault rates than newer infrastructure, so that the number of interruptions per year will be higher. Installing automation in older areas will help isolate faulty sections faster, which will happen more often than for areas with newer cables, so the reduction of continuity of supply indices will be larger in absolute terms (minutes of interruption or average number of interruptions suffered per year for consumers). Yet another example is feeder length. Probabilistically, considering a certain fault rate for conductors, a higher number of faults will occur for longer networks, so reliability will be poorer. Therefore, automation will contribute to deeper changes in continuity of supply indices for longer feeders. The degree of undergrounding is also closely linked to reliability and failure rates, since cables have a much lower failure rate than overhead lines, especially when nude conductors are used.

- Network structure

The structure of the network, in terms of meshing and interconnection of feeders, determines the processes and operations that can be performed for fault location and isolation and service restoration. Urban networks are typically more meshed than networks supplying rural areas.

In networks with radial feeders, there is no alternative path to supply a section of a feeder when a fault occurs in that feeder. Automation can help isolate different sections of the feeder much faster than networks with manually operated switches, so that faults in the downstream section do not affect the upper section, but faults in the upstream section do leave consumers in the downstream section without supply.

Networks that are radially operated but have interconnected feeders enable service to be restored by isolating the faulty section of the feeder and closing the switches at the interconnections, so that the non-faulty section is fed through another feeder. A higher degree of meshing implies more options for reconfiguration. Automation involves fast service restoration for all the consumers connected to non-faulty section(s) of the feeder where the fault has been originated.

Therefore, the automation of switching elements in rural areas will decrease fault location times, but service restoration will only occur after reparation of the faulty section. By contrast, in urban areas, automated switches will be able to also restore service to some network users through reconfiguration, so that reliability indices will be improved to a higher extent.

- Undergrounding degree

As already explained, the use of underground cables or overhead lines has a deep impact on reliability. Furthermore, the effect of implementing automation and other smart grid use cases for reliability improvement is conditioned by the type of network, whether underground or overhead. To begin with, cables have lower failure rates, so a lower number of faults may be expected. Additionally, overhead lines typically suffer transient faults due to accidents caused by wind, the contact of birds or trees, etc. In this case, once the contact with the external element has stopped, reconnection may restore service. By contrast, underground cables typically suffer from permanent faults, for instance due to works in the street, where bulldozers break the cables. Restoration times are also quite different, since underground cables are typically more difficult to access, so that the isolation of the faulty segment becomes the most important in the process of fault management. To sum up, the implementation of different use cases for reliability improvement will have a different impact on underground and overhead networks, predominantly reducing interruption times drastically in the first case, and the number of faults in the latter.

- Degree of automation

The degree of already existing automation has also an effect on the result that may be expected from including a certain number of automated elements or an increase in the automation degree. Given a certain network, the increase of automation in the networks does not have a linear effect on reliability improvement. The impact is deeper when increasing automation for low degrees of automation. For instance, in a MV feeder connected at its end to another MV feeder through a normally-open switch for reconfiguration, adding an automated switch at the mid-point achieves a high reduction of number of affected consumers and duration of interruptions. Adding then a new automated switch also improves reliability, but the

reduction of reliability indices is lower, since the group of consumers affected by faults is already half of the total consumers connected to the feeder.

- Indices of continuity of supply

The impact of these use cases is measured by continuity of supply indices, which measure the average frequency and duration of supply interruptions. However, there are different indices based on different averaging parameters: for instance, SAIDI and SAIFI indicate the average number of interruptions and their duration per consumer, while ASIDI and ASIFI are based on served power. Therefore, reliability indices are biased. When weighting is based on energy or power, interruptions are given higher weighting for larger consumers over smaller ones. If the weighting factor is interrupted power or ENS, consumption during peak demand is preponderant over consumption during low demand periods. By contrast, weighting based on the number of network users treats all users equally, regardless of their size or consumption. The use of different indices in distribution regulation in each country may lead DSOs to follow different strategies for improvement of continuity of supply, prioritizing networks supplying a certain type of users or loads.

Use cases subject to steady-state analysis

The use cases that will be subject to steady-state analysis are based on (i) management of the demand and generation profiles in the network and (ii) network reconfiguration. These use cases have an impact on power flows, voltage profiles and energy losses in the system. The main parameters that can influence the effect of the implementation of these use cases are size, location and profiles of network users (consumers, DG units and owners of other DER) and network characteristics in terms of impedance of the lines, which is related to length of feeders and type and section of conductors. Additionally, when reconfiguration is involved, the structure of the network (meshing, interconnection of feeders, number and location of switching elements) plays a key role. Voltage limits set by regulation or operational standards conditions the actions of the use cases implemented, setting the technical constraints that must be complied with.

- Network characteristics

The impedance of the lines that are used to distribute the power and supply demand determine the voltage drop and the energy losses associated to a certain amount of power flowing through the conductors. Higher values of impedance mean larger voltage drops to supply a certain demand and larger voltage rise when a certain amount of power is injected, as well as larger amounts of power losses for a certain amount power flowing. The impedance of conductors is related to the length of the line and its section: longer lines have a higher impedance, and thicker conductors show a lower impedance.

Lines with higher values of impedance will experience a higher impact from the presence of DER, since power flowing through the line will cause larger voltage variations and losses. However, precisely for this reason, these lines will benefit from a deeper impact from the implementation of use cases aimed at reducing power flows in the system through the management of demand, DG and storage to achieve a better adequacy of local generation and demand. For instance, in a network with a high presence of PV overvoltages may be more frequent for longer lines. The impact of using storage to charge during peak production to

supply demand in the evening will be more drastic if the line is longer avoiding a higher number of problematic situations.

The R/X ratio of the conductors also has an effect on the impact of these use cases. Underground cables have a higher R/X ratio than overhead lines, and conductors at lower voltage levels have a higher R/X ratio than higher voltage levels. If the R/X ratio is higher, the reactive component of the impedance has a higher importance, and therefore, reactive power flows have a higher impact on voltage control. The absorption of reactive power will result in a higher voltage increase, while the injection of reactive power will decrease the voltage in the network to a higher extent. Use cases where DG units can change their reactive power output to comply with power factor set points will consequently have a deeper impact.

- Network users

Naturally, networks with a higher density of demand will experience higher voltage drops and the conductors and transformers will be more loaded. Voltage control actions will be therefore more necessary in those areas with a dense load, especially if demand grows. Similarly, higher shares of DG penetration may lead to higher voltages in the network during periods of high production and low consumption. At a certain point, a very high amount of DG production may cause overvoltages or overloadings of the networks. The implementation of the use cases grouped in this subsection will help mitigate the impact of high consumption or high DG penetration by balancing generation and demand, reconfiguring the grid or managing local reactive power flows. The implementation of these use cases will be more necessary for higher penetration degrees of DG.

The size, location and concentration of DG and other DER units also determines the impact of these use cases. Given a certain volume of DG production in a network, if the DG is more dispersed, the power injection would cause a more homogeneous voltage rise than if the DG production were concentrated in a smaller section of the grid. Furthermore, the injection of power from DG has a local effect, so that the voltage rises in the nodes closer to the DG unit. If DG is located at the beginning of an MV feeder or LV line, in a period of excess of demand, the power to evacuate from the feeder or line will flow along a shorter section of the network than in the case of DG located at the end of the feeder or line. Therefore, voltage will rise to a higher extent and losses will be higher if DG is located at the end of the line. Smaller DG units are typically more dispersed, such as for instance PV panels on rooftops in a residential area, in comparison to a larger PV unit associated to a commercial centre.

Likewise, the location of the DER units managed within the use case also has an impact on the effectiveness of the implementation of the use case itself. The use case will be more effective if the solution implemented is more adequate to the DG and consumption. For instance, in a network with a high penetration of PV panels, using storage to increase network hosting capacity would be more beneficial if batteries located at different points of the network, closer to the DG that is causing overvoltages.

- Voltage level and voltage limits

The impact of use cases where power flows are modified will also be conditioned by the rated voltage in the network. Traditionally, distribution is carried out at different voltage levels. Higher voltage levels involve that for a certain amount of power, the current flowing through the lines is lower, so that energy losses are lower and the voltage drops and/or rises associated to a

certain generation and demand scenario are lower. Voltage problems or overloading will appear in networks with lower voltage for lower shares of DG, i.e. network hosting capacity will be higher for higher nominal voltage.

Comparing LV networks and MV networks, the problems encountered will differ in both cases. Typically, DG and DER connected to LV networks will be smaller in size, and given a certain penetration degree, the units will be more dispersed. The conductors of the networks will be more resistive (higher R/X ratio), so that modifying reactive power flows with power factor set points for DG will have a lower impact. Voltage problems in MV networks may be caused by DG connected either to the LV network or to the MV network.

Distribution regulation and operational standards set different allowed voltage limits, for instance, the European Union sets a maximum deviation of $\pm 10\%$ of nominal voltage, while Spanish regulation establishes a maximum of $\pm 7\%$ and some DSOs operate networks at a maximum deviation of $\pm 4-6\%$. Compliance with the different limits allows for different voltage control strategies and results in a different hosting capacity. Therefore, the quantified impact of smart grid use cases is subject to the limits considered, which must be taken into account for the assessment of replicability.

- Network structure

The use case of Demo 1 uses reconfiguration to shift load (or generation) from one feeder to another. The effect of implementing this use case will be influenced greatly by the options available for reconfiguration, depending on the switching elements, interconnection points, etc. Furthermore, there are different network schemes for reliability that can offer more possibilities for re-distribution of the load between feeders through reconfiguration, such as for instance the use of support cables, which are unloaded cables parting from primary substations to connect feeders at their end through normally-open switches. In this case, part of the load of one feeder can be fed through this support cable, so that overloading in the feeder is avoided.

Use cases subject to time-domain analysis

The impact of islanding use cases is mainly conditioned by the generation and demand and the degree of coincidence in time and the capability to achieve balance in the island in a very short time. Therefore, the most relevant boundary conditions to be addressed by technical SRA are the dynamic characteristics of the control system, the presence of DG, storage and other DER, and generation and demand profiles of the different users connected to the section of the network subject to islanding.

- Characteristics of the control system

In order to ensure stability during islanding, a large storage or DG unit is used in the islanding use cases of Demos 5 and 6. This unit must be able to provide most of the demand in the island and have a very fast response to balance generation and demand in the island. Different DG and storage technologies will have a different dynamic response and degree of controllability. Given a certain network and demand, larger volumes of flexibility and faster response will have a higher probability of success for islanding.

- DER connected to the network

The DG units and storage units in the system can help balance generation and demand in the

island. Therefore, the size, location and controllability of these units will have an effect on these use cases. Larger volumes of DG, storage and flexible demand can ensure a better adequacy of generation and demand in the island, so the duration of islanding that can be sustained will be higher.

In the case of anti-islanding, unintentional islanding may happen in situations where total demand and generation in an area are close. Therefore, having higher penetration degrees of DG will lead to higher risk of unintentional islanding.

- Protection systems

In the use case of anti-islanding, protection schemes are the key to avoid unintentional islanding. Protections that automatically disconnect DG and storage units in case of a fault will prevent the emergence of islands.

6 Representative networks

Representative and reference networks are networks that can be considered appropriate to describe the behavior of a set or cluster of real distribution feeders. In this context, representative networks aim to reproduce the characteristics of actual networks, while reference networks are designed as quasi-optimal networks that could supply actual demand to compare to actual networks and assess their efficiency. Representative and reference were first proposed as a benchmarking tool for regulation of distribution, either modeling average networks (representative networks) or optimal networks (reference networks) to compare actual networks with in order to set the remuneration for the DSOs [3].

The vast amount and diversity of distribution assets across regions and countries makes it difficult to manage data for actual networks for large scale analyses. Representative networks are therefore very valuable for technical analysis of different operation scenarios, technologies, etc. Consequently, the use of representative networks for research in the academia has been very helpful. Actually, the report on RES integration prepared for the European Commission [4] has used representative networks to assess the impact of DG integration and different strategies on distribution planning, expansion and operation. However, only a limited set of networks has been considered to represent all analyzed countries. The lack of publicly available data due to confidentiality issues complicates the construction of representative networks.

This section presents the process carried out throughout Year 3 of the GRID4EU project to build representative networks for the countries of the six Demos, using as input data the information provided by the Demo leaders and described in section 5.

Note: For the specific case of France, DEMO6 has provided, real networks that are representative of the use cases that are going to be tested in GRID4EU technical SRA. It is important to highlight that in France, the choice of a network is extremely linked to the chosen use case that are going to be tested. For these reasons, to date, it is technically very complex to provide the representativity rate of a feeder among the French network for a given use case.

6.1 Construction of representative networks

For each Demo, a set of representative networks has been built with an interactive and iterative process with Demo leaders.

Number of representative networks

Distribution networks are strongly determined by the density of load to supply. In fact, as explained in section 5.2.1, regulation often establishes different types of areas according to population density.

Technical SRA has also taken into account this segmentation. The number of representative networks that are required to take into account the variability of distribution networks in the country (or area operated by the corresponding DSO) has been determined together with the corresponding Demo leader.

Furthermore, technical SRA will focus on MV and LV networks, since all the tested use cases are implemented either in LV or in the MV network. Simulation at MV and LV will be carried out independently, so the set of representative networks will comprise a number of MV networks and also a number of LV networks.

Table 12 presents the different representative networks that will be built for each Demo.

	Germany	Sweden	Spain	Italy	Czech Republic	France
MV Networks	<ul style="list-style-type: none"> • Urban • Urban-rural • Rural 	<ul style="list-style-type: none"> • Urban • Rural 	<ul style="list-style-type: none"> • Urban w/ support cable • Urban w/ distribution centre • Sub-urban • Rural 	<ul style="list-style-type: none"> • High concentration • Medium concentration • Low concentration 	<ul style="list-style-type: none"> • Urban • Rural 	<ul style="list-style-type: none"> • Urban • High concentration rural • Low concentration rural
LV Networks	<ul style="list-style-type: none"> • Urban • Rural 	<ul style="list-style-type: none"> • Urban • Rural 	<ul style="list-style-type: none"> • Urban • Rural 	<ul style="list-style-type: none"> • Urban • Rural 	<ul style="list-style-type: none"> • Urban • Rural 	<ul style="list-style-type: none"> • Urban • Rural

Table 12: Comparative of MV distribution networks in Demo countries.

Size of representative networks

The main objective is to have as representative networks a set of simple models, in order to enable a very high amount of simulation cases, scenarios and variations of the parameters involved for sensitivity analysis. GWP3 proposes to consider representative networks of only a few feeders. Logically, simpler models involve faster simulation and more manageable volumes of results.

Considering more than one feeder allows the analysis of different topologies. In the case of MV

networks it is important to include feeders with different number of MV/LV substations, with different points of interconnection to other feeders or different degrees of automation. Furthermore, in order to assess reliability, reconfiguration processes are simulated, so it is important to be able to model all possible reconfiguration schemes for an MV feeder. In the case of LV networks, it is also necessary to analyze different topologies if there is interconnection of different LV lines and/or possibilities for reconfiguration at certain points of the LV lines.

With respect to use cases based on voltage control, due to the radial operation of distribution networks, the modification of load and generation profiles of the consumers and DER connected to a feeder does not have an effect on the voltage profile of other feeders, so that a couple of feeders are sufficient to assess the impact of such solutions. By contrast, solutions based on the HV/MV substations, such as on-load tap changing or storage connected to the head of the MV network, have an effect on all MV feeders connected to the HV/MV substation. Therefore, the model must comprise at least two feeders from the same substation, so that the different effects may be analyzed. For instance, in a sunny working day at noon, MV feeders supplying residential areas with a high share of PV penetration may suffer from overvoltages due to high feed-in and low demand, while MV feeders supplying commercial or industrial areas may be experiencing voltage drops due to demand. In such situations, increasing the voltage at the primary substation MV bus bar would improve the situation in the first case of MV feeders but have a negative impact for the others.

The representative networks developed for technical SRA in GRID4EU comprise 3-5 MV feeders or LV lines.

Scope and process for representative networks

According to the data provided by the Demo leaders, representative networks may be based on statistical or actual data for the whole country, the part of the country operated by the DSO or the region or area where the Demo is carried out.

Although in some cases the information used to build the representative networks reflects distribution networks in a region, rather than a country, GWP3 considers these networks to be the most representative possible, it is reasonable to use these networks as representative of the country including a sensitivity analysis to the parameters of the network itself, so that any possible variation of networks within the country can be analyzed¹⁰.

For each Demo, the set of representative networks has been developed in an interactive and iterative process. The data gathered from the corresponding DSO is analyzed and a first set of representative network is proposed, using different references to assume values for any parameters that Demo leaders have not been able to provide at a first stage. The proposal is submitted to the Demo leaders to check the validity of assumptions. Then Demo leaders provide their feedback after consultation of technicians, re-defining the values of parameters if necessary. The process is carried out to refine the proposal until it is considered to be representative of the distribution system. In the face of the difficulties that surface when gathering input data in a more abstract way, this iterative methodology has proven to be much more effective.

¹⁰ Please refer to the explanation of the example of Franc for more details, see the above **Note**

7 Conclusions

This document has presented the work carried out during Year 3 for the technical scalability and replicability analysis (SRA) of the use cases tested in the Demos of the GRID4EU project, focusing on the methodological developments and the analysis of the technical boundary conditions of the countries where the Demos are taking place.

GWP3 has developed a methodology for technical SRA, and it has been adapted for the use cases of the GRID4EU Demos. The document describes the practical implementation of these methodologies, based on simulation, using representative networks and considering a large set of scenarios to account for the variability of technical boundary conditions and to enable a sensitivity analysis that can quantify the impact of the different boundary conditions on the outcome of implementing the use cases.

Much effort has been put into gathering and processing the necessary input data to build model networks that can represent the actual networks and to characterize network users in the Demo regions and countries. Due to the unavailability of certain data and confidentiality issues, the information presented in the document is not completely exhaustive and homogeneous, but this document presents indeed the best representation possible for the technical boundary conditions of the countries of the Demos. Sensitivity analyses to technical boundary conditions will enable technical SRA to consider all possible variations that have not been identified in the input data gathering process.

Representative networks have been built for the Demo countries, although the task is still in progress. The resulting networks are based on confidential data and are therefore described in detail in separate and confidential annexes to be submitted to the European Commission.

This document also provides an analysis of the technical boundary conditions assessing qualitatively the effect that changes in the context may have on the scaling-up and replication of different use cases. These conclusions will be further analyzed during Year 4 through simulation using the developed network models to establish more qualitative relationships between the boundary conditions and the outcomes of the implementation of use cases.

8 References

8.1 Project Documents

[DOW] – Description of Work

8.2 External documents

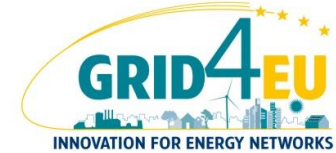
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Annex A: Application of technical SRA methodology to selected use cases

The following section summarizes the main aspects of the application of the technical SRA methodology for the selected use cases of GRID4EU. For this purpose, the table below presents the metrics (KPIs defined by GWP2 and each Demo, as well as other additional indicators) that will be computed in the simulations, the simulation models that will be used and the parameters that will be analyzed in the simulations, for each of the use cases.



Demo	Country	Use Case	KPIs and additional metrics	Simulation	Parameters for sensitivity analysis
1	Germany	Load control in MV	<ul style="list-style-type: none"> • Network hosting capacity • Energy losses • Quality of service indicators: line voltage profiles, avoided overload • Avoided disconnection of DG units • Number of switching operations 	<ul style="list-style-type: none"> • Loadflow analysis (assessment of situation and reconfiguration alternatives) • Reconfiguration (switching plan and smoothing) 	<ul style="list-style-type: none"> • Density of MAS • DG: penetration degree, type of DG • Network: characteristics, topology, technical constraints • Use of network: demand and DG profiles
		Failure management in MV	<ul style="list-style-type: none"> • Fault awareness, localization and isolation time • Reliability indicators: NSE, SAIDI / ASIDI, SAIFI / ASIFI • Number of switching operations 	<ul style="list-style-type: none"> • Fault simulation • Fault management process (including reconfiguration) • Loadflow analysis (check constraints during service restoration process) 	<ul style="list-style-type: none"> • Density of MAS • Operation: fault management process • Reliability levels: failure rates • Network: characteristics, topology
2	Sweden	LV Network Monitoring and Control	<ul style="list-style-type: none"> • Network hosting capacity • Network loading: line voltage profiles, avoided overvoltages and overloads 	<ul style="list-style-type: none"> • Loadflow analysis 	<ul style="list-style-type: none"> • Network: characteristics, topology, technical constraints • Use of network: DER penetration (DG and EV)



Demo	Country	Use Case	KPIs and additional metrics	Simulation	Parameters for sensitivity analysis
					demand and DER profiles
3	Spain	Automatic grid recovery (AGR)	<ul style="list-style-type: none"> • Fault awareness, localization and isolation time • Reliability indices SAIDI, SAIFI, ASIDI, ASIFI 	<ul style="list-style-type: none"> • Fault simulation • Fault management process (including reconfiguration) • Loadflow analysis (check constraints during service restoration process) 	<ul style="list-style-type: none"> • AGR system (fault pass detectors and automated substations) • Operation: fault management process • Reliability levels: failure rates • Network: characteristics, topology
4	Italy	Voltage regulation in MV Anti-islanding protection	<ul style="list-style-type: none"> • Energy losses • Network hosting capacity • Voltage profile • Network availability • Demand response • Avoided overload • Load curtailed • Active DG power curtailment • Anti-islanding • Success/failure of 	<ul style="list-style-type: none"> • Loadflow analysis • DG management strategy and DG active and reactive response model • Storage charging strategy and SoC model • Demand response model • Loadflow analysis • Dynamic analysis: 	<ul style="list-style-type: none"> • DG: penetration degree, type of DG • Network: characteristics, topology, technical constraints • Storage: penetration and characteristics • Volume of controllable load • Use of network: demand and DG profiles • Storage: penetration and characteristics



Demo	Country	Use Case	KPIs and additional metrics	Simulation	Parameters for sensitivity analysis
			<p>advanced protections</p> <p>Network availability</p>	<p>dynamic model of storage and DG, dynamic loadflow analysis</p> <ul style="list-style-type: none"> • Protection scheme model 	<ul style="list-style-type: none"> • DG: penetration degree, type of DG • Volume of controllable load • Network: characteristics, topology, technical constraints • Use of network: demand and DG profiles
5	Czech Republic	Failure management in MV	<ul style="list-style-type: none"> • Fault localization and isolation time • Reliability indicators (SAIDI and SAIFI) • Energy grid losses 	<ul style="list-style-type: none"> • Fault simulation • Fault management process • Loadflow analysis (check constraints during service restoration process) 	<ul style="list-style-type: none"> • Automation degree • Operation: fault management process • Reliability levels: failure rates • Network: characteristics, topology
		Failure management in LV	<ul style="list-style-type: none"> • Fault localization and isolation time • Voltage deviation • Reliability indicators (SAIDI and SAIFI for LV failures) 	<ul style="list-style-type: none"> • Fault simulation • Fault management process • Loadflow analysis (check constraints during service restoration process) 	<ul style="list-style-type: none"> • Implementation of weak bonds and automated cabinets • Operation: fault management process • Reliability levels: failure rates • Network: characteristics,



Demo	Country	Use Case	KPIs and additional metrics	Simulation	Parameters for sensitivity analysis
		Automated islanded operation	<ul style="list-style-type: none"> • Voltage deviation during islanding • Frequency deviation • Reliability improvement • Volume of disconnected load 	<ul style="list-style-type: none"> • Dynamic analysis: stability • Balancing actions: strategy definition and model of dynamic response for storage, DG and flexible demand • Loadflow analysis 	<p>topology</p> <ul style="list-style-type: none"> • Storage: penetration and characteristics • DG: penetration degree, type of DG • Volume of controllable load • Network: characteristics, topology, technical constraints • Use of network: demand and DG profiles
6	France	Islanding	<ul style="list-style-type: none"> • Network hosting capacity • Network losses • Avoided overvoltages 	<ul style="list-style-type: none"> • Dynamic analysis: stability and dynamic model of system and DER • NBA model (storage SoC and charging strategy) • NEM model (demand response and PV management) • Loadflow analysis 	<ul style="list-style-type: none"> • Storage: penetration and characteristics • DG: penetration degree, type of DG • Volume of controllable load • Network: characteristics, topology, technical constraints • Use of network: demand and DG profiles
		Maximize PV	<ul style="list-style-type: none"> • Islanding 	<ul style="list-style-type: none"> • Loadflow analysis 	<ul style="list-style-type: none"> • Storage: penetration and



Demo	Country	Use Case	KPIs and additional metrics	Simulation	Parameters for sensitivity analysis
		production in LV	<ul style="list-style-type: none"> • Load shedding • Successful duration of islanding • Reconnection success • Amount of controlled load • Frequency deviation • Avoided interruptions 	<ul style="list-style-type: none"> • NBA model (storage SoC and charging strategy) • NEM model (demand response and PV management) 	<ul style="list-style-type: none"> • characteristics • DG: penetration degree, type of DG • Volume of controllable load • Network: characteristics, topology, technical constraints • Use of network: demand and DG profiles